Co-funded by the European Union

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Norwegian Embassy
Islamabad

PLASTIC PROCESSOR

Learner Guide

National Vocational Certificate Level 3

Version 1 - September, 2018

NAVTTC

Implemented by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Published by
National Vocational and Technical Training Commission
Government of Pakistan

Headquarter
Plot 38, Kirthar Road, Sector H-9/4, Islamabad, Pakistan
www.navttc.org

Responsible
Director General Skills Standard and Curricula, National Vocational and Technical Training Commission
National Deputy Head, TVET Sector Support Programme, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Layout & design
SAP Communications

Photo Credits
TVET Sector Support Programme

This document has been produced with the technical assistance of the TVET Sector Support Programme, which is funded by the European Union, the Federal Republic of Germany and the Royal Norwegian Embassy and has been commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ). The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in close collaboration with the National Vocational and Technical Training Commission (NAVTTC) as well as provincial Technical Education and Vocational Training Authorities (TEVTAs), Punjab Vocational Training Council (PVTC), Qualification Awarding Bodies (QABs)s and private sector organizations.

Document Version
September, 2018
Islamabad, Pakistan

PLASTIC PROCESSOR

Learner Guide

National Vocational Certificate Level 3

Version 1 - September, 2018

Introduction

Welcome to your Learner's Guide for the Plastic Processor level 3. It will help you complete the training and go on with further study or go straight into employment.

The Plastic Processor level 3 training is to engage young people with a program of development that will provide them with the knowledge, skills and understanding to start their career in Pakistan. This qualification will not only build the capacity of existing workers of manufacturing engineering sector but also support the youth to acquire skills best fit in manufacturing industry.

The main elements of your learner's guide are:

- **Introduction:**
  - This includes a brief description of your guide and guidelines for you to use it effectively
- **Modules:**
  - The modules form the sections in your learner's guide
- **Learning Units:**
  - Learning Units are the main sections within each module
- **Learning outcomes**:
  - Learning outcomes of each learning units are taken from the curriculum document
- **Learning Elements:**
  - This is the main content of your learner's guide with detail of the knowledge and skills (practical activities, projects, assignments, practices etc.) you will require to achieve learning outcomes stated in the curriculum
  - This section will include examples, photographs and illustrations relating to each learning outcome
- **Summary of modules**:
  - This contains the summary of the modules that make up your learner's guide
- **Frequently asked questions**:
  - These have been added to provide further explanation and clarity on some of the difficult concepts and areas. This further helps you in preparing for your assessment.
- **Multiple choice questions for self-test**:
  - These are provided as an exercise at the end of your learner's guide to help you in preparing for your assessment.

Frequently Asked Question

1. What is Competency Based Training (CBT) and how is it different from currently offered trainings in institutes?	Competency-based training (CBT) is an approach to vocational education and training that places emphasis on what a person can do in the workplace as a result of completing a program of training. Compared to conventional programs, the competency-based training is not primarily content based; it rather focuses on the competence requirement of the envisaged job role. The whole qualification refers to certain industry standard criterion and is modularized in nature rather than being course oriented.
2. What is the passing criterion for CBT certificate?	You shall be required to be declared “Competent” in the summative assessment to attain the certificate.
3. How can I progress in my educational career after attaining this certificate?	You shall be eligible to take admission in the National Vocational Certificate Level-4 in Plastic Processor. You shall be able to progress further to National Vocational Certificate Level-5 in Plastic Processor, and take admission in a level-5, DAE or equivalent course. In certain case, you may be required to attain an equivalence certificate from The Inter Board Committee of Chairmen (IBCC).
4. What is the importance of this certificate in National and International job market?	This certificate is based on the nationally standardized and notified competency standards by National Vocational and Technical Training Commission (NAVTTC). These standards are also recognized worldwide as all the standards are coded using international methodology and are accessible to the employers worldwide through NAVTTC website.
5. Which jobs can I get after attaining this certificate? Are there job for this certificate in public sector as well?	You shall be able to take up jobs in the manufacturing and Plastic Processing Industries as a processor for the production of plastic parts, sheet metal parts and household goods.
6. What are possible career progressions in industry after attaining this certificate?	You shall be able to progress up to the level of shop supervisor after attaining sufficient experience, knowledge and skills during the job. Attaining additional relevant qualifications may aid your career advancement to even higher levels.

7. Is this certificate recognized by any competent authority in Pakistan?	This certificate is based on the nationally standardized and notified competency standards by National Vocational and Technical Training Commission (NAVTTC). The official certificates shall be awarded by the relevant certificate awarding body.
8. Is on-the-job training mandatory for this certificate? If yes, what is the duration of on-the-job training?	On-the-job training is not a requirement for final / summative assessment of this certificate. However, taking up on-the-job training after or during the course work may add your chances to get a job afterwards.
9. What is the examination / assessment system in this program?	Competency based assessments are organized by training institutes during the course which serve the purpose of assessing the progress and preparedness of each student. Final / summative assessments are organized by the relevant qualification awarding bodies at the end of the certificate program. You shall be required to be declared "Competent" in the summative assessment to attain the certificate.
10. Does this certificate enable me to work as freelancer?	You can start your small business as a Plastic Processor. You may need additional skills on entrepreneurship to support your initiative.

PLASTIC PROCESSOR

Module-6

Learner Guide

National Vocational Certificate Level 3

Version 1 - September, 2018

Modules

Module 6: 072200915 Operate Injection Moulding Machine

Objective of the module: The aim of this module to provide skills and knowledge to operate injection moulding machine in accordance with the manufacturer's manual

Duration: 175 hours **Theory:** 35 hours **Practical:** 140 hours

Learning Unit	Learning Outcomes	Learning Elements	Materials Required
LU1: Adjust moulding machine parameters	**The trainee will be able to:** Turn on machine as operation manual. Feed parameters as per PPS and job. Verify all parameters as per job/ data sheet	i) Moulding cycle from feeding to ejection • Set processing parameters as per job card • Ensure desired temperatures are achieved • Ensure raw material is ready for processing (De-humidified, etc.) • Ensure all peripheral equipments are working properly (oil pump, air filter, hydraulics, motors, pneumatics, etc.) ii) Recognize screw configurations • Check shot size and speed • Check injection pressure and other parameters	Injection Moulding Machine Mould Utility documentation. Service Manuals. Operational Manuals. Basic Hand tools Job card/PPS
LU2: Perform Dry Run	**The trainee will be able to:** Ensure Mould opening & closing position as per tool Ensure mechanism of Ejector of the tool	i) Knowledge and understanding of mould and it's mechanism ii) Understanding of hydraulic and pneumatic systems iii) Manual operation of injection mounding machine iv) Identify runner, gate and clamping	Injection Moulding Machine Mould Utility documentation. Service Manuals.

	Verify protection of tool as per operation manual and procedure.	v) Identify two plate, slider mould, hot runner mould vi) Identify and set up part ejection in the mould	Operational Manuals. Basic Hand tools
LU3: Perform Semi-auto operation	**The trainee will be able to:** Ensure barrel temperatures has achieved according to data sheet Perform purging till required material ready for sample shot. Start moulding cycle as per SOP. Inspect the samples as per data sheet.	i) Recognize machine controls ii) Learn to adjust temperatures from feed zone to injection point iii) Learn to adjust injection pressure iv) Perform Dry-run v) Perform Semi-auto operation vii) Maintaining product quality as per specifications • Be able to measure components for identification of dimensional defects • Usage of measurement tools is critical: Vernier caliper, micrometer gauge, scale, etc. viii) Recognize different defects and their causes • Be able to visually identify commonly occurring defects, such as gating, flashing, orange-peel, etc. vi) Gain knowledge of rectification of commonly occurring defects.	Injection Moulding Machine Machine Mould Utility documentation. Service Manuals. Operational Manuals. Basic Hand tools
LU4: Perform Production	**The trainee will be able to:** Start machine on auto cycle mode as per operation manual. Perform periodic quality checks as per requirement.	i) Switch machine operation to automatic mode ii) Maintaining product quality as per specifications • Be able to measure components for identification of dimensional defects	Injection Moulding Machine Mould Utility documentation. Service Manuals.

		• Usage of measurement tools is critical: Vernier caliper, micrometer gauge, scale, etc. iii) Recognize different defects and their causes • Be able to visually identify commonly occurring defects, such as gating, flashing, orange-peel, etc. iv) Gain knowledge of rectification of commonly occurring defects.	Operational Manuals. Basic Hand tools
LU5: Perform follow up procedure for machine production	**The trainee will be able to:** Ensure product packed in assigned packaging. Check feed level in hopper /bin, etc. Ensure machine lubrication as per requirement.	i) Knowledge of product packaging • Understand different types of packaging, e.g.; flexible packaging, packing in cartons, etc. • How to pack final product? ii) Raw material input in moulding machine • Ensure consistent raw material feed into hopper/feeder • Be able to use overhead crane or moveable lifts/ladders • Understand the importance of cutting tools in opening raw material bags. • Concept of 'clean slits' using sharp tools to ensure particles of bag don't get mixed in raw material iii) Lubrication requirements and procedure of machine • Understand the concept of lubricating moveable parts of machines • Carefully use mould lubricant sprays	Injection Moulding Machine Mould Utility documentation. Service Manuals. Operational Manuals. Basic Hand tools

		• Ensure spray cans are stored in a secure location after pre-shot application • Be able to identify different mould release agents as per raw material • Be able to provide first-hand feedback to maintenance department for periodic machine maintenance	
LU6: Submit production report	**The trainee will be able to:** Record production report as per given format (kg/units per hour). Submit report to concerned department.	i) Production report writing LU.1 Understand the importance of reporting accurate production quantity LU.2 Be able to fill-in relevant production reports LU.3 Be able to identify waste generated along with identification of machine downtime with reasons ii) Data sharing with relevant departments • Understanding the concept of producing accurate data and benefits of the same on a larger scale • Submission of production reports to production planning department or the supervisor for timely actions.	Injection Moulding Machine Machine Mould Utility documentation. Service Manuals. Operational Manuals. Basic Hand tools
LU7: Transport finished product to concerned department	**The trainee will be able to:** Place finished product in designated area	i) Understand QC protocols • Understand and appreciate the importance of producing products as per specification	Injection Moulding Machine Machine Mould Utility documentation.

	Take approval of finished product from Quality control Deliver relevant packaging documents to store personnel.	• Be able to implement the first quality control protocol on machine to ensure elimination of defective products at sight ii) Inter-department co-ordination • Be able to co-ordinate with QC department with produced batches for relevant approvals iii) Be able to hand over final products to store • Familiarize with handing-over protocols and paperwork.	Service Manuals. Operational Manuals. Basic Hand tools

Examples and Illustrations:

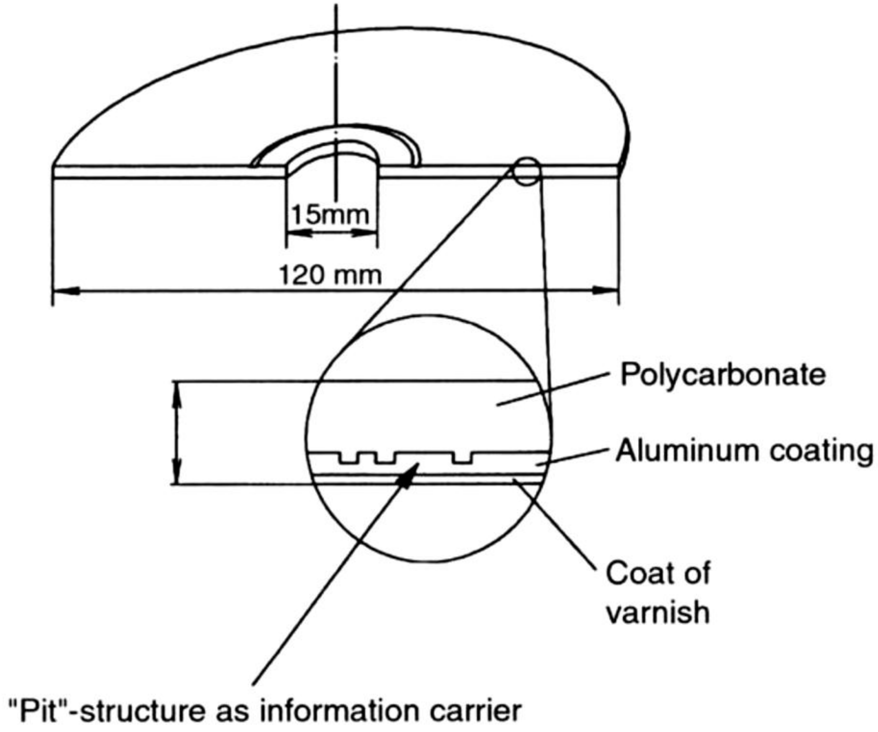
For more details please refer to the book: Training in Injection Moulding, 2nd Edition, by HANSER Publishers, Munich.

Some key introductions:

the most important processing method for plastics	In comparison to the classic methods of metal fabrication and processing (such as milling, drilling, turning, etc.), injection molding represents a manufacturing method which is still young. However, injection molding has already become the most important method in plastics processing technology
plunger machines	The early injection molding machines were plunger machines. The plastic was melted in a heated cylinder and injected into the mold by the plunger. This type of machine is no longer found, except in research laboratories, for making very small quantities of experimental articles.
screw principle	Most modern injection molding machines operate on the screw principle. The molding compound is melted by band heaters and the frictional heat produced by the rotating screw, In the injection operation, the rotation of the screw is stopped, and the screw begins to function as a plunger. The screw must therefore fulfill the functions of conveyance, mixing, and injection. Separate plasticating screws and injection plungers are often used in the processing of elastomers.

thermoplastics	Thermoplastics represent the most important group of plastics to be processed in injection molding. Typical injection-molded parts made from thermoplastics include automobile hubcaps and bumpers, gears in kitchen appliances, screw-on caps and lids, bottle crates, printer cartridges, and ball-point pens.
Compact Disk (CD)	Even the Compact Disk (CD) is produced from polycarbonate (PC) by the injection molding method.
elastomers	Another important materials group are the cross-linked polymers, such as elastomers and thermosets. Typical elastomer molded parts manufactured by injection molding include bellows, shock-absorbing components in automobiles, seals, and molded tubes,
thermosets	Thermosets consist of densely crosslinked polymers, that can also be processed by injection molding. Thus, produced articles are used in boats, in the automotive field and in the electrical industry (insulation). Thermoset moldings find particular application, where their non-conductive properties and heat-resistance are essential. Injection molding provides a cost-effective mass-production process of articles for the electrical industry.
	Injection Molding -A Discontinuous Single-Stage Process
primary processing method	Injection molding, as a primary processing method, is particularly well suited for the mass-production of molded articles, because the conversion of the raw material into a finished product usually requires just a single operation. Little or no finishing is required, and even complicated geometries can be produced in a single operation.
ideal production process	It is an ideal production process with the proviso, that large batches are produced, because the injection molding tool is usually made for a single article only.
expensive molds	It is typical within the context of primary processing technology, that each mold is unique. Molds are therefore very expensive in comparison to most forming tools and dies used in metals fabrication, because they are not universally employable.
production process	The process for molding thermoplastics proceeds as follows: • The material is fed into the hopper on the machine. • Within the heated cylinder, the material is conveyed, melted, and mixed thoroughly by the rotating screw. • The molten molding compound (melt) is then injected into the mold under high pressure. • The melt cools within the heat-balanced mold and thus gains the inherent stability needed for its removal. • The article is now removed from the mold, and a new injection molding cycle can begin.
high degree of accuracy	Parts produced by injection molding display a very high degree of dimensional accuracy- for example, to 1/100mm (4 x 10^{-4} in). Even greater accuracy is possible in special applications.
CD	With the Compact Disk, information is stored in minute pits formed in the surface. These pits, produced as direct reproductions by the injection molding process, are only a few microns wide and deep.

Injection Molding -The Injection Molding Machine and Mold	
main components	• The injection molding machine • The mold
injection molding machine	The injection molding machine is in turn divided into the following: • Plasticating (plastification) unit and the injection unit • Clamping unit • Controls (hydraulics, electrical system)
mold	Different molds are needed for different injection-molded articles. It is therefore necessary to replace the entire mold in order to produce a different part from the one currently being made.
profitable production	Production of certain articles (e.g., household appliances, certain automotive subassemblies, CDs) would not be profitable at all without the means, of producing them from plastics by injection molding.
special features	When articles hitherto produced from classic materials (such as wood or metal) are to be made by the injection molding process, it is advisable, to give serious consideration to the special properties of plastics materials, as well as the more salient points of injection molding as a production method. This plastics-oriented procedure requires an understanding of the basic principles of the manufacturing and production processes involved, and also of the plastics material's behaviour. The book provides a comprehensive overview of the principles involved in injection molding.
CD	For that purpose, we follow a modern plastics article (a Compact Disk) from the starting material to the form, in which it will ultimately be used. The possibilities for recycling will also be explained. As a high-tech product, the CD is particularly well suited to serve as an example of modern plastics processing and injection molding technology. The diagram shows a CD and its dimensions.



Aside from viscosity, other factors also influence the processability of plastics in the injection molding process. The summary table below shows some of the types of plastics used in injection molding, as well as the characteristic material properties which are important in processing (e.g., shrinkage in processing, flowability, and processing temperature range).

Chemical name composition	ISO 1043 DIN 7728	Density [g/cm^3]	Processing temperature [°]	Flowability g = good m = medium p = poor	Shrinkage in processing [%] r = glass-fiber reinforced
Polystyrene	PS	1.05	180–280	g	0.3–0.8
Styrene-buta-diene copoly-mers	SB	1.05	180–280	g	0.4–0.7
Styrene-acrylo-nitrile compoly-mers	SAN	1.07	200-260	m	0.4-0.7; 0.1–0.3r
Acrylonitrile-butadiene-styrene copolymers	ABS	1.08–1.12	210–270	m p	0.4–0.7 0.2–0.4r
Polyethylene	PE	0.91–0.97	180–270 240–300	g m p	1.2–2.8; 1.2–2.5
Polymethyl methacrylate	PMMA	1.18	170–240	m	0.3–0.7
Polyamide	PA	1.04–1.15	230–290	g	0.7–2.0; 0.2–0.8r
Cellulose acetate	CA	1.31	180–230	g	0.4–0.7
Polycarbonate	PC	1.20	280–320	p	0.6–0.8; 0.2–0.5r
Polyvinyl chlor-ide, rigid (un-plasticized)	PVC	1.38	190–210	p	0.4–0.7
Polyoxymethy-lene	POM	1.41	180–230	m	1.8–3.0; 0.2–0.6r
Polypropylene	PP	0.91	240–300	m p	0.5–1.2r

It can be seen from the table that the range of processing temperatures is very narrow for some thermoplastics but very broad for others. For example, PVCU (unplasticized or rigid PVC) can only be processed within a very narrow temperature range (190-210°C), while POM can be processed between 180 and 230°C.

The subsequent Table shows the material properties of PC, from which CDs are produced, as well as the setting parameters, which were used for programming the injection molding machine employed.

Material properties
Solid, rigid, impact resistant up to −100°C, (−148°F), high heat resistance, crystal clear, non-toxic.
Resistant to
Oil, gasoline, diluted acids, alcohol, waxes, fats, simple soaps
Not resistant to
Strong acids, alkali solutions, benzene, amines, ammonia, some solvent components.
Material characteristics
Flame retardant, extinguishes away from flame, burns brightly, produces soot, chars, forms blisters, smells of phenol.
Cylinder temperature

Heating zone 1	230–260°C
Heating zone 2	250-300°C
Heating zone 3	260–320°C
Heating zone 4	260–320°C
Nozzle zone	280–330°C

Injection pressure
Very high injection pressures (1300–1800 bar = 19.000–26.000 psi) are required, as the material is extremely viscous.
Holding pressure
Pressure usually amounts to about 40–60% of the injection pressure.
Back pressure
50–150 bar (725–2175 psi)
Injection speed
Subject to length of flowpath and wall-thickness. Fast injection for thin walls. Where good surface quality has been specified, injection should be a little slower.
Screw RPM
High screw torque required, therefore medium screw speeds should be applied.
Melt cushion
2–6 mm (0.08–0.24"), subject to feed volume.
Mold temperature
Not lower than 85°C (185°F). Mold filling and article quality improve with increasing temperature. High mold temperature increases cycle time only marginally, as the glass transition temperature is at 145°C (293°F).
Pre-drying
4–12 hours (high-speed drying oven 2–5 hours) at 100–120°C (212–248°F). Optimum elongation, hardness and notched impact strength are obtained at a moisture content below 0.02%.
Shrinkage
0.7–0.8%; 0.1–0.5% with PC-GF (glass filled).
Injection volume
15–85% of the respective cylinder volume.
Shutting the machine down
If production is stopped over night, purge the cylinder of material and keep heat on at 160–180°C (32–356°F).

It will be obvious by now, that many factors must be considered in order to produce high quality moldings. The processing values can also vary within wide ranges. The molding of CDs requires a PC of very low viscosity and a processing temperature range of 320-360°C. Low viscosity is needed, in order to enable the melt to reproduce the fine geometry of the pits on the information side of the CD with high precision. If this is not accomplished, data will be lost. Although CD-players have built-in error correction, this is capable of correcting lost information (non-existent or only partially formed pits) to a limited extent only.

Machine size:

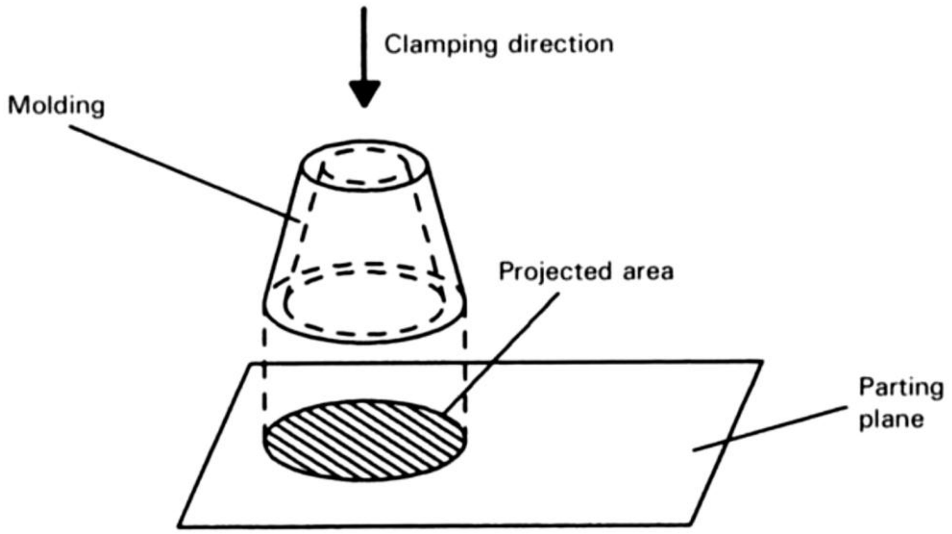
In principle, of course, it could be stated that the size of the machine must be chosen in accordance with the size of the molded article: the larger the molding, the larger the machine. But this isn’t always true, especially where small molded parts are concerned. It is usually much more economical to manufacture many small moldings simultaneously on a large machine, than to manufacture just one article at a time on a small machine.

Article Weight:

The size of the molded part-especially in its relation to machine selection requires a closer examination. It should first be explained that ‘size’ is defined as volume. The heavier the article, the more molding compound must be provided by the plasticating and injection unit within a given period of time.

Projected Article Area:

Apart from a molding’s volume, its dimensions must also be considered. The selection of a machine for the production of a given molding is primarily determined by the ‘projected area’ of that article - i.e., the area which projects in the clamping direction. Meaning of this concept is illustrated in the following figure:



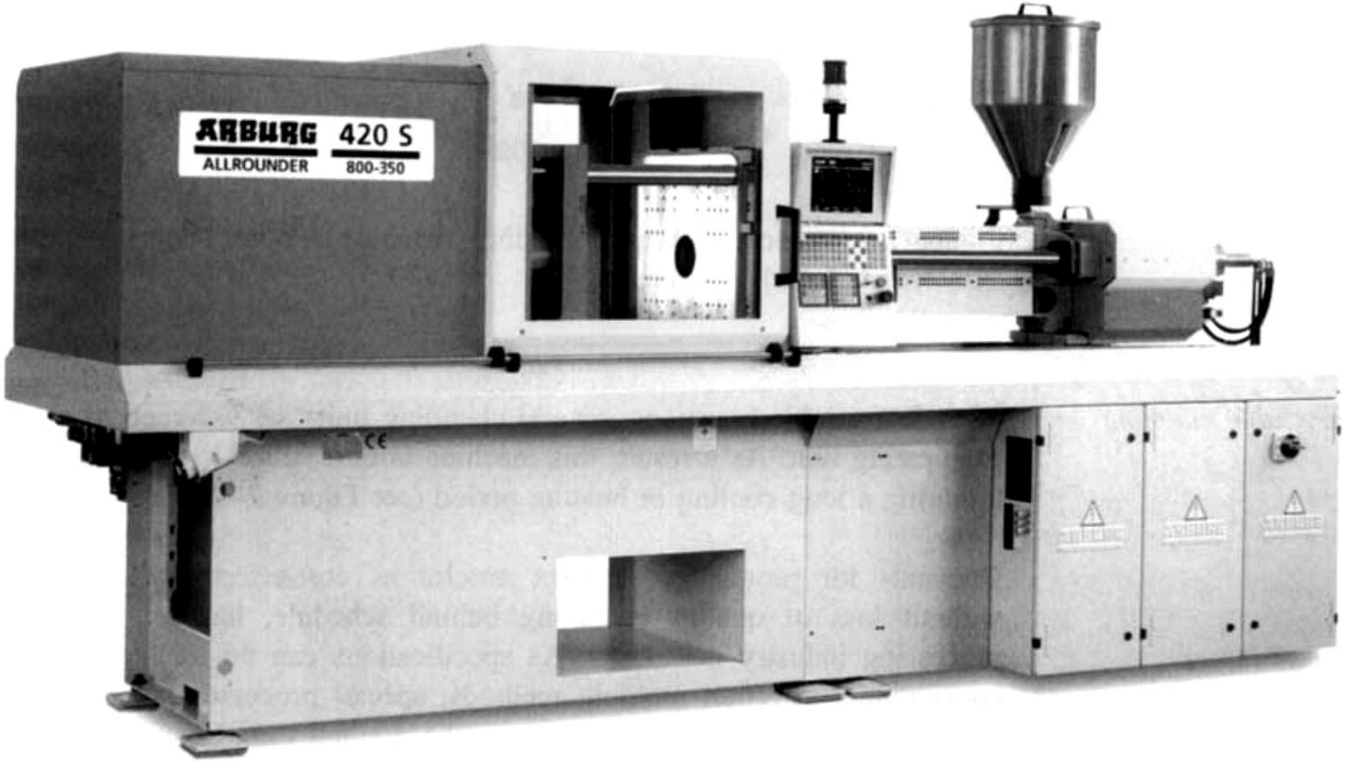
With the CD, the projected area equals the circular surface formed by the CD. Because diameter of the CD is 120mm (4.75 in), the projected area is 113 cm^2 (17.5 in^2).

With injection molding, the molding compound is injected into the mold under high pressure, which can be in excess of 2000 bar (29,000 psi) or 200 N/mm2 (1 bar = 10^5 N/m^2 = 10^5 Pa). By way of comparison, an automobile tire holds a pressure of approximately 2 bar (29 psi). The mold must be held shut against the injection pressure so that no molding compound escapes at the parting line between the mold halves (flash). This clamping force is provided by the clamping unit. Injection molding machines are classified into sizes which correspond to this clamping force (12 - 8000 t).

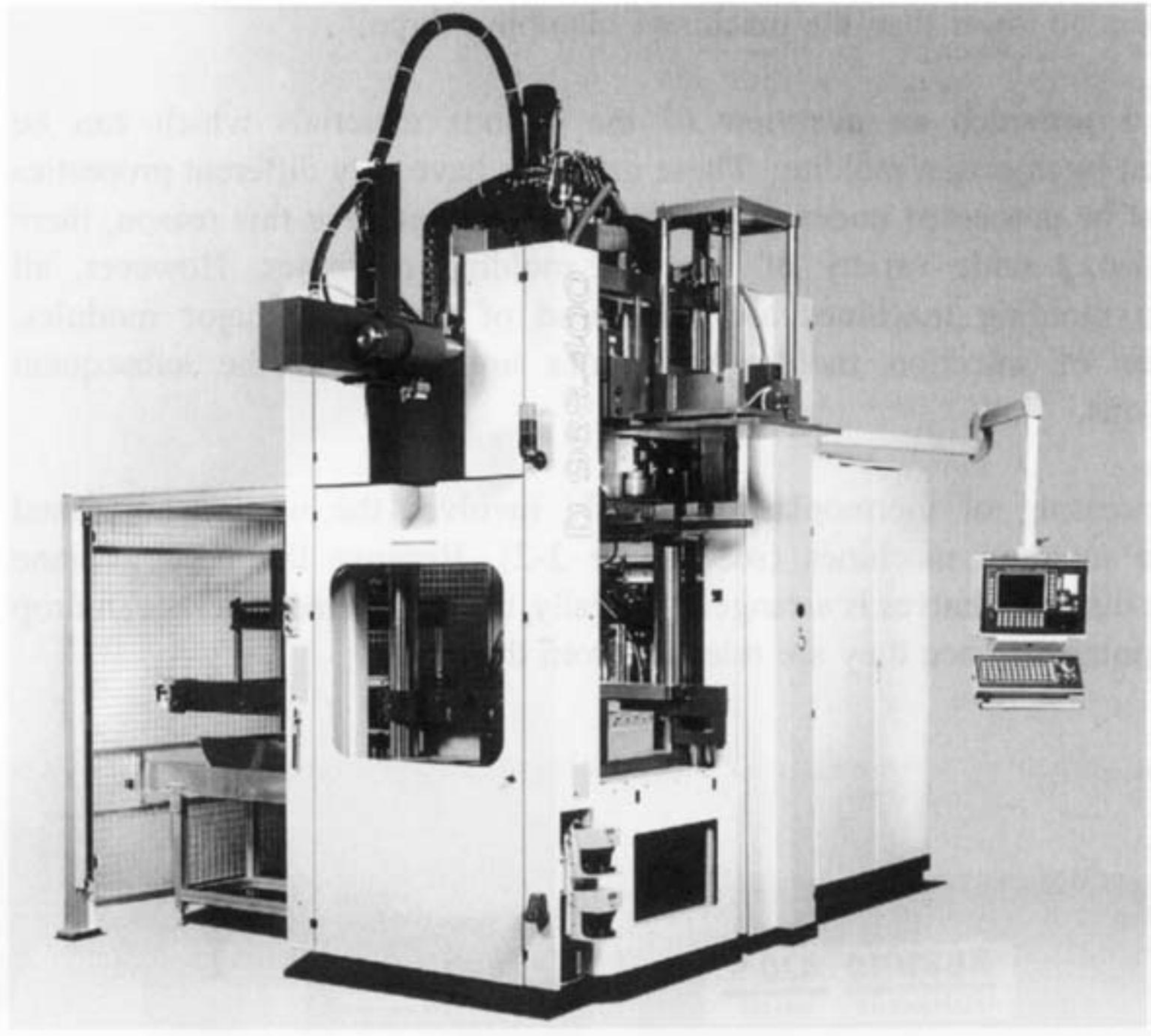
The force acting against the clamping force, thereby attempting to part the mold, is known as the mold parting force. It results from the pressure acting upon the melt, multiplied by the article's projected area, which lies in the clamping movement direction.

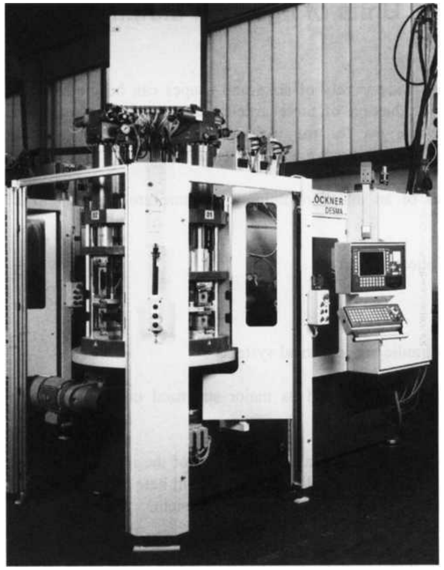
In order to achieve good quality moldings, i.e. without flash, the mold parting force must be lower than the machine's clamping force.

The processing of thermoplastics usually involves the use of horizontal injection molding machines. Because the parting plane between the mold halves is arranged vertically, the completed articles can drop into a container, once they are released from the mold.


ARBURG
420 S
ALLROUNDER
800-350

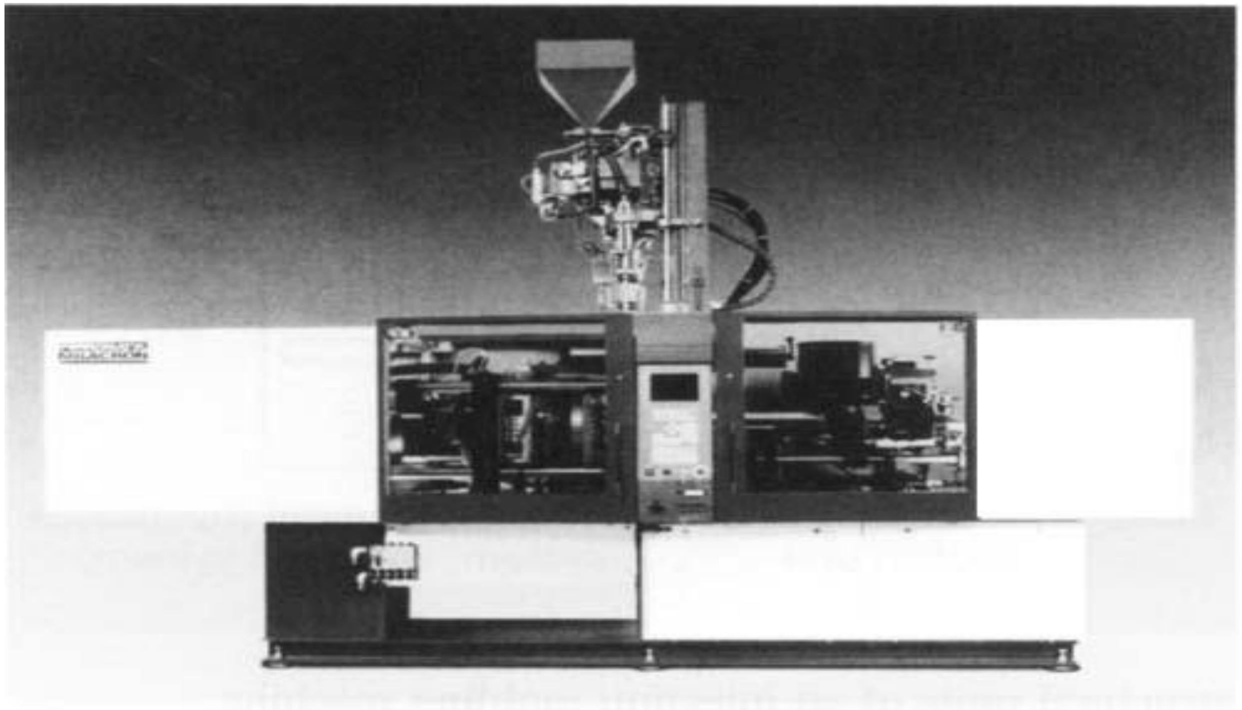
In the vertical machine, the parting plane between the mold halves runs horizontally. As a result, this machine is especially well suited to the production of insert moldings (e.g., electrical plugs) (see Figure 2-3). Most moldings made of elastomers are produced on vertical machines.





With rotary table machines, several clamping units are assigned to a single plasticating unit. As a result, this machine is best suited to molding articles requiring a long cooling or heating period (Figure on left).

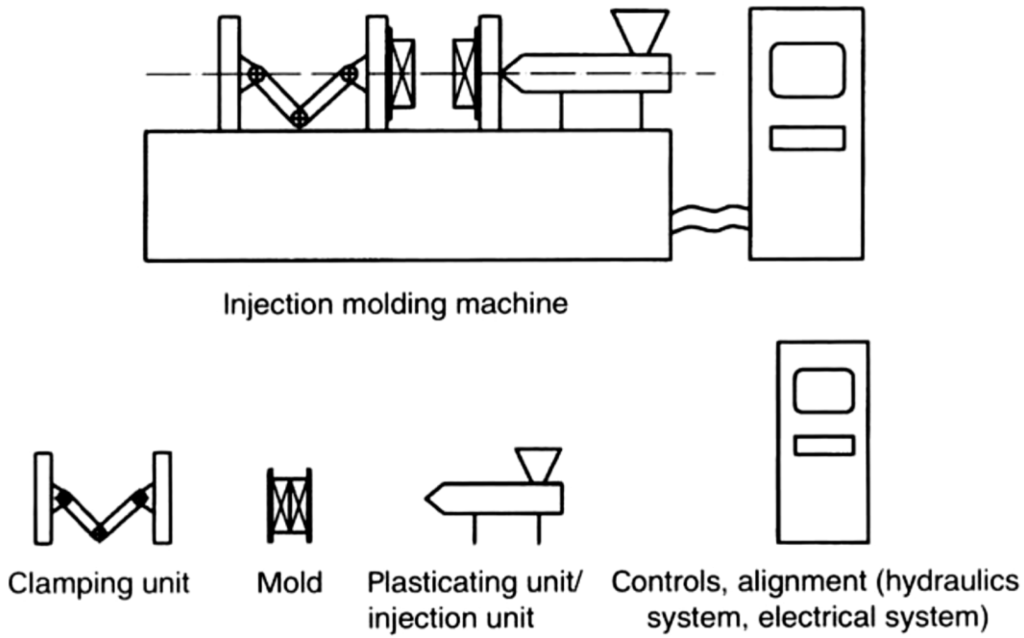
Demands for producing complex articles as cost-effectively as possible, without loss of quality or falling behind schedule, has set the plastics processing industry new tasks. As specifications can no longer be met by conventional injection molding methods, special processes -such as multicomponent injection molding - have to be applied (Figure below). With multi-component injection molding, at least two plasticating injection units are assigned to a single clamping unit. This method allows two differently colored plastics materials (automobile rear-lights) to be injected one over the other, forming a single molding.



Structural Units of Injection Molding Machines

Molded articles in a wide variety of sizes and shapes can be produced by injection molding. Production of these articles under optimum conditions requires alternative designs for the various sizes of injection molding machines, as well as their respective auxiliary equipment.

The major modules of an injection molding machine are common to all designs:



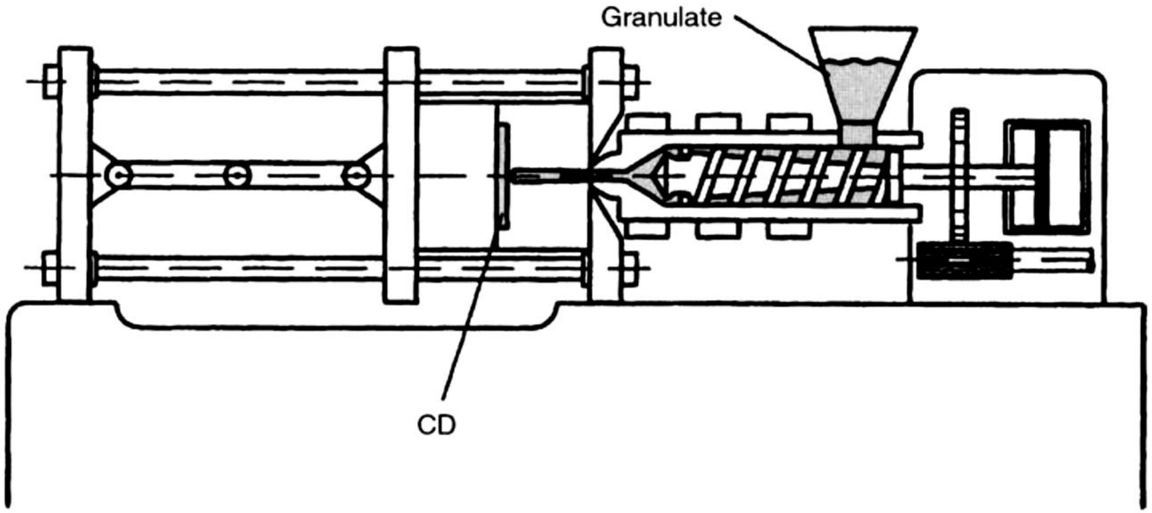
- Plasticating and injection unit
- Clamping unit
- Controls with hydraulic and electrical systems

An injection molding machine and its major structural units is shown in figure.

The mold is ordinarily not seen as a structural unit of the injection molding machine. However, in order to simplify matters, it will here be considered as part of the ‘‘overall’’ injection molding machine’s system.

The moldings to be produced determine the relative positions of these structural or modular units to each other, as well as their sizes. Various articles can be produced on a single injection molding machine, but each part requires its own (different) mold. The individual structural units of injection molding machines and their functions will now be described in greater detail. By way of an example, this description will refer to a machine used for molding CDs.

To understand the functions of individual modules, it is best to trace the path of the polymer through the machine from the raw resin (usually in granular form) to the finished product. The basic principle is demonstrated with the diagrammatic cross section of a CD-producing injection molding machine in Figure 2-7. The complete path of the material from hopper to mold is highlighted.



Production of the completed CD is much more complicated, of course. After it has been injection molded, it is given a metal coat by “sputtering”, which is necessary for reflecting the laser beam. The CD is subsequently subjected to quality checking and is then printed.

Controls:

The control and regulatory unit of the machine is usually housed in a separate control cabinet alongside the machine. In addition to the display instruments, the control cabinet also contains the electrical and electronic circuit elements and controls.

On older machines it is customary for the desired machine parameters to be set with limit switches located directly on the major modules or by push buttons on the control cabinet.

On modern injection molding machines, the keyboard and display screen have become the preferred devices for inputting and monitoring of set-values. With CNC-controlled machines, the heart of modem open-as well as closed-loop control is the microcomputer or a PC (Personal Computer). Apart from open loop and feedback control of the injection molding process sequences, these computers are also capable of monitoring and saving data.

Computer controls of this type employ interfaces, that enable them to exchange information for the production data acquisition (PDA), for instance, or quality data management (CAQ), handling devices or heat-balancing data. They can also enable hardcopy of production data to be printed.

Phases of an Injection Molding Cycle:

This lesson introduces the injection molding process in all of its phases (stages): injection phase, holding pressure phase, cooling phase, feed phase, and removal. The lesson also describes the machine motions associated with these process phases. In processing elastomers and thermosets, the cooling phase - as it applies to the processing of thermoplastics -is replaced by a heating phase.

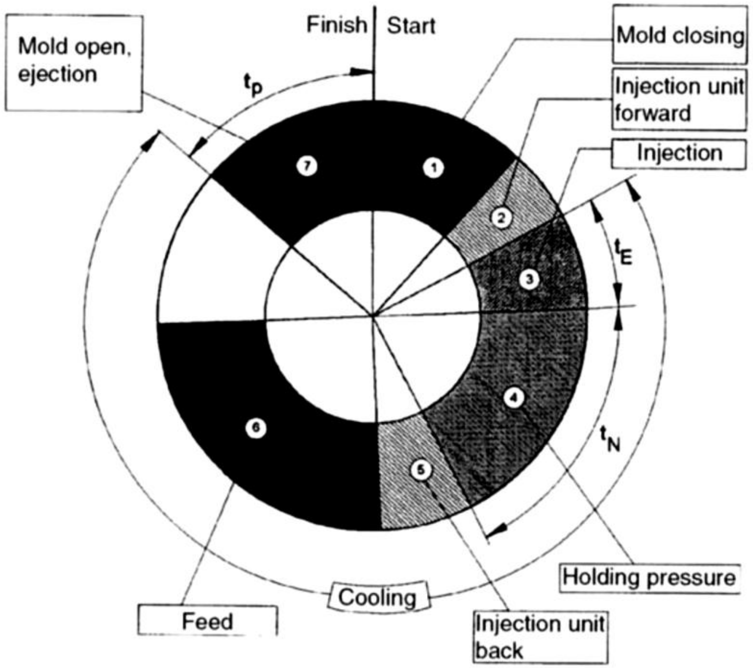
To manufacture an injection-molded part, the machine's structural units must work together in a practical manner. This cooperation between the units results in the injection molding process during which the molded part is formed.

The injection molding process consists of individual phases or stages which follow one another, overlapping to some extent, and are continuously repeated. We refer to a process of this type as a cycle and therefore speak of a repeating injection molding cycle. Nowadays, it is customary for the injection molding cycle to proceed automatically from phase to phase.

In most cases the cycle also repeats itself automatically. Only under certain conditions or for special molded parts may it be necessary for the machine to stop at the end of a cycle. After manual intervention by the machine operator, the machine is prepared for the next cycle and then restarted. This is done with molded elastomer parts, for example, which generally must be removed by hand.

The CD is produced by a fully automatic method, for example. In this case the machine operator intervenes only when problems arise.

The various times making-up an injection molding cycle are shown with the example of a CD:



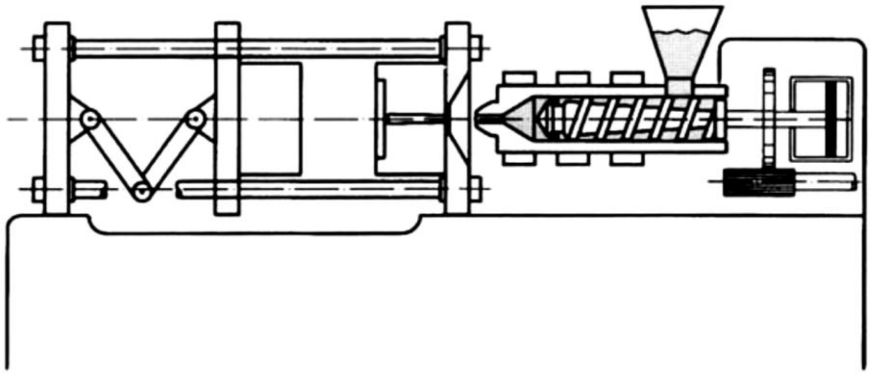
Phase	*Time [s]*
Mold closing	0.4
Injection	0.3
Holding pressure	0.3
Remaining cooling time	2.1
Mold opening	0.4
Handling (plus sprue punch-off)	0.4
Total cycle time	3.9

Due to its short cycle time, the CD is counted amongst fast cycling articles, similar to those produced for the packaging industry (e.g. cups). However, cycle times of other moldings may take from half- to several minutes. This depends on many influencing factors, such as article volume, material, gating design and demolding possibilities, amongst others.

The way the article is actually being molded cannot be observed directly. However, the machine's structural units can provide clues to the phase of the injection molding cycle the machine is currently executing.

Therefore, parallel to the description of the injection molding cycle phases, as seen from the material aspect, an explanation will also show, in which form the machine's structural units are involved.

To start molding production, all machine modules must be in their respective home position



Mold and Clamping Unit

The clamping unit is open. There is no molded part in the cavity of the mold. The ejectors are in the retracted position. The mold has been adjusted to the prescribed temperature.

Plasticating Unit

The screw and cylinder of the plasticating unit have been heated to the prescribed temperature. The screw is in the retracted position. Plasticated, molten material is present in the injection chamber in front of the screw. The nozzle has been closed off so that no material can escape.

Controls

If only one cycle is to be executed, the controls are in the semiautomatic mode. If a practically unlimited number of cycles are to be executed, the controls are in the fully automatic mode. The machine operator must start the process by pressing a button. Usually the process will start only if all machine components are in their respective starting conditions. If this is not so, the controls issue an appropriate error message or automatically restore the components to their starting conditions.

Hydraulic- and Electrical Systems

Of course, one precondition for the start of production is that the hydraulic and electrical systems of the machine must be switched on. Furthermore, the machine's hydraulic oil must be up to the set operating temperature.

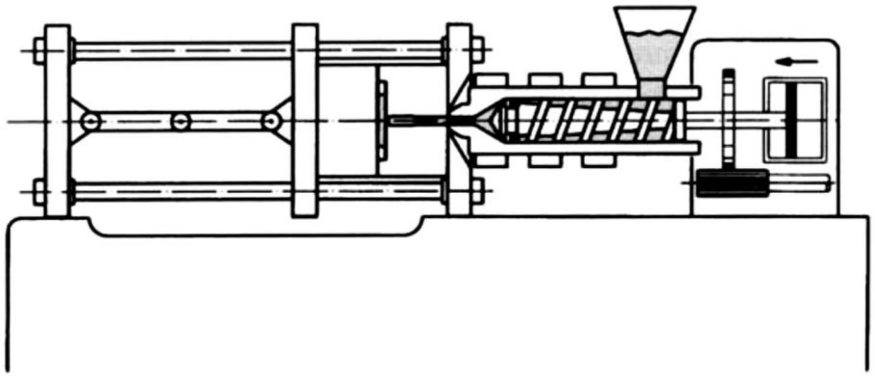
The material, i.e. the molding compound, is present in the screw's antechamber as thoroughly mixed melt. In processing conventional thermoplastics (PS, PVC, PE), the material is at approximately 200-300°C. The material, from which CDs are produced, is heated to approximately 330°C. The consistency of the plastics melt is roughly comparable to that of honey.

Once the machine operator issues the starting signal, the injection molding cycle begins with the closing of the mold.

Injection Phase

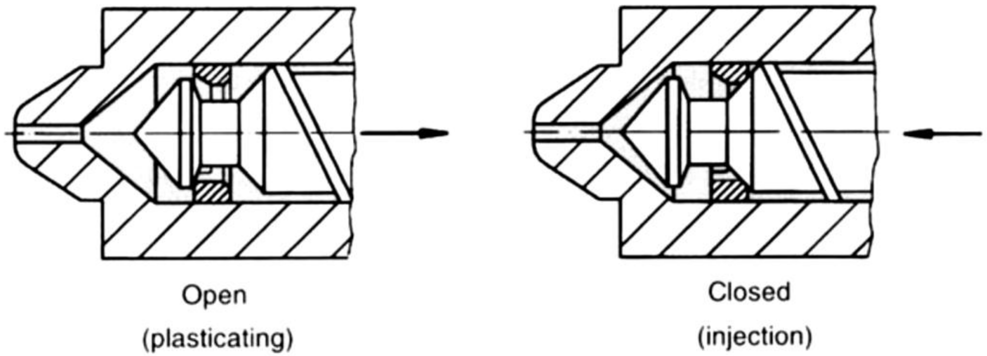
Mold and Clamping Unit

The clamping unit moves the two halves of the mold together. A clamping force is built up, thus locking the mold tightly.



Plasticating Unit

The plasticating unit moves up to the mold's sprue bush. The nozzle is opened, and the material located in the screw's ante-chamber is injected into the mold by the forward movement of the screw. As soon as the screw moves forward, pressure is exerted upon the non-return valve (check-ring valve) on the screw-tip by the material in the ante-chamber. As a result, the check ring of the non-return valve is pushed back onto its seat, thus stopping any melt escaping rearward over the screw flights. The screw now functions as a plunger during the injection process (figure below).



Controls

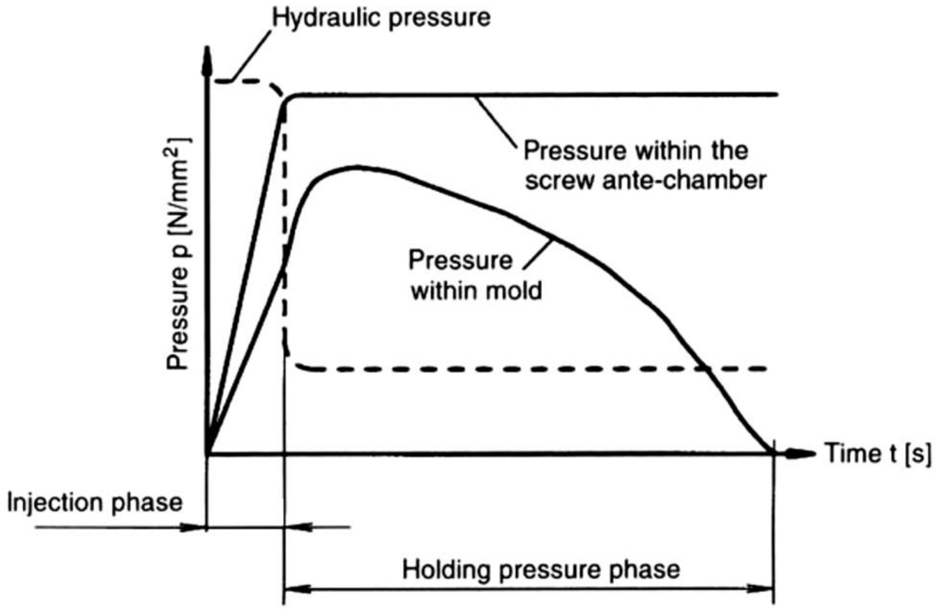
The controls must ensure that the structural unit movements are coordinated, while proceeding at the intended speeds and pressures. This places high demands on the precision of the controls.

Hydraulics

The hydraulic system must exert its highest power-output during the injection phase. Besides maintaining the clamping force, the hydraulic system must also be able to inject the plastics melt into the cavity at high, but precise, speed. To accomplish this, the hydraulic system must overcome the resistance offered by nozzle and mold. At the start of the injection process, the molten, homogenized material is poised in the injection chamber. The nozzle is closed, so that no material can escape. As soon as the plasticating unit has been moved against the mold's sprue bush, the nozzle can be opened to allow the melt free passage into the mold. At the same time, the hydraulic system exerts pressure on the screw, which moves in an axial direction, i.e. forward towards the nozzle. The material is thus forced out of the screw's ante-chamber and pushed into the mold cavity. The fluid, molten material must re-solidify within that cavity, so that the finished article can be removed later. Therefore, molds employed for thermoplastics are cooled or heat-balanced, in order to dissipate the heat introduced into the material during the melting process, thus allowing it to solidify.

As soon as the melt contacts the mold during the injection operation, it begins to cool and solid. Therefore, injection must occur quickly so that the cavity is filled while the compound is still fluid. This requires very high pressure, because the melt is merely viscous, despite the high temperatures used. The melt flow must overcome the resistance offered by the nozzle, sprue, and cavity, as well as some other obstacles, such as wall friction. The pressure in front of the screw may therefore exceed 2000 bar (29,000 psi) in the injection operation. The resistance in the nozzle, sprue, and cavity causes this injection pressure to decrease gradually in the direction of flow. Despite this, high pressures also occur within the mold. The clamping unit must be capable of holding the mold tightly shut against these pressures.

Figure below shows the pressure-curve inside the mold, in front of the screw, and in the machine's hydraulic system. The pressure inside the mold reaches its maximum value, when sufficient melt has been injected to completely fill all cavities.



The pressure in the hydraulic system is actually much lower than that shown in above Figure. The reason is, that this pressure is intensified to a higher value by the hydraulic ram's projected area. The hydraulic pressure acting on the hydraulic ram's large projected area transmits a great amount of force to the screw's "ram" tip. This force produces the high pressure within the injection chamber. The most critical point of the injection phase has now been reached. Most of the molding compound is still in a fluid state, so almost all of the pressure applied by the screw can be transmitted to the mold. If the injection pressure were maintained beyond this point, the resulting pressure within the mold could be great enough to overcome the clamping force. The mold would be forced apart in the parting plane, allowing melt to escape from the cavity.

This can have serious consequences. Flash forms on the molding, which will require finishing work, or the article may even have to be rejected. The consequences for the mold or the machine can be considerably more critical. The high forces applied can result in serious damage to mold or clamping unit.

It is therefore critical, that the injection pressure is switched off at the right moment. If this occurs too soon, it will result in the production of incompletely filled parts. Change-over to holding pressure asks for particularly high precision of the machine's control and hydraulic systems.

Holding Pressure Phase

As soon as the plastics melt fills the mold, it begins to cool. This cooling process begins at the mold wall and proceeds toward the center. For a certain period, the melt remains fluid inside the molding. As it cools, the molding material decreases in volume; in other words, it 'shrinks.' If the pressure were completely switched off after the injection phase, the molding would detach itself from the wall as it cools. There would no longer be any control over the molding's dimensions. It is easy to imagine the consequences in the example of the CD: the surface would become uneven, the scanning by laser would become less reliable-in short, the CD would be utterly useless.

This can be avoided. As long as the internal region of the molding remains in a fluid state, the pressure on the melt is maintained. Supplemental fresh material is forced into the mold in sufficient quantity to compensate for shrinkage. Of course, this works only as long as the sprue's inside remains soft enough. That is one reason, why the sprue should be positioned at the thickest point of the molding, if possible. Besides this, it should also be dimensioned accordingly. Holding pressure phase is the term for the phase in which just enough pressure is applied to compensate for shrinkage by the supplemental injection of material. This phase must last until the sprue has solidified-in other words, until no more melt can be supplementally forced into the molding. That event is known as 'sealing point'. In contrast to the injection phase, no flow resistance must be overcome in the holding pressure phase. Furthermore, practically no movement of material occurs in this phase. For these reasons, the holding pressure can generally be set to a lower level than the injection pressure. It is important to set the pressure to the proper level. If the holding pressure is too low, or if the holding pressure period is too short, this would result in the production of a defective molding.

It is important, to take a closer look at the position of the screw in the holding pressure phase. At the start of the holding pressure phase, the cavity has already been filled with most of the melt, that it is meant to receive. A small quantity is subsequently injected to compensate for shrinkage. But even at the end of the holding pressure phase, some residual material should still be in the injection chamber. This 'melt cushion' enables pressure to be transmitted between the screw and the cavity or sprue. This melt cushion is absorbed in the next shot.

Controls

During the holding pressure phase, the machine controls must ensure that the hydraulic pressure, which moves the screw, remains at the prescribed level. This will allow the supplemental injection of just enough material into the cavity to compensate for the shrinkage of the molded part. For this purpose, most machines offer the option of running a sequence of different stages of holding pressure levels. These stages are adapted to the geometry of the molded part.

Hydraulics

The hydraulic pressure is at a lower level during the holding pressure phase than the injection phase. The change-over from injection phase to holding pressure phase is critical, as far as the hydraulic system is concerned. The ‘injection’ mode is characterized by high screw speeds and high pressure, while the ‘holding pressure’ mode is characterized by a very low screw speed and a relatively low hydraulic pressure. The transition from the former mode to the latter must be performed with extreme precision and within the shortest possible time. This demands high precision of the switching operations. The injection and holding pressure phases are followed by two other phases,

which proceed concurrently.

Cooling Phase

The material is now in the cavity of the mold. It has reached the cavity in a flowable state and must now solidify under the influence of the relatively low mold temperature. This will allow the finished molded part to be removed. The solidification of the molded part must occur under controlled conditions so that no undesirable stresses develop within the molded part. These stresses would warp the molded part.

Feed Phase

The sprue on the molded part has solidified, thus preventing any further injection of supplemental molding compound. The plasticating unit can thus fulfill its other tasks. New material can be prepared in readiness for the next cycle.

Cooling Phase

For the material within the mold cavity, the holding pressure phase is concluded as soon as the sprue solidifies-in other words, as soon as it is ‘sealed.’ From this point on, no more material can enter the cavity. During the injection and holding pressure phases, the material in the cavity has already begun to cool against the relatively cold mold wall. The outer layers have soldified very quickly. The cooling time therefore starts as early as injection. Cooling takes longer in the middle of the molded part. The surplus heat of melt remaining there must be dissipated through the outer layers to the mold wall. Now it becomes apparent that plastics are poor conductors of heat. The thermal conductivity of plastics is approximately 100 times poorer than that of steel. Heat transfer can be effectively defined with the help of mathematical equations. This makes it possible to perform advance calculations of the cooling time, during which the molded part must remain in the mold until it is sufficiently cooled. The cooling time also depends on for how long a period it is intended to cool the article within the mold. It is not necessary, to wait until the entire molding has cooled to mold temperature. It suffices, for the outer part of the molding to cool just enough, so that it can be removed from the mold in stable condition. It would also be ill-advised to allow the part to cool within the mold for longer than absolutely necessary. The reason is that the machine is essentially in a waiting mode during the cooling period and is therefore unproductive.

The choice of the proper cooling time is also especially important from the profitability aspect. Apart from the complicated equations for defining the cooling process - as applied in computer simulations of injection molding - there are also simple equations which make it possible to calculate cooling times with a pocket calculator or by hand.

Cooling Time Equation

The cooling time equation has been derived at as a simple approximation for defining heat-transfer within the molding during the cooling process in the injection molding tool:

$$t_c = \frac{s^2}{\pi^2 \times a_{eff}} \times \ln\left(\frac{4}{\pi} \times \frac{T_m - T_w}{T_E - T_w}\right)$$

t_c[s] = cooling time to be calculated

s[mm] = article thickness

T_m[K] = melt temperature at the start of the injection process

T_w [K] = mold temperature

T_E [K] = demolding temperature (assumed temperature at the molding's center, at which it is to be removed)

a_{eff} [mm^2/s] = effective temperature conductivity (the molding compound's physical characteristics, which can be found in Tables, subject to the mold wall temperature)

The following equation can be employed for a rough calculation of the cooling time:

$t_c = 2s^2$

t_c[s] = cooling time

s[mm] = the article's wall thickness

The article's largest wall thickness is decisive, as it determines the cycle time.

According to this formula, a CD with a wall thickness of 1.14 mm (0.045 in) requires a cooling time of approximately 2.6 seconds. (For wall thickness in inches, the formula for cooling time is CD = 2000 s^2.)

Mold and Clamping Unit

The status of mold and clamping unit during the holding pressure phase is identical with the one of the cooling phase.

Plasticating Unit

During the cooling period, material is prepared in the plasticating unit for the next shot. A detailed description of the events which take place in the plasticating unit during this phase is given in the section titled ‘feed phase.’

Control and Hydraulic Systems

Because the cooling phase represents a waiting phase for the machine, no actions need to be taken as far as hydraulics and controls are concerned during this phase. The events which take place during the concurrent feed phase are described in the ‘feed phase’ section.

Feed Phase

During the feed period- following the completion of the injection and holding pressure phases -material for a new shot must be prepared and provided in the proper quantity. The material is ‘fed’ or ‘metered.’

To this end, the material in the hopper above the plasticating unit is drawn in by the rotating screw and conveyed along the screw flights in the direction of the nozzle. As it moves toward the nozzle, the material is exposed to many different stresses. Heat is transmitted to the material from the cylinder wall of the plasticating unit. This transfer of heat is called thermal conduction.

The material is sheared by the rotation of the screw and further warmed by the resulting frictional heat. This effect is intensified by the fact that the height of the screw flights decreases in the direction of the nozzle. The material is thus being compressed increasingly. It is simultaneously mixed (homogenized) in a thorough manner. The pressure conditions in the space between the screw and the cylinder wall cause trapped air to be conveyed in the direction of the feed zone.

The intense compression and mixing of the material is desirable for ensuring that its properties are as uniform as possible. By the time it reaches the tip of the screw, the material has become molten. It accumulates in front of the screw in the ante-chamber. As the screw can be moved in an axial direction, it yields to the pressure of the accumulating material and moves backward. In order to improve homogenization, this movement is restricted by adjustable resistance, known as back-pressure.

In most cases, more energy is introduced into the material by friction than by the hot cylinder wall. Ultimately, this energy must be produced by the drive motor. Therefore, the amount of energy introduced is especially dependent on the screw speed and back pressure setting. The screw speed influences the time required to prepare the material.

When the settings for the process are selected, it is important to make sure, that the plasticating time does not exceed the cooling time. The reason is, that the plasticating time can vary as a result of variations in material characteristics. If the plasticating time were longer than the cooling time, these variations would directly affect the cycle time, possibly causing the quality of the molding to vary as well. The following rule therefore applies: The plasticating time must not be allowed to determine the cycle time.

Furthermore, an optimum cooling time offers the advantage of greater profitability, since it allows more moldings to be produced, due to time-saving.

The molding's cooling phase m s concurrently with the feed phase. As soon as the feed phase has ended, the material is available in the injection chamber for the next cycle. During the waiting period- while waiting for completion of the molding's cooling phase -a heat exchange occurs between the melt in the screw's ante-chamber and the cylinder wall. It is important to ensure, that during this waiting period the melt neither cools excessively nor absorbs too much heat and starts to decompose.

Mold and Clamping Unit

The mold and clamping unit are not involved in the plasticating operation.

Plasticating Unit

The preparation of new material begins immediately after the completion of the holding pressure phase. If a shut-off nozzle is used, it will close as soon as the holding pressure phase has timed-out. In this case the plasticating unit will be retracted from the mold to avoid excessive heat-transfer from the hot nozzle to the cooler mold.

If no shut-off nozzle is used, the plasticating unit cannot be retracted until the feed phase has ended. Otherwise, the molding compound would escape from the nozzle prematurely.

During the plasticating process, the screw is rotated by a hydraulic motor. The material descends from the hopper and enters the feed zone. The rotation of the screw then conveys the material toward the screw tip and through the open non-return valve. The screw is forced backward by the material accumulating in the injection chamber (ante-chamber) in front of the screw tip. As soon as the introduced melt has pushed the screw back to trigger the adjustable feed stroke limit switch, screw rotation is stopped. During the feed phase, the plasticating unit has readied the material for the next cycle. It has thus completed its task and is now in a waiting position.

Mold Layout

The dimensioning of the mold (phase I1 of the mold design) essentially includes the rheological, mechanical, and thermal mold layout. These aspects of the layout can be further divided into several steps, each with its own special emphasis:

Rheological:

- Determining the filling pattern
- Rheological calculation of the filling- and holding-pressure phase
- Layout of the runner system

Thermal:

- Cycle time calculation
- Energy balance of the mold overall
- Heating/cooling system layout

Mechanical:

- Kinematics
- Rigidity analysis

The quantitative layout of the cavity region and gating system requires primarily rheological expertise - in other words, knowledge of the flow characteristics of polymer melts.

The dimensioning of the mold temperature control system requires corresponding knowledge of the heat transfer subject. Mechanical and kinematic expertise are required in the dimensioning of the mold structure and the layout of the article removal system.

Rheological Mold Layout

The filling characteristics of the cavities are determined in the rheological mold layout. The filling phase and holding pressure phase determine the properties of the molded part. The rheological mold layout can include several steps:

- Establishing the filling pattern (qualitative)
- Rheological calculation of the filling- and holding-pressure phase (quantitative, e.g. pressures and temperatures) and
- Layout of the runner system

Establishing the filling pattern, which can also be determined graphically, makes it possible to confirm the positions of

- Weld-lines (which develop at the conflux of two different melt-sections)
- Air entrapments (which develop when air is trapped by the melt)
- Suitable sprue positions.

Figure 8-2 shows the establishing of the filling pattern for two simple, plate-like moldings. This shows the positions reached by the flow fronts at different times. Each plate is filled from the gate (feed point). Emanating from a single point by laminar flow, the flow-fronts spread like waves into the mold cavity, which has been empty until now. This results in concentric circles around the feed point. If the cross section is altered, as shown on the right side of Figure 8-2, the filling pattern will also change. For rectangular cross sections, these relationships can be calculated approximately by the following formula:

$$\frac{\Delta l_1}{\Delta l_2} = \frac{s_1}{s_2}$$

where A1 [mm] stands for the flow front progress and s [mm] for the article’s wall thickness.

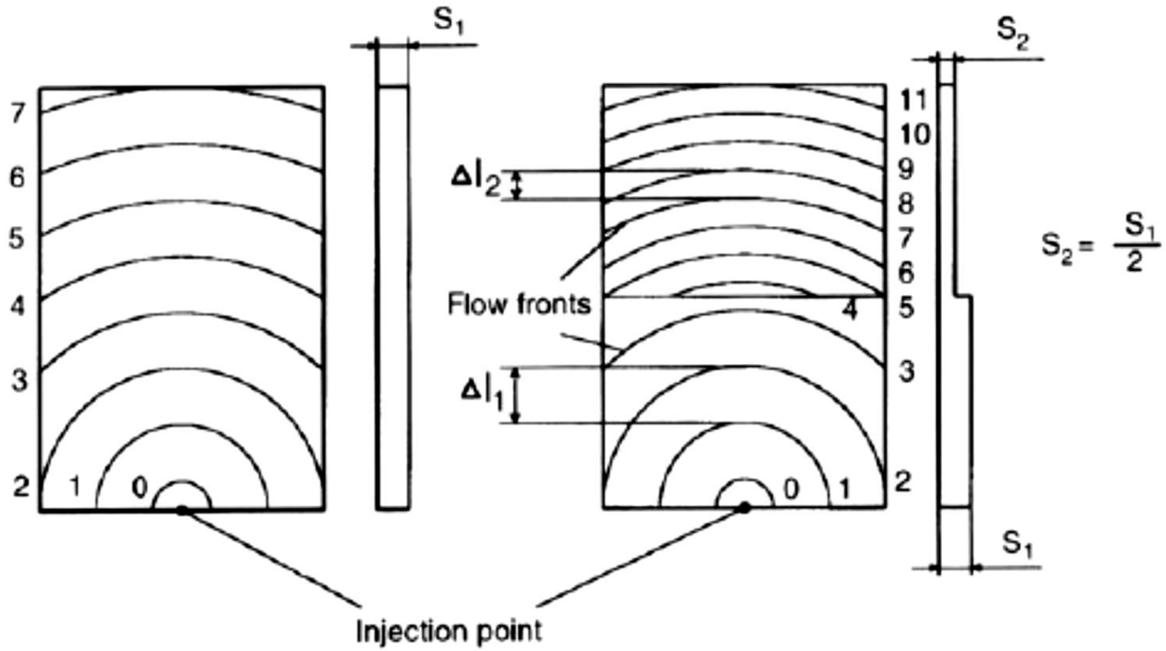


Figure 8-2 Establishing filling patterns for two simple, plate-like moldings

For example, if the height of the cross section is reduced by half, the distance from one flow front to the next will also be cut in half. This means that filling the right plate will take longer than filling the left one.

The following example illustrates the filling simulation. When molding a toy locomotive profile air is trapped at the far side, opposite the gate (Figure 8-3 left). This can also be predicted by simulation (Figure 8-3 right).

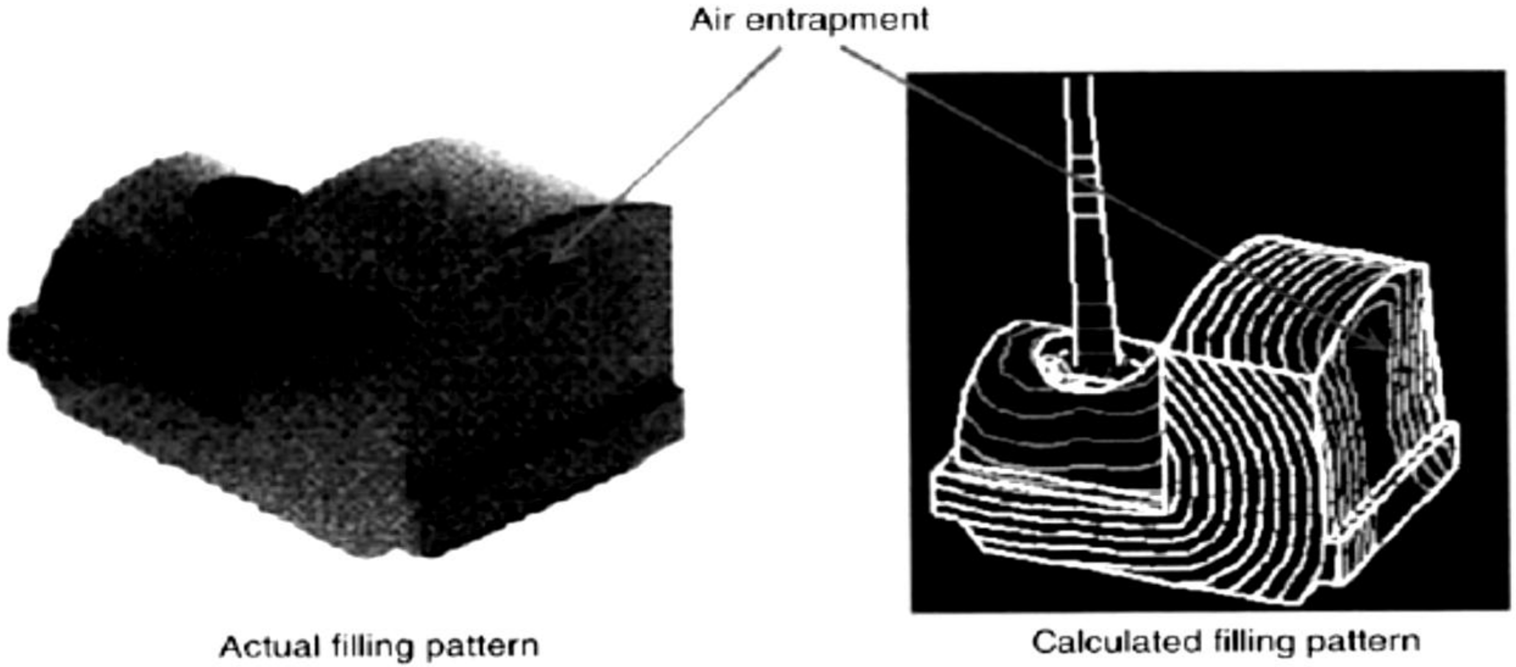
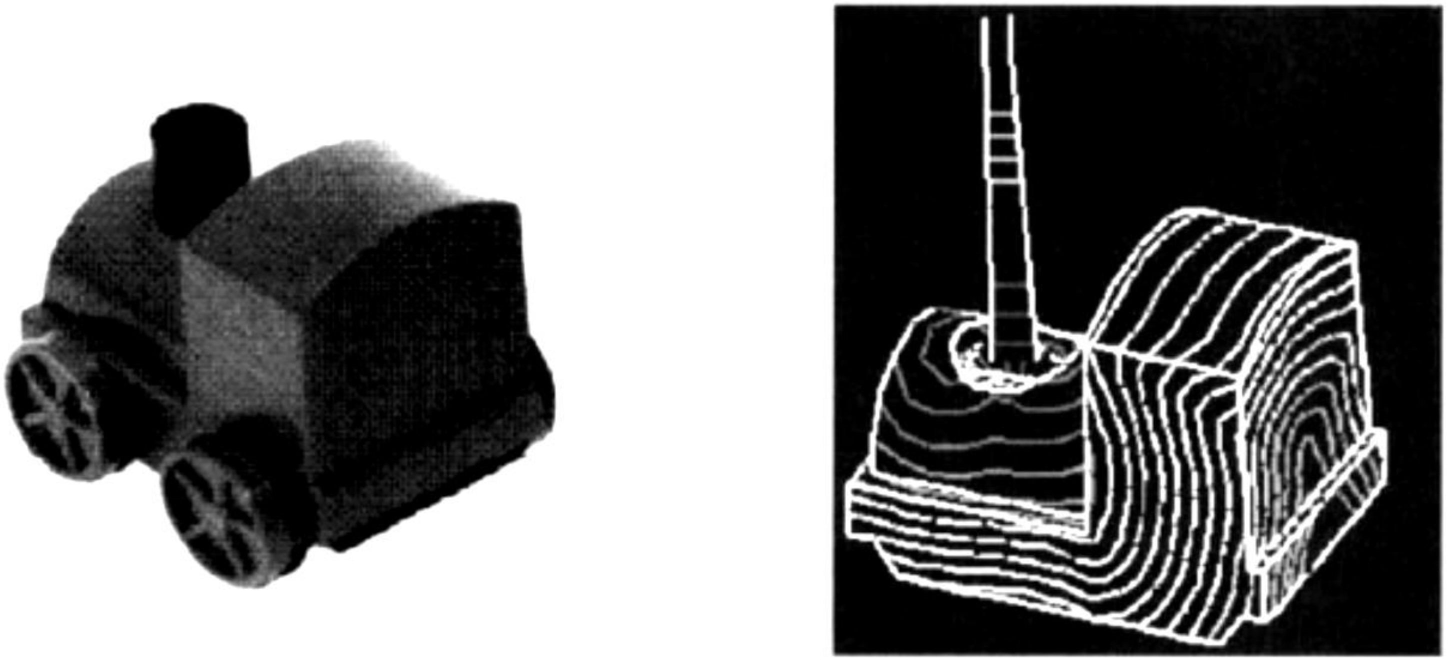


Figure 8-3 Filling pattern of toy locomotive

The profile of the flow front can be optimized in such a way by varying the wall thicknesses, that air entrapment is eliminated. Figure 8-4 shows the flow front profile, as established by computerized filling simulation, based on a filling pattern method. This could also be produced manually, with a pair of compasses and a ruler.



Perfect locomotive

Optimized filling pattern

Figure 8-4 Flow front optimized by simulation

Even the positions of weld-seams, which develop when two flow fronts meet, can be determined with the aid of simulation.

This filling pattern is generally created independently of material properties and process parameters. In other words, it is partly established by applying simple graphic rules. The actual rheological layout of the mold is based on the following specifications: material and processing data, such as the compound's melt density, the injection rate, the injection temperature, and the material's rheological properties. These, for instance, enable statements to be made, regarding:

Pressure requirements for mold filling:

- Melt temperatures
- Speeds/velocities
- Shrinkage characteristics

The pressure requirement for filling the mold cavity determines not only the injection molding machine model to be chosen, but also the size of the mold construction elements.

Like the filling phase, the cooling phase is also critically important to the quality of the molded part. The injected part is cooled within the injection mold for the length of time needed for the part to become sufficiently solid and capable of being removed.

The mold temperature control system must therefore be laid out in a manner which allows the heat of the molded part to dissipate uniformly and within the shortest possible time. Aside from the quality of the molded part, therefore, profitability is also strongly affected, because of the effect on the cycle time.

The shorter the cooling time, the shorter the cycle time will be. The thermal mold layout also includes several stages:

- Calculation of cycle time
- Energy balance of the overall mold
- Layout of the heat-balancing system

With knowledge of the material temperature, wall temperature, ambient temperature, plus the specification of the article removal temperature, it becomes possible to analyze the energy balance of the overall mold. Decisions on whether and how to provide the mold with thermal insulation are made at this stage of the layout. The performance of the temperature control system is also established at this stage. Figure 8-5 shows the heat balancing of an injection molding tool.

The term heat balance space refers to the space considered for heat exchange phenomena. The heat flow emanating from the molded article enters the balance space. The following pass-out of the heat balance space: the heat flow dissipated by the heat-balancing medium, the convective- as well as the radiant heat-flow (both to the environment), and the thermal conductivity flow, which enters the platens.

The next step is the layout of the heat-balancing system. This step involves establishing the number of heat balancing circuits required, the distances between the cores for the heat-balancing medium, the distances between the cores and the cavity surface, and the temperature and throughput rates of the heat-balancing medium. The design of the heat-balancing system is precisely determined by this layout. The goal is the most uniform dissipation of heat from the cavity region which can possibly be achieved.

The optimal cycle time, which was described in the previous lesson, is calculated in the final stage. This maximizes the profitability of production. The cooling time amounts to 50-700/0 of the cycle time. It increases by the square of the article's wall-thickness. For this reason, wall thicknesses exceeding 6 mm (1 /4 in) are rarely chosen.

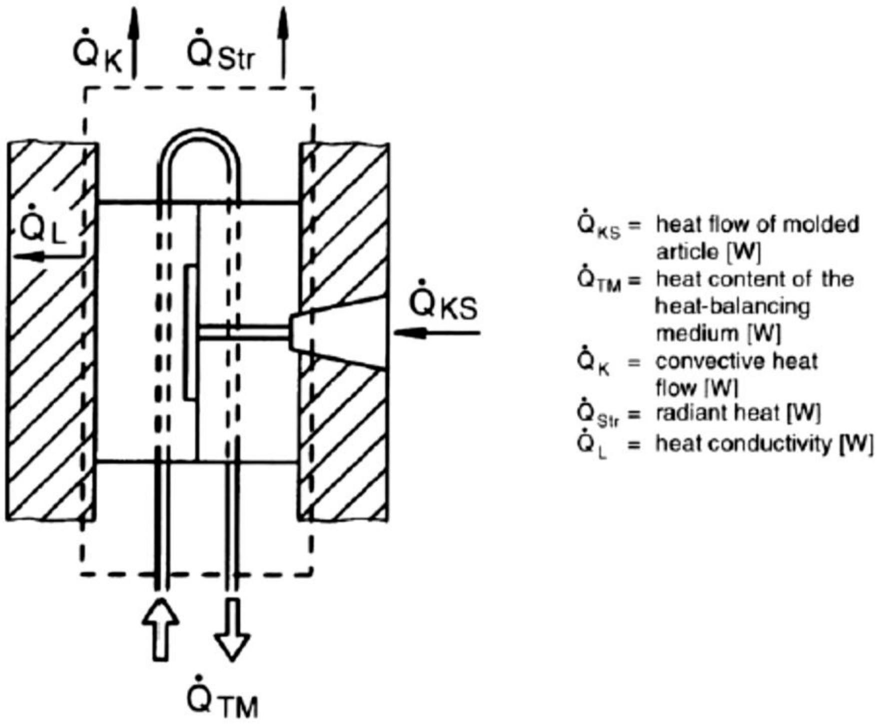


Figure 8-5 Heat balance of an injection molding tool

A rule of thumb formula for calculating cooling is given in greater detail in Lesson 7.5. The formula employs variables of the melt temperature, wall temperature, demolding temperature, as well as the plastic material's thermal conductivity.

Calculation of the CD's cooling time results in:

- The CD has a wall thickness of 1.14mm (0.045in) and is made of polycarbonate. It is processed at a material temperature of approximately T_M = 330°C. The mold wall temperature is T_W = 60°C and the thermal conductivity of the plastics material amounts to a_{eff} = 0.01 mm^2/s. The demolding temperature-measured at the center of the molding-is assumed to be about TE = 110°C.
- Calculation by cooling time formula results in a cooling time of T_E = 2.5 s

Current cycle times for the fully automatic production of CDs are given as 3.9 seconds, with the cooling time accounting for approximately 2.7s. But it is quite possible, to achieve even shorter cycle times for this process.

Mechanical Mold Layout

Injection molds are among the most heavily loaded devices in industry, as they are exposed to clamping forces of up to several thousand tons and internal mold pressures up to 2000 bar (29,000 psi). Because these molds are intended for the manufacture of molded parts of extremely high precision, it is necessary to consider the deformations undergone by the injection mold under these loads.

The mechanical mold layout is also produced in several stages. For example, factors related to kinematics and rigidity in the clamping direction are considered.

Because mold deformations are intended to occur in the linear-elastic range, an overlap between loads and deformations is permissible in principle. Linear-elastic means that the deformation changes linearly (i.e., along a straight line), as the force exerted upon a component increase. When the load is removed, deformation will return to zero. The component behaves like a spring. The modulus of elasticity is a measure of linearity for this response. The higher the modulus of elasticity, the less deformation will be experienced by a stressed component.

The individual parts of a mold basically behave like a spring. When a spring is subjected to a load, it is compressed. When the load is removed, the spring relaxes and returns to its starting condition.

Therefore, the mold deformations are calculated on the basis of a spring model. The deformation characteristics of the component being tested can be simulated by an appropriate combination of springs. An example of a simple mold and the corresponding spring model are shown in the schematic diagram in Figure 8-6. The five elements of the component are divided into five springs. The laws of elasticity for series and parallel combinations of springs are needed for the calculation.

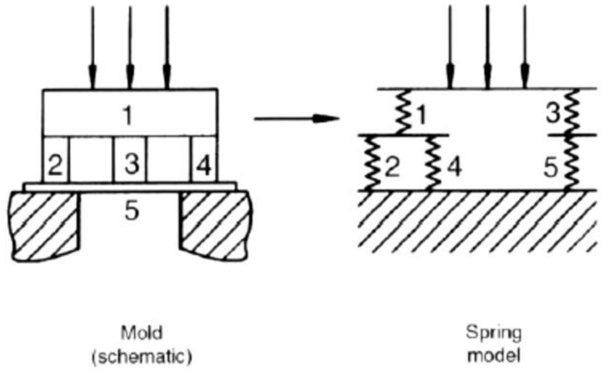


Figure 8-6 Spring-set model

One layout step is the consideration and dimensioning in the clamping direction. The criterion for this aspect of the layout is that platen deflection must not give rise to any prohibitively large gaps in the parting plane, which would allow melt to intrude (flashing). This flash would eventually result in the destruction of the mold. An additional step in the mechanical layout involves the consideration of components such as ejector pins and guidance systems. The forces which figure prominently in these considerations are inertial and frictional forces. These forces load not only the above-mentioned components but also the molded part. It is sometimes necessary to overcome a high degree of static friction, especially when the part is removed from the mold. This static function is frequently more likely to cause damage to the molding than to the ejector pins.

Time-consuming calculations are necessary for complicated mold geometries and stresses. These tasks are carried out by computer programs.

Figure 8-7 shows a section through a mold in its stressed and unstressed condition. This computer calculation clearly indicates deformations of 4.0 mm (0.15 in) (unstressed condition) to 4.1 mm (0.16 in) (stressed condition) in the cavity area. For easier understanding, the deformation in the stressed condition has been exaggerated-that is, the representation is not true to scale.

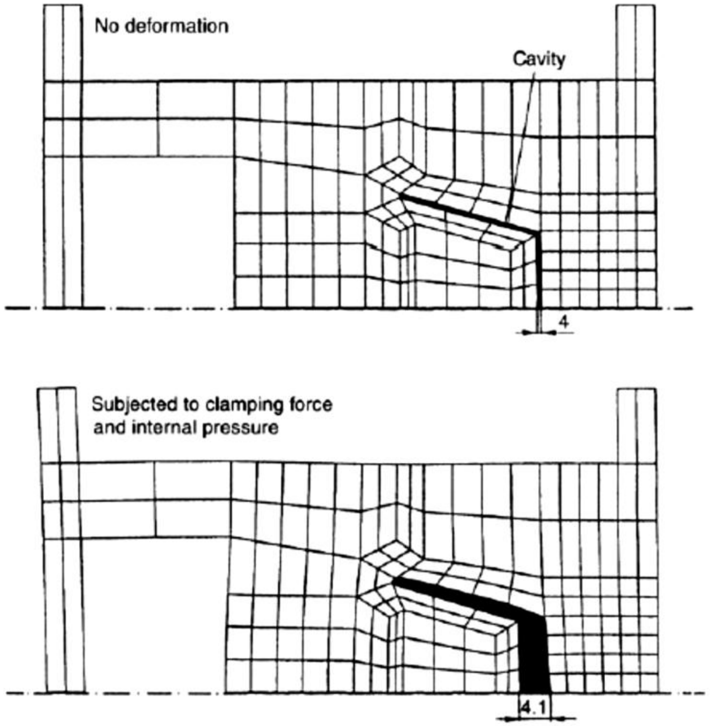


Figure 8-7 Simulation of deformation characteristics

Importance of using PPEs

PPE is equipment that will protect workers against health or safety risks on the job. The purpose is to reduce employee exposure to hazards when engineering and administrative controls are not feasible or effective to reduce these risks to acceptable levels.

PPEs:

Name & Usage	Picture of PPE	Name & Usage	Picture of PPE
Safety goggles – used to protect eyes from flying particles (chips, sparks etc.)		Safety shoes – used to protect feet from spatters of welding and impact of other falling objects	
Face shield - used to protect face from welding sparks, radiations, arc and spatters		Face mask – used to protect from inhaling fumes, dangerous gases etc.	
Hard cap – used to protect the head from injury due to falling objects		Leather Apron – used to protect welder's body from welding spark and spatters	
Leather gloves – used to protect hands during welding		Cotton gloves – used to protect hands from sharp edges of sheets and plates	

Importance of housekeeping and safe storage of tools and equipment

The main function of housekeeping is to ensure cleanliness, comfort, convenience, privacy, health and hygiene in a safe environment. It includes keeping work areas neat and orderly. All the tools and equipment must be stored properly.

Importance of making a check list

It ensures you get your daily, weekly and monthly tasks done on time, helps you keep track of projects on deadline and ensures you're organized throughout the day.

Video links:

Plastic Injection Molding – University of Illinois: https://www.youtube.com/watch?v=RMjtmsr3CqA
Molding Machine Parts and Operation - Technology of Injection Molding: https://www.youtube.com/watch?v=DbaWBXe9-vQ
Instructional video: 80 Ton Arburg Injection Molder: https://www.youtube.com/watch?v=VxayepUk3r0

PLASTIC PROCESSOR

Module-7

Learner Guide

National Vocational Certificate Level 3

Version 1 - September, 2018

Module 7: 072200916 Operate Pipe Extrusion Machine

Objective of the module: The aim of this module to provide skills and knowledge to operate pipe extrusion machine in accordance with the manufacturer's manual

Duration: 150 hours **Theory:** 30 hours **Practical:** 120 hours

Learning Unit	Learning Outcomes	Learning Elements	Materials Required
LU1: Inspect extrusion machine pre-start parameters	**The trainee will be able to:** Check control variables as per process Check extruder parameters as per standard Check downstream parameters as per standard	i) Machine controls • Learn to input processing parameters in the machine and peripheral components ii) Peripheral equipment such as air compressors, chillers, vacuum pump, printer, dryer, etc. • Ensure working and operation of all affiliated equipment	Extruder High speed mixer Pipe extrusion downstream line Extruded product samples Operation manual Basic Hand Tools
LU2: Carry out operation	**The trainee will be able to:** Perform purging. Ensure extrude flow as per requirement Guide the extrudate to haul-off unit. Check pipe concentricity as per standard. Start vacuum bath according to instruction set Ensure cutting as per size	i) Machine controls ii) Temperature adjustment from feed-zone to metering zone iii) Usage of Purging material to ensure clean extruder and die iv) Input Raw material for production of pipe v) Ensure concentric extrudate output from die head vi) Ensure vacuum is obtain in water bath vii) Pipe dimensions as per standard viii) Ensure cutting of pipe in desired length	Extruder High speed mixer Pipe extrusion downstream line Extruded product samples Operation manual Basic Hand Tools

LU3: Start production as per requirement	**The trainee will be able to:** Adjust pipe sizing as per job card. Fix printer as per job card. Manage production rate as per machine capacity to achieve standard component	i) Machine operation in automatic mode • Be able to perform semi-auto operation • Up on successfully obtaining required product specification, switching the machine to auto mode ii) Peripheral equipment such as air compressors, chillers, vacuum pump, printer, dryer, etc.	Extruder High speed mixer Pipe extrusion downstream line Extruded product samples Operation manual Basic Hand Tools
LU4: Perform follow up procedure	**The trainee will be able to:** Verify pipe length as per order Verify pipe standard dimensions and visual inspection Generate parameters report according to set format.	i) Knowledge of pipe standards (BS 3505, etc.) • Understand the difference in producing pipes as per multiple standards • Memorize dimensions of pipes as per commonly used standards ii) Maintaining product quality as per specifications • Be able to measure components for identification of dimensional defects • Usage of measurement tools is critical: Vernier caliper, micrometer gauge, scale, etc. iii) Raw material input in machine • Ensure consistent raw material feed into hopper/feeder • Be able to use overhead crane or moveable lifts/ladders	Extruder High speed mixer Pipe extrusion downstream line Extruded product samples Operation manual Basic Hand Tools

		• Understand the importance of cutting tools in opening raw material bags. • Concept of 'clean slits' using sharp tools to ensure particles of bag don't get mixed in raw material iv) Lubrication requirements and procedure of machine • Understand the concept of lubricating moveable parts of machines • Be able to provide first-hand feedback to maintenance department for periodic machine maintenance v) Recognize different defects and their causes • Be able to visually identify commonly occurring defects, such as eccentricity, burn lines, blistering, etc. • Gain knowledge of rectification of commonly occurring defects.	
LU5: Submit production report	**The trainee will be able to:** Note machine hours as per format. Record production (kg/hr) as per format. Record rejection (kg/no.) as per procedure and format.	i) Production report writing • Understand the importance of reporting accurate production quantity • Be able to fill-in relevant production reports • Be able to identify waste generated along with identification of machine downtime with reasons ii) Data sharing with relevant departments • Understanding the concept of producing accurate data and benefits of the same on a larger scale	Reporting formats Job card Extruder High speed mixer Pipe extrusion downstream line Extruded product samples Operation manual Basic Hand Tools

	Record machine downtime (hrs/min) on set format. Record machine output(productivity) on set format	• Submission of production reports to production planning department or the supervisor for timely actions.	
LU6: Transport finished product	**The trainee will be able to:** Ensure finished goods are counted according to organization procedure. Deliver relevant packaging documents to store personnel	i) Understand QC protocols • Understand and appreciate the importance of producing products as per specification • Be able to implement the first quality control protocol on machine to ensure elimination of defective products at sight ii) Inter-department co-ordination • Be able to co-ordinate with QC department with produced batches for relevant approvals iii) Be able to hand over final products to store • Familiarize with handing-over protocols and paperwork.	Reporting formats Job card Basic Hand Tools Medium of material transport

Examples and illustrations:

For further details, please refer to the following books:

1) Understanding Polymer Processing, by Hanser Publishers, Munich
2) Extrusion: The Definitive Processing Guide and Handbook by © 2005 William Andrew Publishing
3) The Dynisco Extrusion Processors Handbook 2nd Edition by John Goff and Tony Whelan, The DYNISCO Companies

Introduction:

During extrusion, a polymer melt is pumped through a shaping die and formed into a profile. This profile can be a plate, a film, a tube, or have any cross-sectional shape. Ramtype extruders were first built by J. Bramah in 1797 to extrude seamless lead pipes. The first ram-type extruders for rubber were built by Henry Bewley and Richard Brooman in 1845. In 1846, a patent for cable coating was filed for trans-gutta-percha and cis-hevea rubber and the first insulated wire was laid across the Hudson River for the Morse Telegraph Company in 1849. The first screw extruder was patented by Mathew Gray in 1879 for the purpose of wire coating. However, the screw pump can be attributed to Archimedes, and the actual invention of the screw extruder in polymer processing by A.G. DeWolfe of the United States dates to the early 1860s. The first extrusion of thermoplastic polymers was done at the Paul Troester Maschinenfabrik in Hannover, Germany in 1935.

Pumping

Although ram and screw extruders are both used to pump highly viscous polymer melts through passages to generate specified profiles, they are based on different principles. The schematic in Fig. 4.1 shows the principles that rule the work of ram extruders, screw extruders, and other pumping systems. The ram extruder is a positive displacement pump based on the pressure gradient term of the equation of motion. Here, as the volume is reduced, the fluid is displaced from one point to the other, resulting in a pressure rise. The gear pump, widely used in the polymer processing industry, also works on this principle. On the other hand, a screw extruder is a viscosity pump that works based on the pressure gradient term and the deformation of the fluid, represented as the divergence of the deviatoric stress tensor in Fig. 4.1. Figure 4.2 represents the simplest form of a viscosity pump. Here, the inner cylinder turns and drags the highly viscous fluid in the counter-clockwise direction, until it is pushed out of the system. Various situations can be described with this type of pump:

- (Case 1) Open discharge,
- (Case 2) Closed discharge, and
- (Case 3) Flow resisting die.

The open discharge case is where the pump is open to the atmosphere and consequently does not encounter a flow resistance. Here, the maximum flow rate is generated, and no pressure is built up. In the closed discharge case, the exit of the pump is blocked, leading to no flow rate and a maximum pressure build-up. In the flow restricting die case the fluid exiting the pump encounters a resistance, such as a die, where it is forced to flow through a narrow gap. Here, the pressure generated by the shear deformation is consumed by the die.

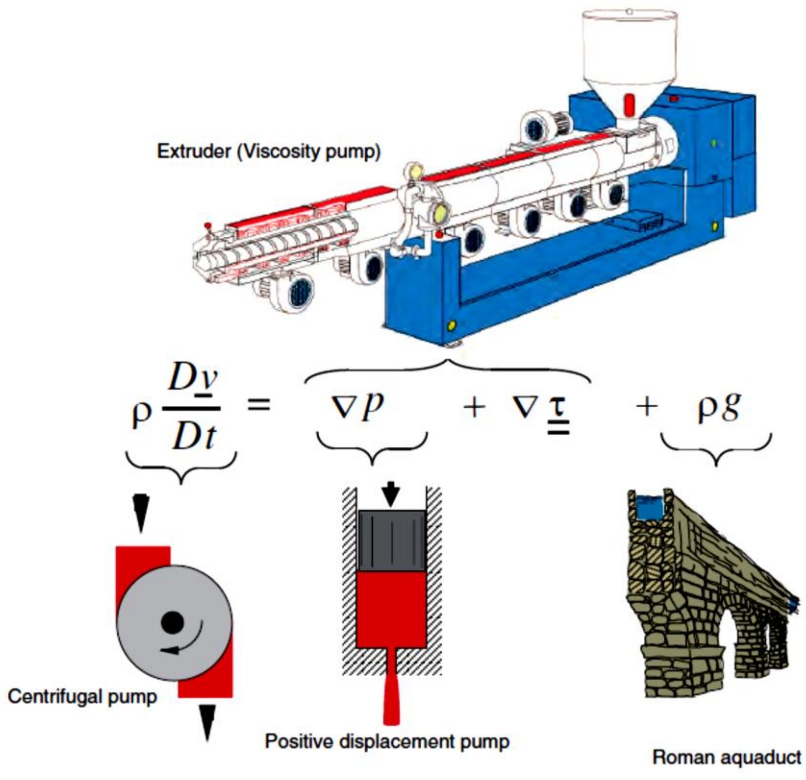


Figure 4.1 Schematic of pumping principles

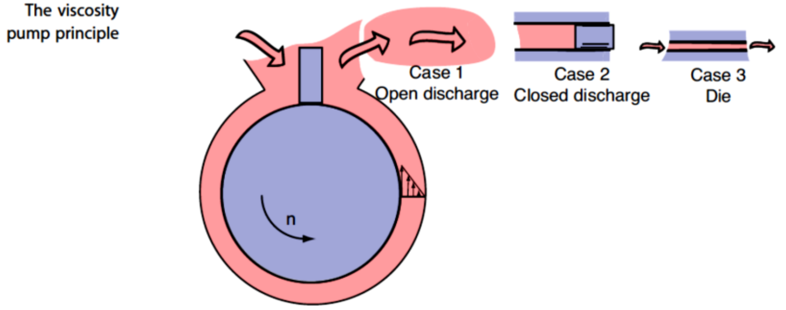


Figure 4.2 Schematic of a viscosity pump

The centrifugal pump, which works based on the fluid's inertia is also represented in the figure and is typical of low viscosity liquids. The Roman aqueduct, shown on the right of the figure, is driven by gravitational forces. In today's polymer industry, the most commonly used extruder is the single screw extruder, schematically depicted in Fig. 4.3. The single screw extruder can either have a smooth inside barrel surface, called a conventional single screw extruder, or a grooved feed zone, called a grooved feed extruder. In some cases, an extruder can have a degassing zone, required to extract moisture, volatiles, and other gases that form during the extrusion process.

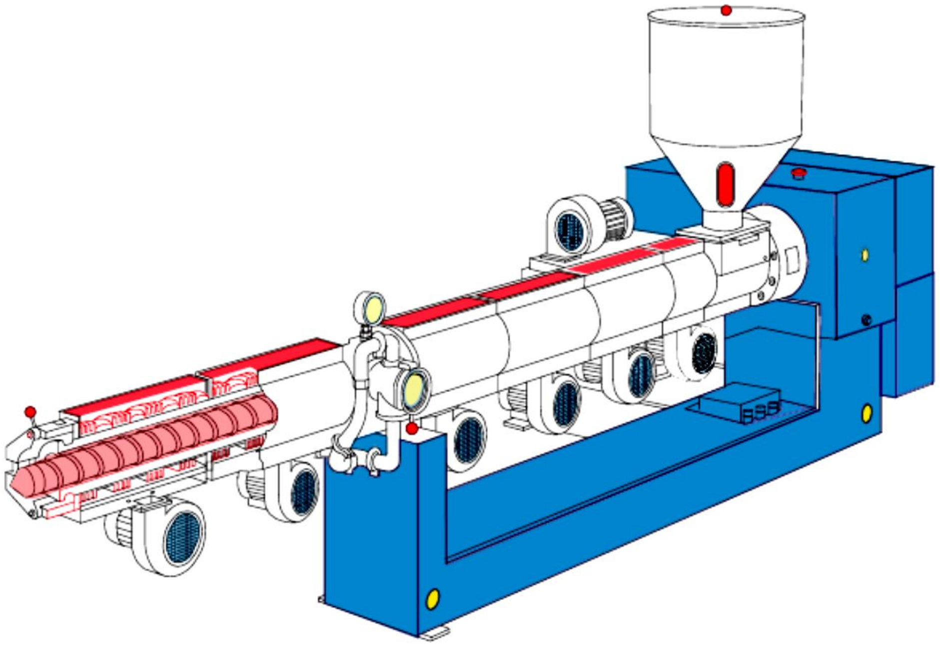


Figure 4.3 Schematic of a single screw extruder (Reifenhäuser)

Another important class of extruders are the twin-screw extruders, schematically depicted in Fig. 4.4. Twin screw extruders can have co-rotating or counter-rotating screws, and the screws can be intermeshing or non-intermeshing. Twin screw extruders are primarily employed as mixing and compounding devices, as well as polymerization reactors.

The Plasticating Extruder

The plasticating single screw extruder is the most common equipment in the polymer industry. It can be part of an injection molding unit and is found in numerous other extrusion processes, including blow molding, film blowing, and wire coating. A schematic of a plasticating, or three-zone, single screw extruder with its most important elements is shown in Fig. 4.5. Table 4.1 presents typical extruder dimensions and relationships common in single screw extruders.

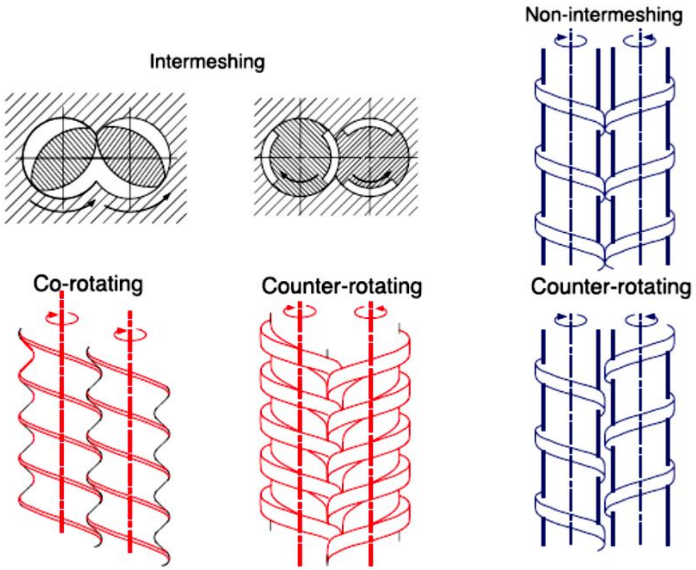


Figure 4.4 Schematic of different twin screw extruders

The three zone extruder – solids, melting and pumping zones

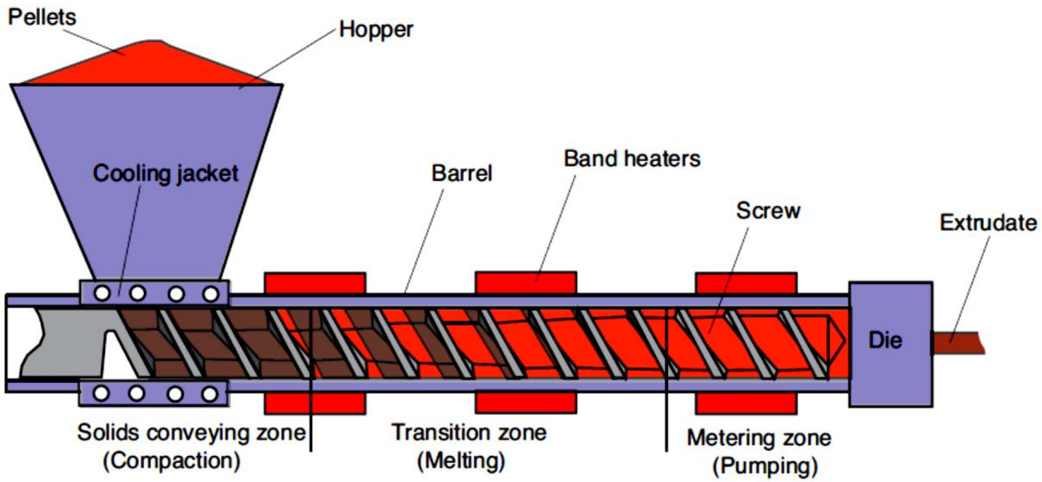


Figure 4.5 Schematic of a plasticating single screw extruder

Table 4.1 Typical extruder dimensions and relationships (the notation for Table 4.1 is defined in Fig. 4.6.)

L/D	Length to diameter ratio 20 or less for feeding or melt extruders 25 for blow molding, film blowing and injection molding 30 or higher for vented extruders or high output extruders
D U.S. (in) Europe (mm)	Standard diameter 0.75, 1.0, 1.5, 2, 2.5, 3.5, 4.5, 6, 8, 10, 12, 14, 16, 18, 20, and 24 20, 25, 30, 35, 40, 50, 60, 90, 120, 150, 200, 250, 300, 350, 400, 450, 500, and 600
φ	Helix angle 17.65° for a square pitch screw where $L_s = D$ New trend: $0.8 < L_s/D < 1.2$
h	Channel depth in the metering section (0.05–0.07) D for $D < 30$ mm (0.02–0.05) D for $D > 30$ mm
β	Compression ratio: $h_{feed} = \beta h$ 2 to 4
δ	Clearance between the screw flight and the barrel 0.1 mm for $D < 30$ mm 0.15 mm for $D > 30$ mm
n	Screw speed 1–2 rev/s (60–120 rpm) for large extruders 1–5 rev/s (60–300 rpm) for small extruders
u_B	Barrel velocity (relative to screw speed) $= \pi D n$ 0.5 m/s for most polymers 0.2 m/s for unplasticized PVC 1.0 m/s for LDPE

Characteristic speed inside an extruder is 0.5 m/s for most polymers

- the solids conveying zone
- the melting or transition zone
- the metering or pumping zone

The tasks of a plasticating extruder are to:

- transport the solid pellets or powder from the hopper to the screw channel
- compact the pellets and move them down the channel
- melt the pellets
- mix the polymer into a homogeneous melt
- pump the melt through the die

The pumping capability and characteristic of an extruder can be represented with sets of die and screw characteristic curves. Figure 4.7 presents such curves for a conventional (smooth barrel) single screw extruder. The die characteristic curves are labeled K1, K2, K3, and K4 in ascending order of die restriction. Here, K1 represents a low resistance die, such as for a thick plate, and K4 represents a restrictive die, such as is used for film. The different screw characteristic curves represent different screw rotational speeds. In a screw characteristic curve, the point of maximum throughput and no pressure build-up is called the point of open discharge. This occurs when there is no die. The point of maximum pressure build-up and no throughput is called the point of closed discharge. This occurs when the extruder is plugged. The lines also shown in Fig.4.7 represent critical aspects encountered during extrusion. The curve labeled T_{max} represents the conditions at which excessive temperatures are reached as a result of viscous heating. The feasibility line ($\dot{m}_{min}$) represents the throughput required to have an economically feasible system. The processing conditions to the right of the homogeneity line render a thermally and physically heterogeneous polymer melt.

The Solids Conveying Zone

The task of the solids conveying zone is to move the polymer pellets or powders from the hopper to the screw channel. Once the material is in the screw channel, it is compacted and transported down the channel. The process to compact the pellets and to move them can only be accomplished if the friction at the barrel surface exceeds the friction at the screw surface. This can be visualized if one assumes the material inside the screw channel to be a nut sitting on a screw. As we rotate the screw without applying outside friction, the nut (polymer pellets) rotates with the screw without moving in the axial direction. As we apply outside forces (barrel friction), the rotational speed of the nut is less than the speed of the screw, causing it to slide in the axial direction. Virtually, the solid polymer is then “unscrewed” from the screw.

The Melting Zone

The melting or transition zone is the portion of the extruder where the material melts. The length of this zone is a function of the material properties, screw geometry, and processing conditions. During melting, the size of the solid bed shrinks as a melt pool forms at its side, as depicted in Fig.4.13(a),which shows the polymer unwrapped from the screw channel. Figure 4.13b presents a cross section of the screw channel in the melting zone. The solid bed is pushed against the leading flight of the screw as freshly molten polymer is wiped from the melt film into the melt pool by the relative motion between the solids bed and the barrel surface. Knowing where the melt starts and ends is important when designing a screw for a specific application.

The solid bed profile in a single screw extruder

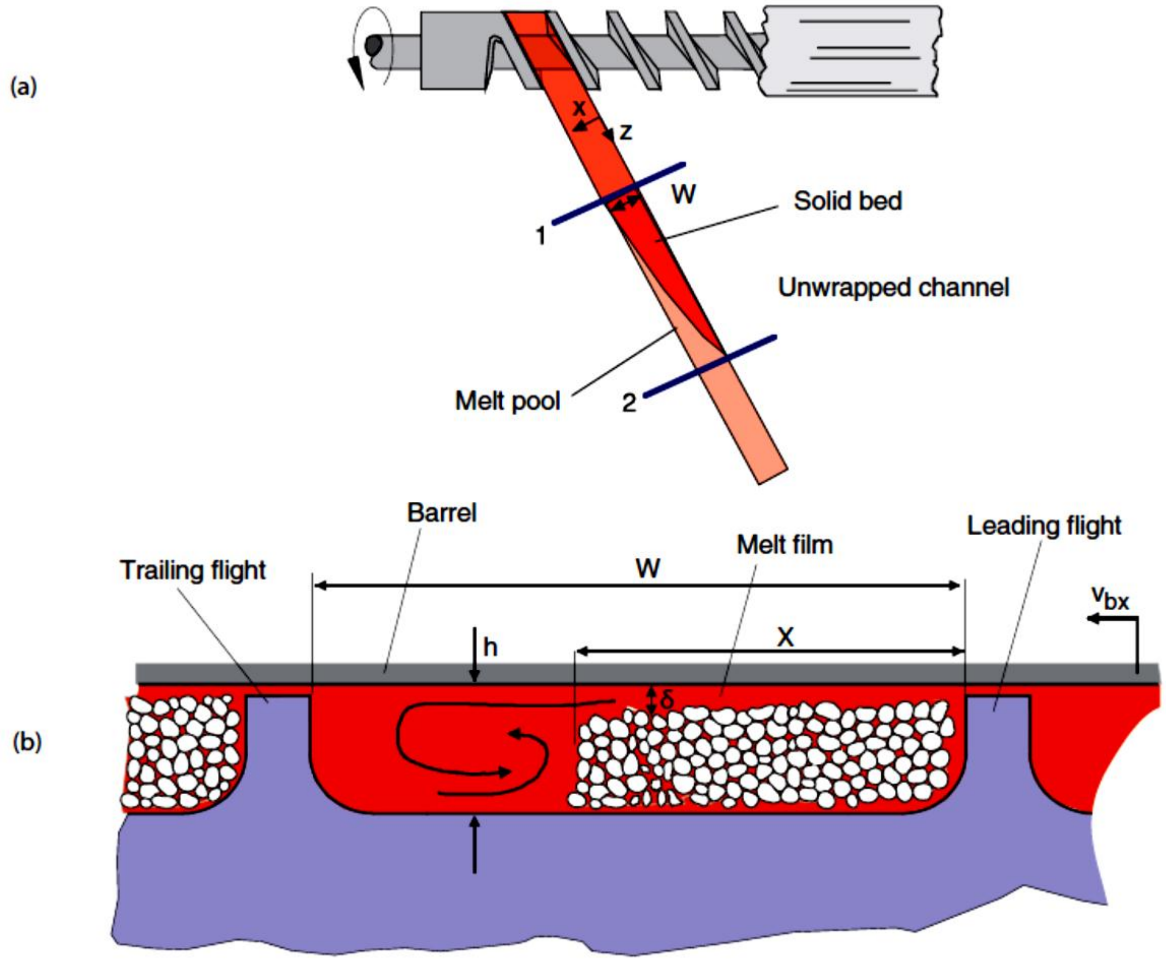


Figure 4.13 (a) Solids bed in an unwrapped screw channel and (b) screw channel cross section

The Metering Zone

The metering zone is the most important section in melt extruders and conventional single screw extruders that rely on it to generate pressures sufficient for pumping. The pumping capabilities in the metering section of a single screw extruder can be estimated by solving the equation of motion with appropriate constitutive laws. A restrictive extrusion die would clearly work best with a shallow channel screw, and a less restrictive die would render the highest productivity with a deep channel screw. In both the grooved barrel and the conventional extruder, the diameter of the screw determines the metering or pumping capacity of the extruder.

Extrusion Dies

The extrusion die shapes the polymer melt into its final profile. The extrusion die is located at the end of the extruder and it used to extrude:

- flat films and sheets
- pipes and tubular films for bags
- filaments and strands
- hollow profiles for window frames
- open profiles

As shown in Fig. 4.18, depending on the functional needs of the product, several rules of thumb can be followed when designing an extruded plastic profile. These are:

- Avoid thick sections. They add to the material cost and increase sink marks caused by shrinkage.
- Minimize the number of hollow sections. hollow sections add to die cost and make the die more difficult to clean.
- Generate profiles with constant wall thickness. Constant wall thickness in a profile makes it easier to control the thickness of the final profile and results in a more even crystallinity distribution in semi-crystalline profiles.

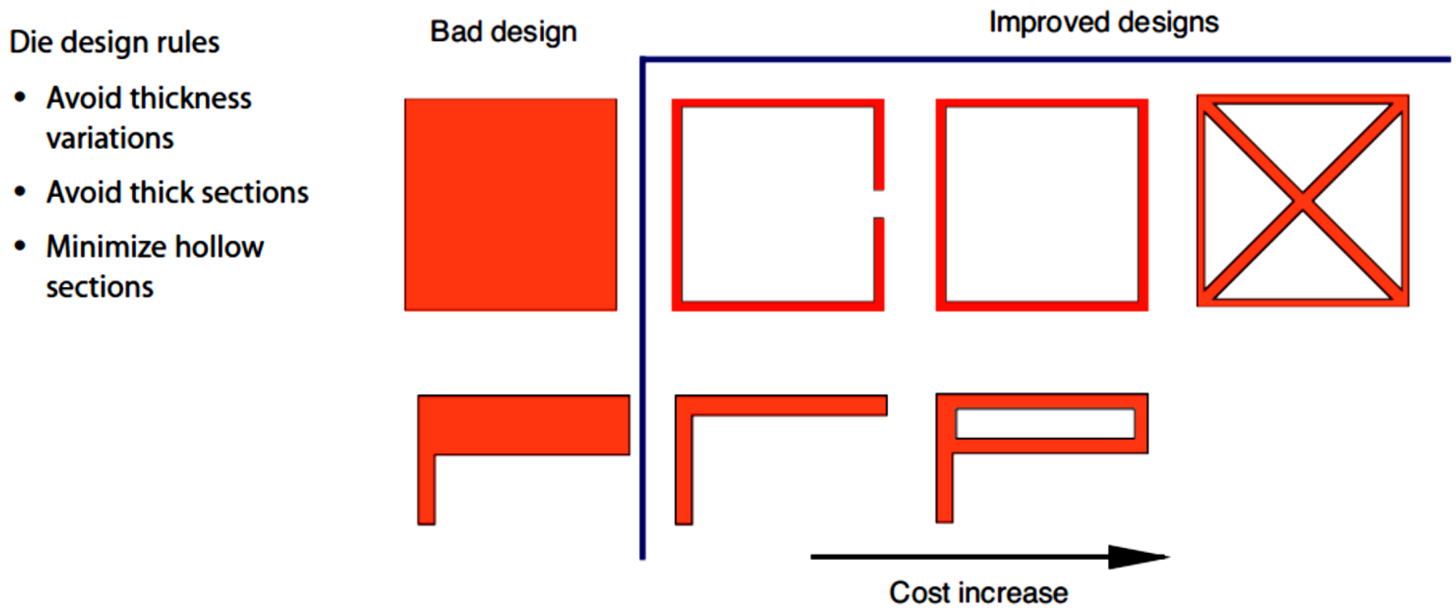


Figure 4.18 Extrusion profile designs

Sheeting Dies

One of the most widely used extrusion dies is the coat-hanger sheeting die. A sheeting die, such as depicted in Fig. 4.19, is formed by the following elements:

- Manifold: evenly distributes the melt to the approach or land region
- Approach or land: carries the melt from the manifold to the die lips
- Die lips: perform the final shaping of the melt
- Flex lips: for fine tuning when generating a uniform profile

To generate a uniform extrudate geometry at the die lips, the geometry of the manifold must be specified appropriately. Figure 4.20 presents the schematic of a coat-hanger die with a pressure distribution that corresponds to a die that renders a uniform extrudate.

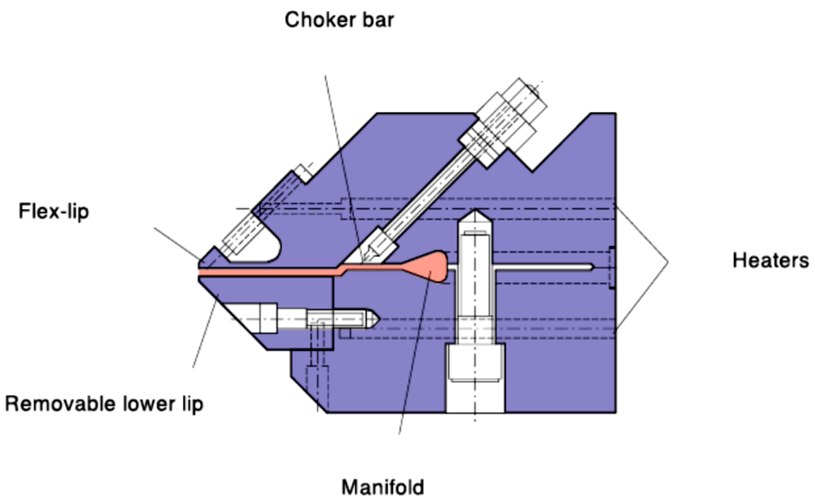


Figure 4.19 Cross section of a coat-hanger die

The goal in sheeting die design is to have a uniform product

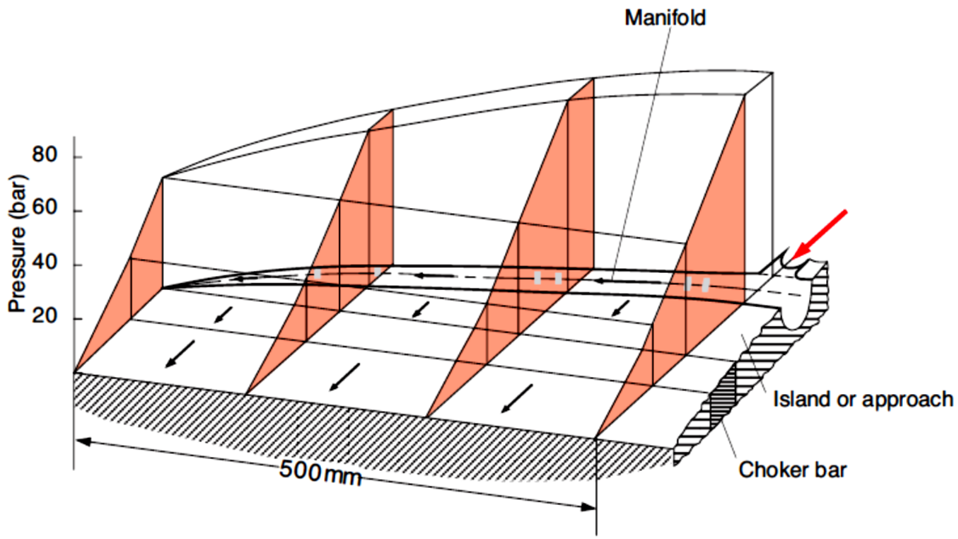


Figure 4.20 Pressure distribution in a coat-hanger die

It is important to mention that the flow through the manifold and the approach zone depend on the non-Newtonian properties of the polymer extruded. So the design of the die depends on the shear thinning behavior of the polymer. Hence, a die designed for one material does not necessarily work for another.

Tubular Dies

In a tubular die, the polymer melt exits through an annulus. These dies are used to extrude plastic pipes and tubular film. The simplest tubing die is the spider die, depicted in Fig. 4.21. Here, a symmetric mandrel is attached to the body of the die by several legs. The polymer must flow around the spider legs, causing weld lines along the pipe or film. These weld lines, visible streaks along the extruded tube, are weaker regions.

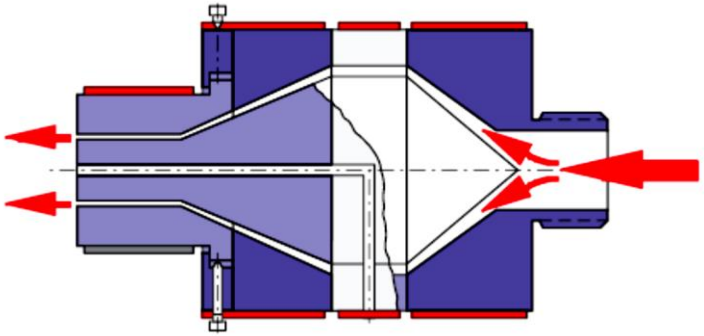


Figure 4.21 Schematic of a spider leg tubing die

To overcome weld line problems, the cross-head tubing die is often used. Here, the die design is similar to that of the coat-hanger die, but wrapped around a cylinder. This die is depicted in Fig. 4.22. Since the polymer melt must flow around the mandrel, the extruded tube exhibits one weld line. In addition, although the eccentricity of a mandrel can be controlled using adjustment screws, there is no flexibility to perform fine-tuning such as in the coat-hanger die. This can result in tubes with uneven thickness distributions.

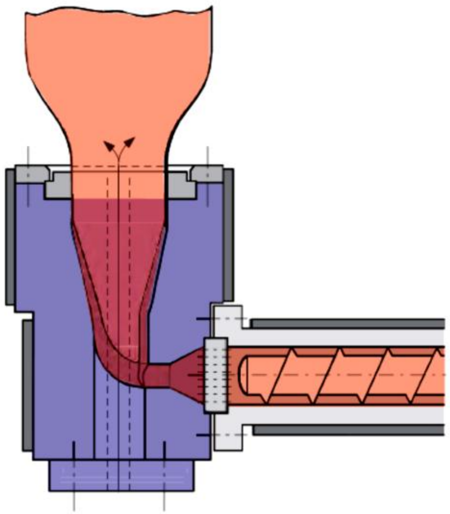


Figure 4.22 Schematic of a cross-head tubing die used in film blowing

The spiral die, commonly used to extrude tubular blown films, eliminates weld line effects and produces a thermally and geometrically homogeneous extrudate. The polymer melt in a spiral die flows through several feed ports into independent spiral channels wrapped around the circumference of the mandrel. This type of die is schematically depicted in Fig. 4.23.

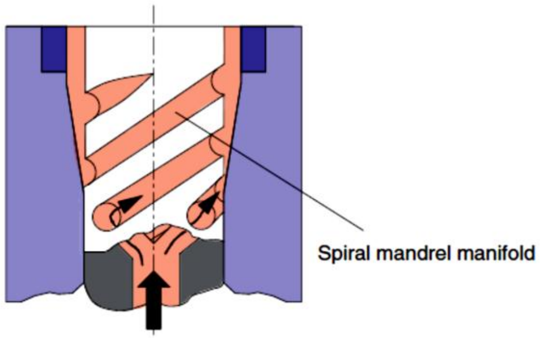


Figure 4.23 Schematic of a spiral die

Extruder Setpoints for Various Resin systems

Material	Feed Zone, °F (°C)	Transition Zone, °F (°C)	Metering Zone, °F (°C)	Die Zone, °F (°C)
ABS	400° (204°)	425° (219°)	440° (227°)	460° (238°)
Nylon 6	420° (216°)	460° (238°)	480° (249°)	500° (260°)
Nylon 6,6	530° (277°)	535° (280°)	545° (285°)	540° (282°)
LDPE	340° (171°)	355° (180°)	365° (185°)	375° (191°)
LLDPE	300° (149°)	325° (163°)	364° (185°)	410° (210°)
HDPE	340° (171°)	380° (193°)	400° (204°)	400° (204°)
PP	375° (190°)	410° (210°)	430° (221°)	430° (221°)
Polystyrene	350° (177°)	400° (204°)	440° (227°)	450° (232°)
HIPS	375° (191°)	420° (216°)	450° (232°)	450° (232°)
PMMA	360° (182°)	400° (204°)	430° (221°)	445° (230°)
Flexible PVC	265° (130°)	340° (171°)	355° (181°)	365° (181°)
Rigid PVC	300° (149°)	320° (160°)	340° (171°)	365° (181°)
PC	510° (266°)	530° (277°)	550° (288°)	560° (293°)
Noryl®	450° (232°)	480° (249°)	510° (266°)	510° (266°)
Ultem®	600° (316°)	640° (338°)	675° (357°)	675° (357°)
PET	520° (270°)	550° (290°)	510° (265°)	510° (265°)
PBT	470° (243°)	490° (121°)	500° (260°)	500° (260°)
Polysulfone	550° (288°)	600° (316°)	650° (343°)	650° (343°)
Acetal	400° (204°)	390° (199°)	400° (204°)	410° (210°)
Thermoplastic Polyurethane	330° (166°)	360° (182°)	380° (193°)	380° (193°)

For further details, please refer to: ***Extrusion: The Definitive Processing Guide and Handbook, William Andrew Publishing***

Twin Screw Extruder Equipment

There are many twin-screw extruders commercially available. The one to use depends on the end-use application. Different models have two parallel screw shafts that either rotate in the same direction (called corotating) or rotate in opposite directions (called counterrotating), with varying distances between the screw shafts. If the centerline distance between the shafts is less than the screw diameter, the screws are called intermeshing, while screws with a distance between the shafts equal to the screw diameter are non-intermeshing. Figure 11.1 shows a short segment conveying screw element with parallel corotating and counterrotating screws that are fully intermeshing. In non-intermeshing extruders, the screw lengths of the two shafts can be equal or one screw can be longer than the other to provide better pumping capability to the die.

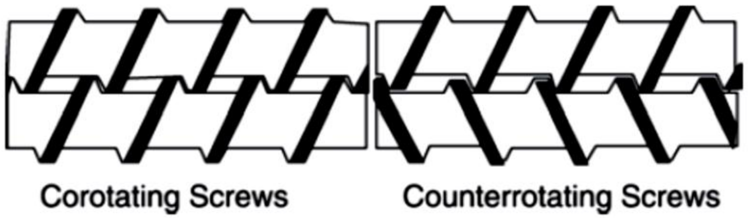


Figure 11.1. Corotating and counterrotating fully intermeshing screws.

Another common twin-screw extruder is a conical, where the counterrotating, intermeshing screws are tapered rather than parallel. Figure 11.2 shows the screw geometry in a conical extruder.

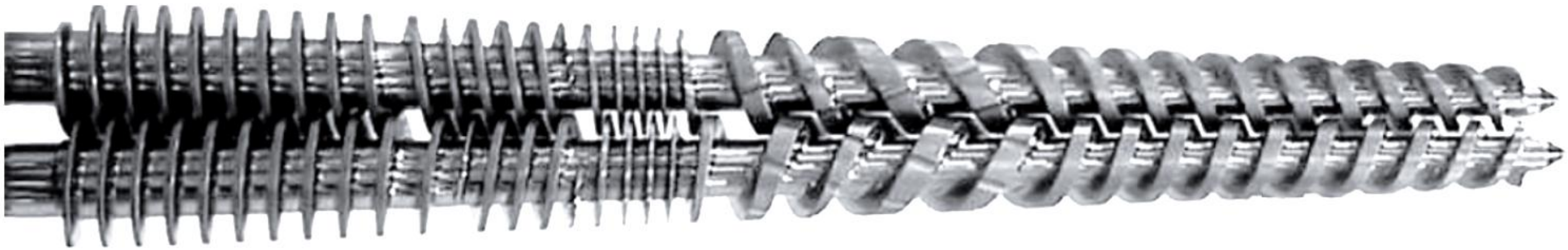


Figure 11.2. CPM conical counterrotating twin screw extruder screw shafts.[1]

The principal differences in parallel intermeshing and non-intermeshing twin screw extruders depend on whether the screws are rotating in the same direction, corotating, or in opposite directions, counter- rotating, and the distance between the screws. Figure 11.3 summarizes the different parallel twin screw extruders and applications where the different twin screw extruders are used. High-speed, corotating twin screw extruders are used for compounding resin with additives (colorants, fillers, flame retardants, reinforcements, stabilizers), devolatilization to remove solvents, and reactive extrusion (chemical reactions done in situ in the extruder). Low-speed corotating and counterrotating extruders are used to produce profiles and pipe. Counterrotating twin screws are used for compounding PVC and other resin systems. Non-intermeshing, counterrotating extruders are principally used for devolatilization and chemical reactions, i.e., grafting, polycondensation, addition, controlled cross-linking, and functionalization. Twin screw extruders are finding homes in sheet and film extrusion, where different formulation ingredients can be compounded and formed in the same extrusion. This eliminates compounding and re-extruding to produce a final part. Figure 11.4 identifies four of the five major equipment components (drive, feed, screw and barrel, and the die or head) of a parallel twin screw extruder.

The fifth component is the control cabinet. The drive system is composed of a DC motor, cooling system for the motor, coupling between the motor and gear box, thrust bearing, gear box, oil lubrication and cooling for the gear box, and shaft coupling between the gear box and the extruder screws. One feed port is located at the rear of the extruder in the first barrel section. Additional feed streams can be added in numerous locations along the barrel length through gravity from a volumetric or gravimetric feeder, liquid feed using a pump with a liquid injection nozzle, and/or a side feed extruder or stuffer to add polymer, additives, fillers, or reinforcements at locations along the barrel. Screw and barrel sections are both modular. Barrel sections can be added or removed to make the extruder barrel longer or shorter to increase or decrease compounding capabilities, depending on the product application. A set of screw shafts is required for each extruder length. Additional barrel sections are normally added to increase process flexibility for downstream feeding or venting. Each barrel section is normally cooled with water and heated with cast heaters to control barrel temperature. Screws are modular, with different elements combined in a strategic design to localize the feeding, melting, conveying, mixing, pumping, and venting at specific locations along the extruder barrel. Screw designs are easily changed or modified to optimize the processing, depending on the materials being fed and the product requirements. The adapter between the extruder and die can be equipped with a screen pack to generate additional backpressure or for melt filtration.

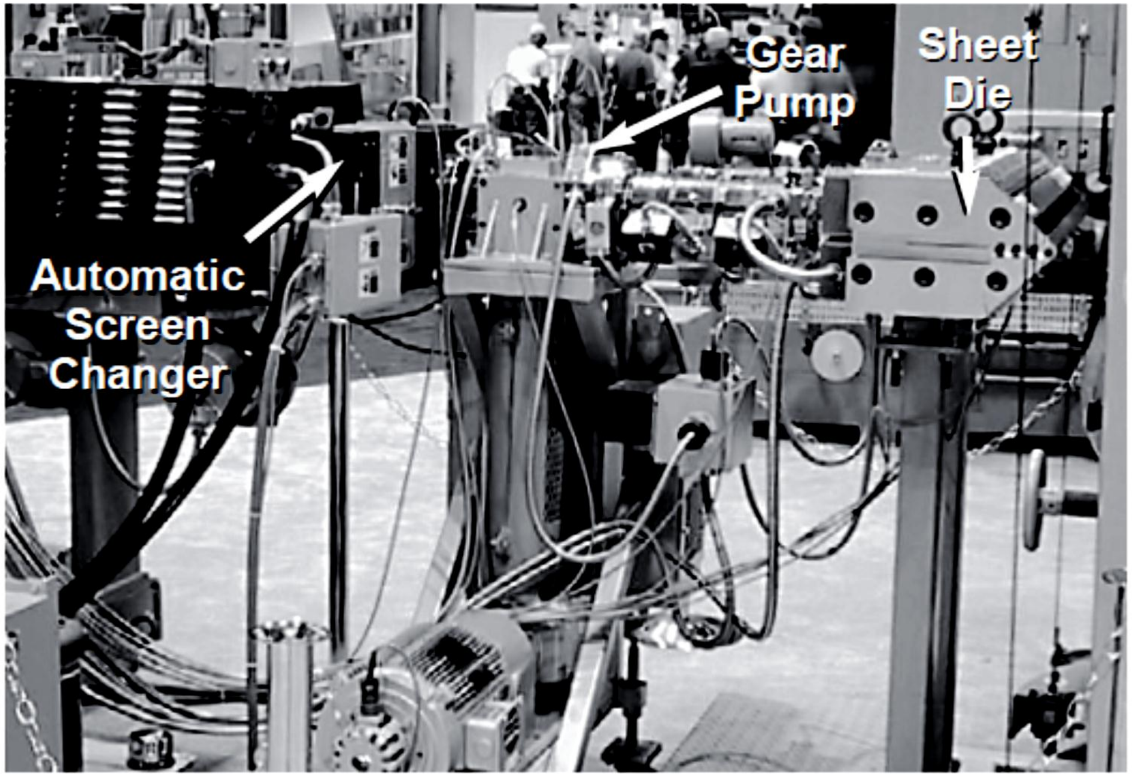


Figure 11.5. HPM setup with gear pump and automatic screen changer.

Figure 11.5 shows an automatic screen changer and gear pump between the head and the die in a sheet extrusion line. Melt temperature and pressure transducers are located at the extruder head to monitor and/or control the process.

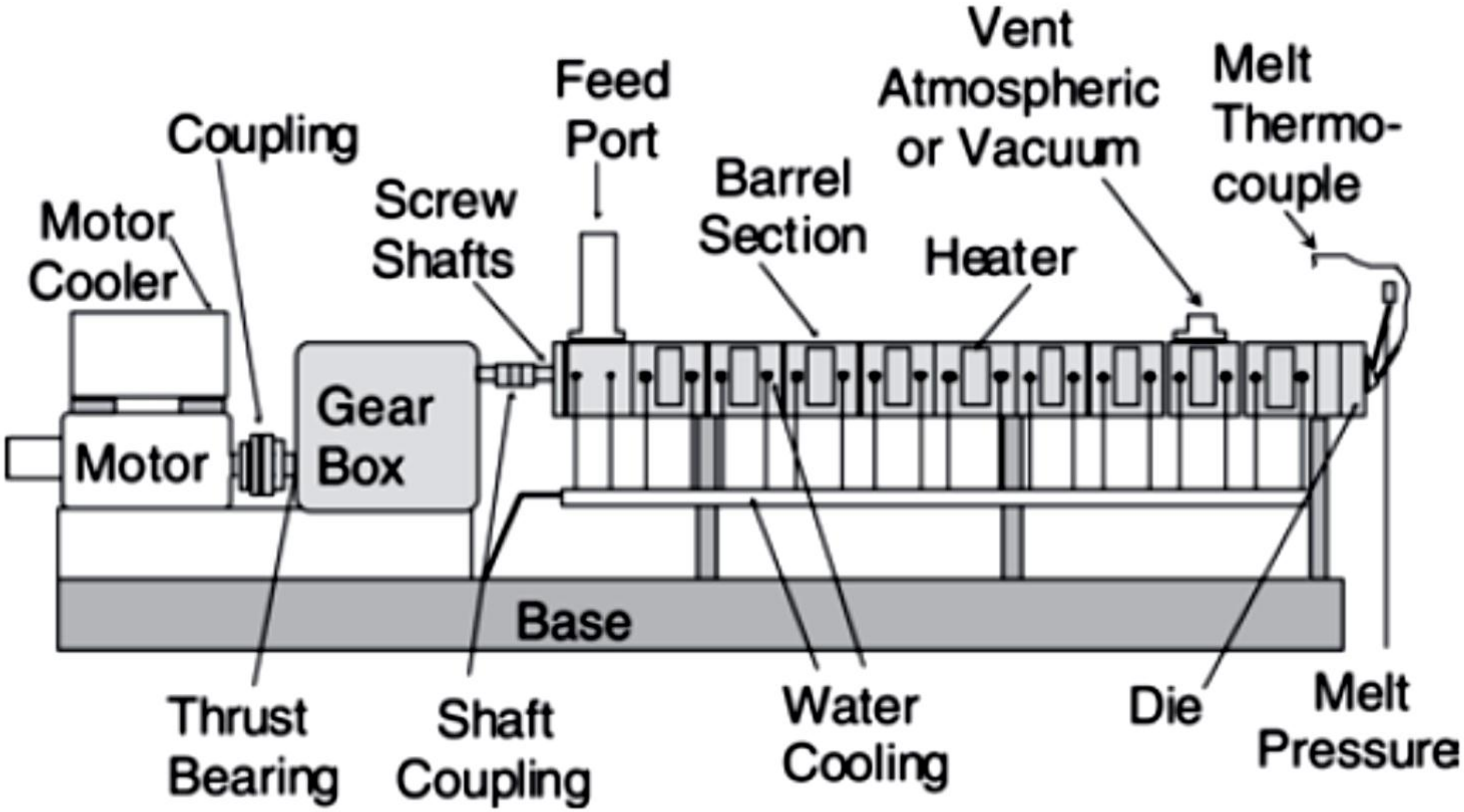


Figure 11.6 identifies individual elements in a twin-screw extruder.

The difference between corotating and counterrotating twin screw extruders is the screw rotation relative to each other. In corotating extruders, both screws rotate in the same direction, while in counter-rotating extruders, one screw rotates clockwise and the other screw rotates counterclockwise. With corotating screws, both screws have either right-handed or left-handed thread, depending on the screw rotation (CW vs. CCW). In counterrotating extruders, one screw has a right-handed thread and the other screw a left-handed thread.

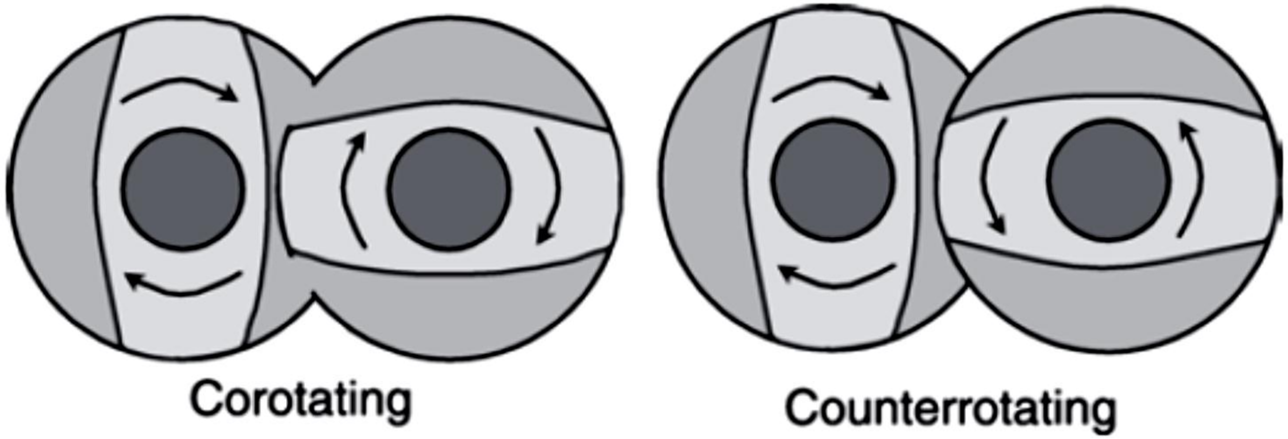


Figure 11.7 shows the corotating and counterrotating screw rotations viewed from the end of each element from the die end.

Polymer flow in a fully intermeshing, corotating extruder makes a figure 8 pattern, as the material does not pass between the screws. This generates high- and low-pressure regions for the material near the extruder apex, as shown in Fig. 11.8.

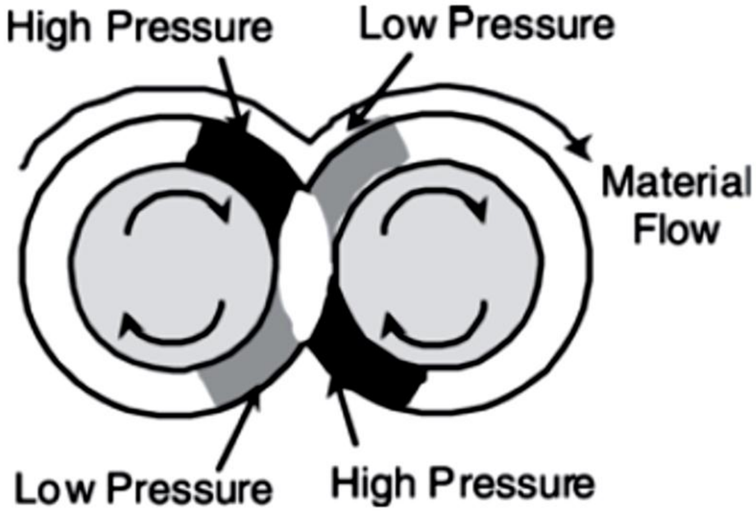


Figure 11.8. Material flow in co-rotating screws.

Polymer flow in a counterrotating extruder is forced between the two screws, resulting in a high-pressure region at the nip, where the material is being forced between the screws, and a low-pressure region at the nip exit.

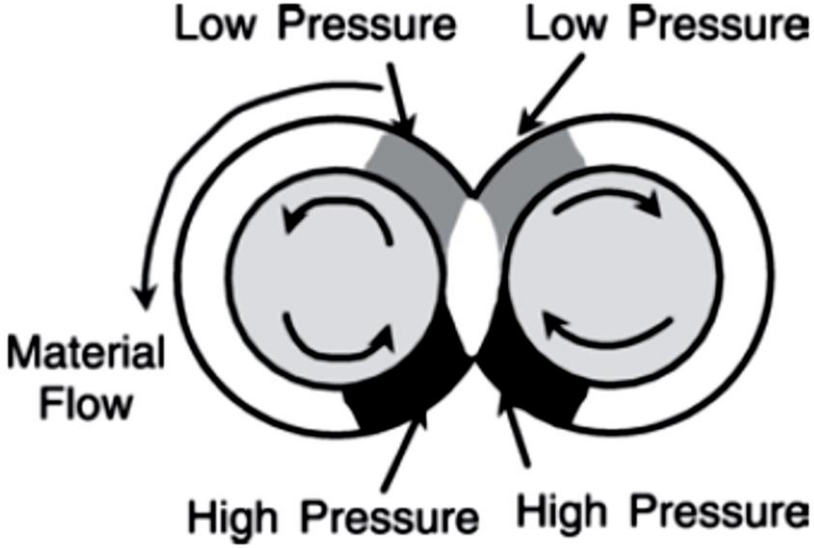


Figure 11.9 demonstrates the flow in a counterrotating extruder with the high and low-pressure areas.

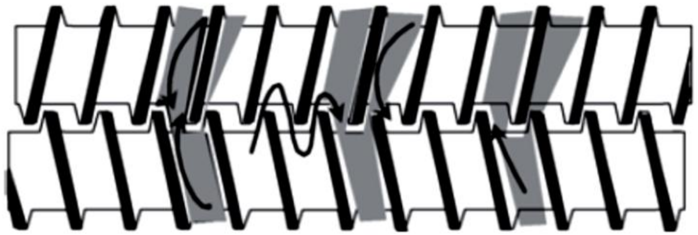


Figure 11.10. Counterrotating screw open to flow in both length and across.

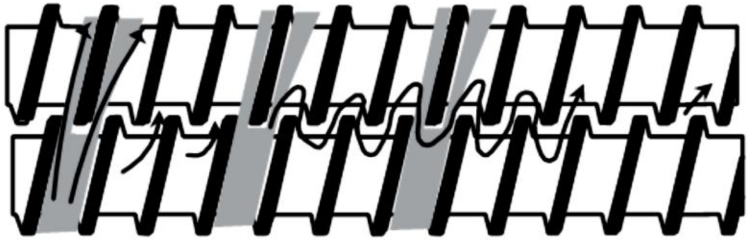


Figure 11.11. Corotating partially intermeshing screw length and cross-direction open to material flow.

Figure 11.10 & 11.11 show the intermeshing region for corotating and counterrotating screws.

In addition to identifying twin screw extruders based on screw rotation, the distance between the two screws varies from fully intermeshing to non-intermeshing. Material flow and the shear generated depend on the intermeshing. Screw designs (Table 11.1) are defined as either open or closed, based on whether material can flow in a particular direction. If material can flow in an axial or longitudinal direction from the feed throat to the die, the screw is open in the length direction. Theoretically material can move from one channel to the next channel, allowing flow in the lengthwise direction. If the screw is closed to material flow in the axial direction, the length is considered closed.

Table 11.1. Comparison of Intermeshing and Nonintermeshing Twin-Screw Extruders[1]

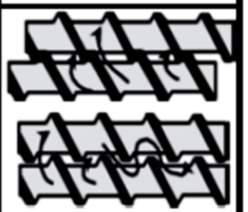
Screw Distance	Material Flow	Counterrotating	Corotating
Fully Intermeshing	Closed to Length and Cross		Impossible
	Open to Length Closed to Cross	Impossible	
	Open to Length and Cross	Possible, Not Practical	Kneading Blocks and Gear Mixers
Partially Intermeshing	Open to Length Closed to Cross		Impossible
	Open to Length and Cross		
Noninter-meshing	Open to Length and Cross		

Figure 11.10 shows a partially intermeshing, counterrotating screw that is open to flow in both the axial direction and cross-machine direction. In the cross-machine direction, the channel is considered open if the material can flow around a particular screw channel. Figure 11.11 shows partially intermeshing, corotating screw elements with material flow both lengthwise in the axial direction and across the extruder as the material passes between the screws. With fully intermeshing, corotating screws, material cannot pass between the screws (refer to Fig. 11.8). One screw is rotating down and the other screw is rotating up, preventing material cross-flow. Table 11.1 shows the various twin-screw extruder

configurations and those screw configurations that allow material flow axially and across the channel and those that don't. Normal leakage flow caused by the requirements for mechanical clearance between the two screws is not considered in the material flow behavior. Whether the screw configurations are open to cross or lengthwise flow is directly related to the conveying, mixing, and pumping efficiency in a particular extruder. If the axial length is closed, the pathway down the screw is divided into isolated areas with no opportunity for flow in the axial direction. Open cross-flow allows a material path around the screw and the polymer flows in the radial direction, as it is transferred back and forth between screws. If the cross-direction is closed, material cannot flow between adjacent screws, resulting in no flow in the radial direction. When both the length and cross-flow are open, good distributive mixing along with poor pressure generation result. Good distributive and dispersive mixing but poor pressure generation occur with the length open and the cross-material flow closed. If both the length and cross-flow directions are closed, good dispersive mixing results with good pressure generation. Non-intermeshing twin screw extruders are open both axially and across the barrel, regardless of whether the extruder is corotating or counterrotating.

	Corotating Intermeshing	Counterrotating Intermeshing	Counterrotating Nonintermeshing
Practical Residence Time, minutes	0.35–6	0.35–6	0.35–6
Residence Time Distribution	Variable	Variable/ Tighter	Variable
Dispersion	High	High	Good
Heat Transfer	Excellent	Excellent	Excellent
Venting	Excellent	Excellent	Excellent
Pumping	Good	Excellent	Fair
Self-Wiping	Excellent	Good	Fair
Zoning	Excellent	Excellent	Good
Output Rate	High	Moderate	High
Distributive Mixing	Good	Good	Excellent

Table 11.2 compares processing parameters for the three basic parallel twin screw extruders.

The various processing parameters compared are defined below:

• Practical residence time is the time polymer, additives, or other formulation components will spend in the extruder from feed to the die.

• Residence time distribution is the shortest to longest time different particles spend in the extruder.

• Dispersion is breaking up large particles or agglomerates and uniformly dispersing them throughout the melt.

• Heat transfer is the ability of the barrel heaters to transfer heat into the material being processed to create a uniform temperature profile throughout the melt.

• Venting is the ability of the extruder to remove volatiles or moisture through a single or multiple vent port along the barrel length.

• Pumping is delivering a uniform melt pressure and material supply to the die.

• Self-wiping is one intermeshing screw element removing polymer from the adjacent screw element.

• Zoning is where specific areas or zones in the extruder accomplish specific extrusion objectives such as melting, mixing, feeding, etc.

• Output rate measures the throughput rate or pounds/hour that can be delivered by a specific extruder size or diameter.

• Distributive mixing uniformly distributes all components and melt temperature in the extrudate.

Drive

The drive is comprised of a DC motor, motor cooling, coupling between the motor and the gear box, gear box, and coupling between the gear box and the screw shaft. The DC motor provides constant torque to the screw.

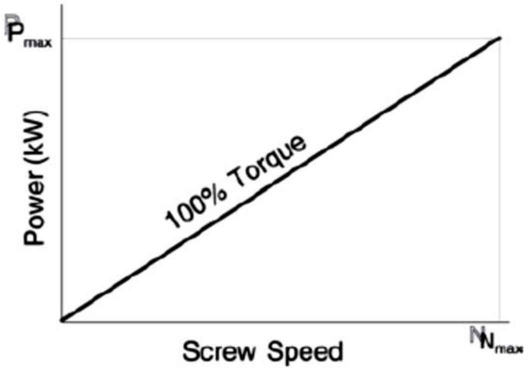


Figure 11.27. Relationship of power, screw speed, and torque.

Figure 11.27 shows power versus screw speed at 100% torque. The gear box and torque transfer through the shaft and screw elements limits maximum power. At 100% torque, the screw speed is directly related to the power. To produce high screw speeds, torque, and throughput, motor horsepower has increased in recent years. Newer twin screw extruders have motors and gear boxes that are larger than the barrels to supply the necessary power. The DC motor is cooled with a top-mounted blower. A filter to remove any particles from the intake air keeps the cooling air contaminant-free. If the filter becomes clogged, preventing enough cooling from reaching the motor, the motor will automatically shut down to prevent damage from overheating. If the filter is dirty and insufficient air is circulating during a run, the extruder motor may shut down, and the cause or reason for shutdown is hard to detect. It is impossible to restart the motor until it cools sufficiently.

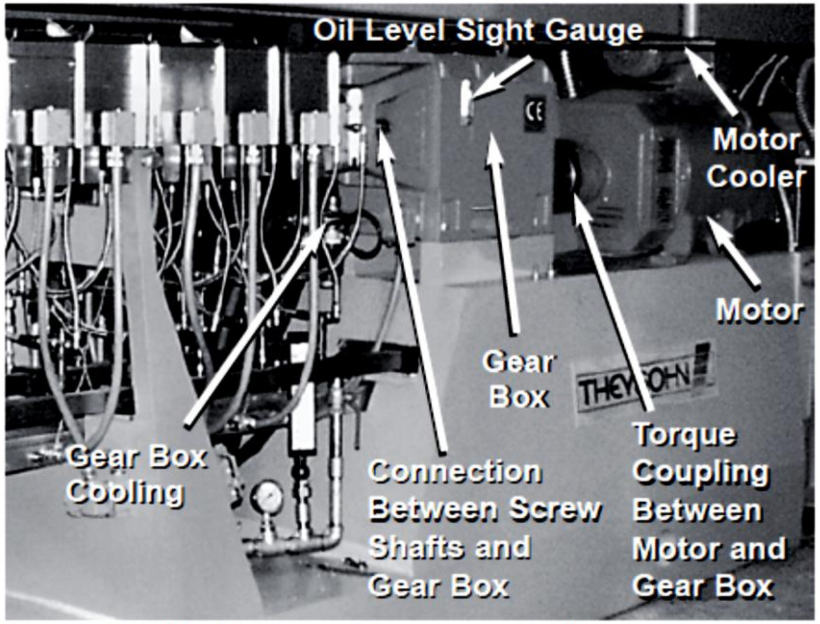


Figure 11.28. Drive system components.

Between the motor and the gear box, Fig. 11.28, is a fully interlocked torque limiting coupler that disengages at a predefined torque limit to protect the motor from damage in the event the high torque limit is reached. If the coupler disengages, it is rotated in the reverse direction to reengage. If the torque coupler disengages, the extruder feed systems stop and all hoppers on the extruder are empty. It may be difficult to restart the extruder if it is full, as the screws will not be able to rotate before the extruder reaches maximum torque. Two possible scenarios exist: the screws can be turned a small amount before they reach maximum torque, or the screws cannot be turned at all without reaching maximum torque, causing the torque coupler to disengage. In the event the screws turn, rotate the screws very slowly, shutting down the extruder just before the torque limit is reached, disengaging the coupling mechanism. Continue this process until the screws turn continually at low rpm. As material exits the extruder, the screw speed can be gradually increased as the torque decreases. Once the screw speed reaches the desired level, gradually add polymer and other formulation ingredients to the extruder until the product is running at the desired rate. In the second scenario, where the screws cannot be turned at all before reaching the torque limit, verify that no material or other foreign object is caught in the extruder screws. If there is a foreign object, remove it and start the screws. Assuming no foreign object is found, raise the barrel temperatures until the screws can be rotated. Once rotation is attained, gradually clear the material from the extruder by the procedure described previously. After the screw speed is back up to full rpm, lower the barrel temperatures and run the process under normal conditions. If the torque is close to the extruder torque limit at the desired throughput rate, the following steps can be taken to reduce the torque level:

• Increase the screw speed.
• Increase the resin melt temperature.
• Decrease the feed rate.
• Change the screw design to generate less shear and torque.

Gear boxes transfer the motor power to the screw shafts. At the entrance to the gear box is the torque limiting coupling, and at the exit is the gear box connection to the screw shaft. Gear boxes have increased in size with higher throughput rates, requiring larger motors and more torque. Oil is pumped to the gear box to lubricate the gears and shafts during rotation in the gear box. The oil must be cooled to prevent thermal degradation, which leads to gear box wear. Some newer extruder models have gear boxes with the ability to run both corotating and counterrotating screws, depending on the application. To change from corotating to counterrotating, another screw shaft with enough elements to construct a left-handed screw is required to intermesh with the right-handed elements on the corotating screw. A second alternative is to have two sets of shafts and screw elements to quickly make the conversion from corotating to counterrotating or vice versa.

Feed

Material is starve fed to parallel, intermeshing, corotating and counterrotating twin screw extruders. Some formulation components are fed above the feed opening in zone 1 through a feed pipe or feed hopper. The feeder is supported above the extruder feed throat by a mezzanine or hung from or placed on some other support system above the extruder. Extrusion throughput rates are determined by the feed rate in a starve-fed machine, and not by the screw speed. Screw speed determines the residence time in the extruder and the screw fill. Screw speed and feed rate are balanced to prevent the extruder from over-torqueing and shutting down. Feeders are normally either volumetric (run at constant screw speed, vibratory speed, or belt speed) or gravimetric (sometimes called loss-in-weight). Gravimetric feeders deliver a constant weight per unit time as the screw speed, vibrations, or belt move faster or slower to produce the specified throughput rate. Each feeder can deliver a resin, premix, additives, fillers, reinforcements, colorants, or stabilizers to different locations along the extruder. The feeders used depend on the available feed ports, the feeders available, the feeder size and accuracy, and the ingredients. The ideal situation has gravimetric feeders properly sized for each ingredient. At start-up, the individual feed rate for each material stream is gradually increased with the extruder speed until all feeders are set at the desired rate and the screw speed is high enough to provide sufficient torque to run the product.

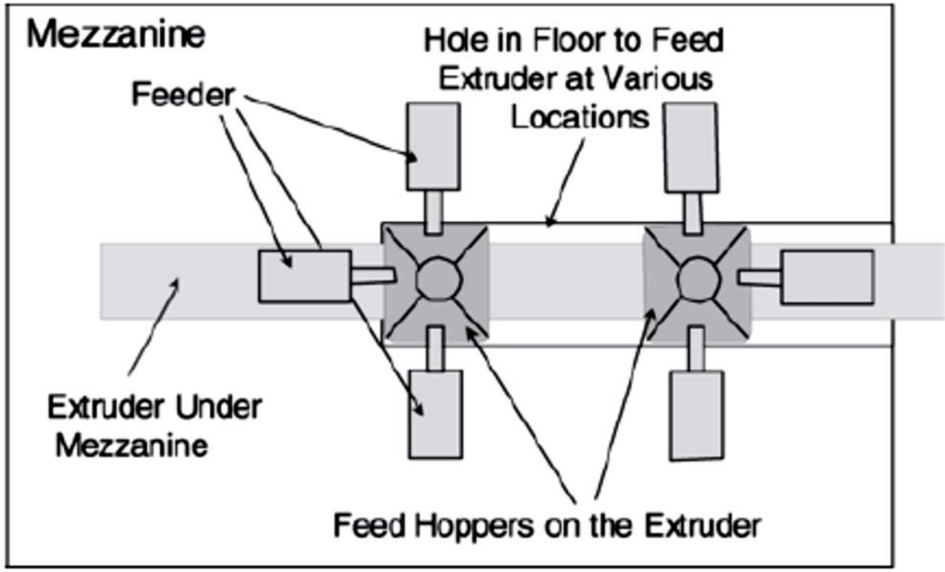


Figure 11.29. Feeder arrangement on a mezzanine.

Figure 11.29 shows a feeder layout on a mezzanine above a twin-screw extruder for supplying different ingredients to the extruder below. This configuration shows six individual feeders. Some are large, feeding ingredients at high rates, while others are small, feeding additives at less than 1%. In many operations this many feeders are not available, and some components are remotely premixed in batches and transported to a particular feeder.

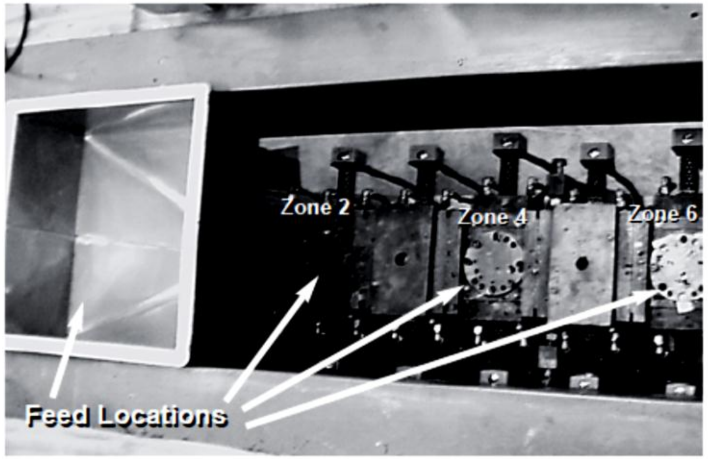


Figure 11.30 shows a view from above the mezzanine looking down on the feed hopper in barrel zone 1 and the extruder below. In barrel zones 2, 4, and 6, additional materials can be fed to the extruder by removing the barrel plugs. The actual feed ports used in a particular operation depend on the ingredients, the extrusion objectives, the ingredient temperature stability, how much shear or work the additives require or can absorb, and the screw design.

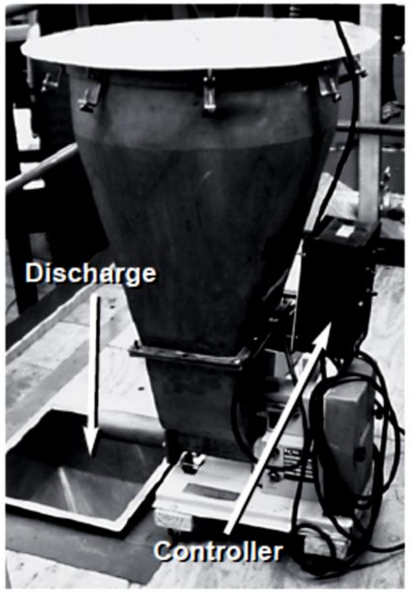


Figure 11.31 shows a volumetric feeder set over the feed hopper in barrel zone 1, ready to feed material to the extruder.

Ideally, solid material fed to a corotating screw is fed over the outside screw that is turning down into the extruder, so the material is conveyed into the barrel. If it is fed on top of the screw that is coming up, the material has to be transferred to the other screw before it can be fed into the extruder. In the transfer from one screw to the other at high screw rpm, resin pellets can bounce out of the extruder throat. In counterrotating extruders, the material is fed over the outside of each screw turning down into the extruder to capture the material and convey it forward into the barrel.

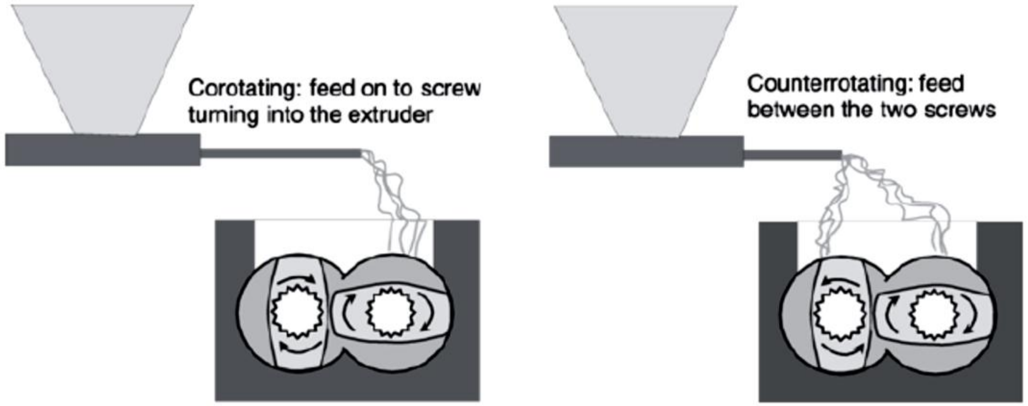


Figure 11.32 shows the proper feed locations in both corotating and counterrotating, intermeshing extruders. Material fed downstream by gravity also needs to be fed on the proper side of the screw turning down into the barrel to obtain a good bite on the material. A downstream feed port, where material is gravity fed to screws partially filled with molten polymer, may have an opening on only one screw side, where rotation is turning down into the barrel, to assist feed material addition in co-rotating and counterrotating extruder screws.

Liquid can be added via an injection port and a liquid feed pump.

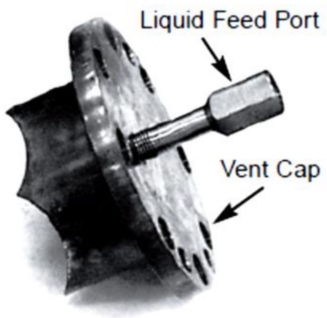


Figure 11.33 shows a barrel cap or vent cap with a liquid injection port that was removed from either zone 2, 4, or 6 in Fig. 11.30. The vent cap is drilled for a pressure transducer; the liquid injection port is fabricated to fit into the pressure transducer type hole. Injection ports can be fabricated with different size holes to feed different quantities. The liquid feed pump is attached to the injection port on the vent cap with metal piping. For safety the liquid feed pump is equipped with a pressure gauge to measure the injection line pressure and a relief valve in the event pressure becomes excessive. Liquid feed is introduced as soon as the extruder is started, preventing molten resin from backing up into the injection port, clogging the line, and/or freezing off the liquid injector tip, preventing liquid addition.

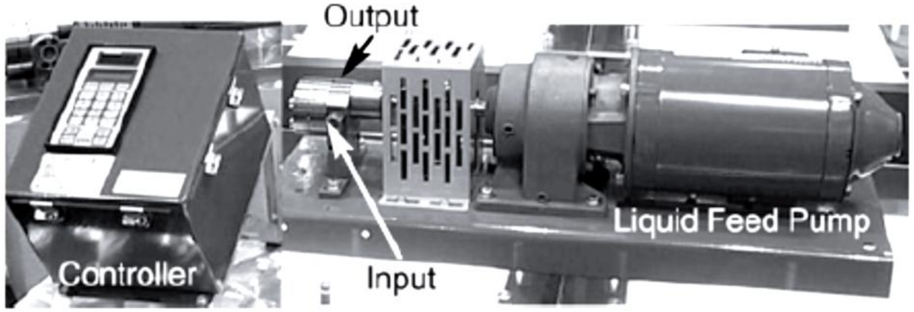


Figure 11.34 shows constant speed liquid feed pumps and a controller.

Some materials are best fed downstream into the melt using a side feed extruder or stuffer. High aspect ratio polymer reinforcements such as fiberglass are fed downstream into the melt to minimize fiber attrition. Molten plastic acts as a buffer, minimizing fiber breakage and lubricating the screws where the fiber is added. If one feeds high aspect ratio reinforcements into the first extruder zone with pellets, the solid pellets plus the screw rotation will chop the fibers into very short lengths.

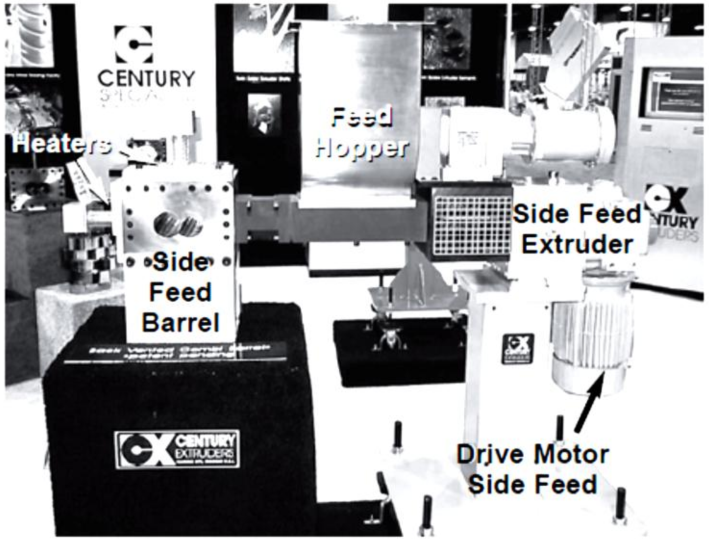
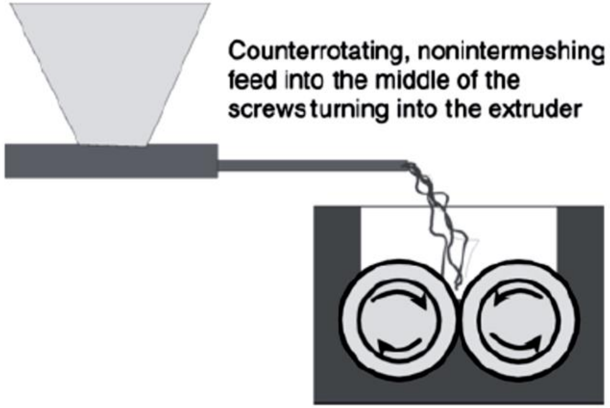


Figure 11.35 shows a twin-screw side feed extruder used to starve feed fillers, reinforcements, or other additives from a feeder on the mezzanine into the polymer melt downstream. Fillers and reinforcements are fed into a low-pressure zone after the resin is completely melted. (Other

materials, such as mineral fillers, temperature-sensitive additives, resins, etc., can also be fed downstream with the side feed extruder.) Additive addition down- stream reduces its residence time and the shear experienced.

Side feed extruders are sometimes called stuffers. These extruders have very short barrels with various screw geometries that convey but don't compress the material while feeding different resins, fibers, and/or additives. The side feed extruder barrel clamps to the main extruder barrel, with the side feed screws extending through the main extruder barrel wall almost to the main extruder screws. Material from the side feed extruder is fed at high rates directly into the polymer melt. The first barrel section or feed zone on the extruder is normally water cooled with no heating present. Cooling is provided to prevent resin or additives from prematurely melting and sticking to the feed throat. Over time, sticky or pre-melted material can agglomerate around the feed throat opening, causing a bridge to block the feed opening. Feed screw elements are deep flighted with large pitch to provide the maximum open area to transport resin away from the feed opening and into the extruder; see Fig. 11.36 (below).

At startup the screw speed is normally run at low rpm with a significantly reduced feed rate until material exits the die. Once polymer flow through the extruder and die is established, the extruder screw speed is increased, followed by the feed rate, until the desired throughput is attained. During this time screw torque is carefully monitored to assure that the extruder does not exceed the drive torque limit, causing the machine to shut down. The feed rates into the extruder are carefully monitored to verify that the screw speed is sufficient to remove all the material being fed to the extruder and no build-up is occurring in the feed hopper. If material builds up in the extruder feed hopper, either the extruder screw speed must be increased or the feed rate decreased. The individual feeders can be slaved to the extruder; in the event the extruder shuts down, the feeders automatically stop feeding. This prevents resin build-up in the various feed locations along the barrel when the extruder stops unexpectedly. Assuming the extruder shut down because it exceeded the torque limit, any material in the feed throat (or other feed locations) needs to be vacuumed out prior to restarting the extruder. If the extruder stops due to exceeding the torque limit, the screw speed is brought back up to high rpm again before the feed stream is restarted at a low rate and gradually increased.



Feed is introduced into non-intermeshing, counterrotating extruders between the screws, as shown in Fig. 11.37 (above). With the screws turning down into the barrel, the material is picked up and conveyed forward into the barrel.

Screw and Barrel Heating and Cooling

The screw and barrel is where polymer is fed, melted, conveyed, mixed, devolatilized, and pumped to the die. Both the screws and barrel sections are modular and can be arranged in any configuration necessary to accomplish a particular extrusion objective. Barrel sections normally have either rectangular or circular outside dimensions, depending on the manufacturer. They are assembled with either a rod through all the sections or with bolts holding the sections together. The barrel is supported at different locations along its length to prevent it from sagging. Each barrel contains a thermocouple to control the heating and cooling input. The heating and cooling elements, different barrel sections, vent caps, insulated barrel covers, and a barrel support are identified. Barrel sections have flanges on each end for alignment and connection to the next barrel. While it is a sizable task, barrel sections can be disassembled, reconfigured, and reassembled to move feed and vacuum sections. Some machines (particularly smaller ones) may have a clamshell barrel design where the barrel separates in the middle and the entire screw length is exposed. Clamshell barrels are one-piece construction rather than modular sections that bolt together. Individual heating and cooling zones along the barrel provide temperature control similar to a water-cooled single screw extruder. Barrel sections, like extruders, come in different length to diameter ratios (L/Ds). Typical lengths depend on the screw diameters and the manufacturer. Some common L/Ds are 2.5, 3, 4, 5, 6, 8, 10, and 12. There are many different barrel sections:

- one used for feeding with an opening on top (vent barrel)
- feeding into the side with a vent on top (combi barrel)
- a solid barrel (closed barrel)

The vent barrel has an opening on top that may be either circular or rectangular and is used to vent volatiles from the barrel or to feed different formulation components. The first barrel section in the extruder is opened on top for feeding all or part of the formulation into the extruder. It is cooled and normally has no side heaters. The normal figure 8 pattern bore connects to an end plate that prevents the formulation from traveling backward toward the drive system, with the other end connecting to the next barrel section.

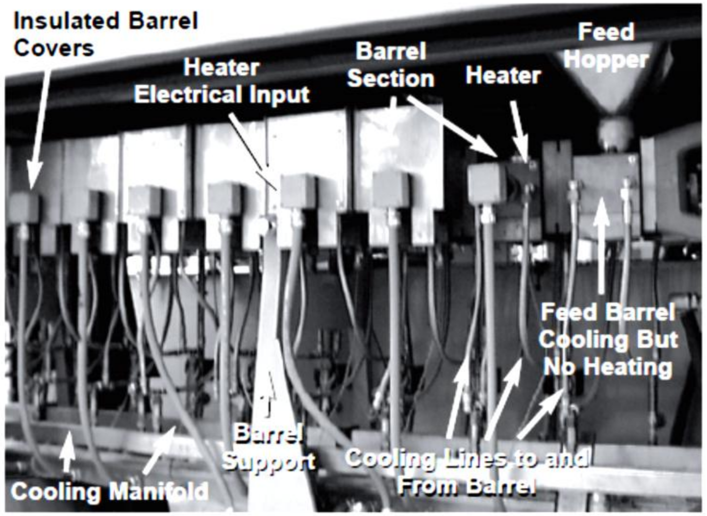


Figure 11.40 shows the feed section with a hopper, water cooling, and the absence of heaters.

Other vent or feed barrel sections have an opening on top with cast heaters contacting the barrel on the other three sides. Barrel section 2 (the one after the feed throat) contains a vent plug and is heated on three sides with cooling (these barrel sections have the capability to be either heated or cooled as the process requires). This same barrel section can be used to feed liquid through an injection nozzle, to gravity feed polymer further downstream, or to vent volatiles with a vent stack. The vent stack can be open for atmospheric venting or it can be connected to a vacuum port to remove higher volatiles through vacuum venting. The combi barrel has an opening on top for gravity feeding and a side opening for feeding with a side feed extruder. The barrel section in Fig. 11.35 is a back-vented combi barrel (supplied by Century Extruders and is patent pending) with the side feed extruder attached. Combi barrel sections are cooled similarly to other barrels, but only two of the four sides are heated when the side feed extruder is connected. If the side feed extruder is not in use, the port can be plugged and heated similarly to the vent barrel. The last barrel section is a closed barrel with no openings on the top or side, shown in Figs. 11.42 and 11.43.

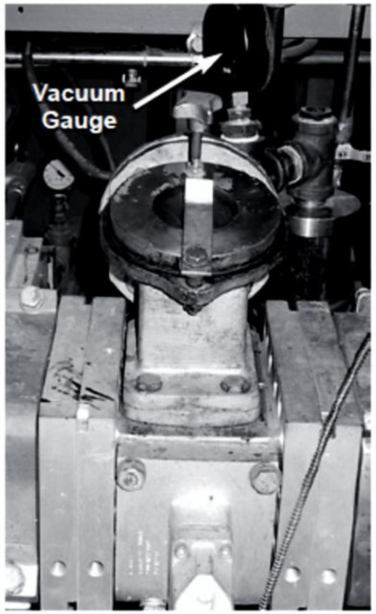


Figure 11.41. Vented barrel section.

This barrel is heated with cast heaters on all four sides and cooled similarly to the other sections. It is seen in Fig. 11.40 and is the barrel section with the heater on top. Each heater is L-shaped, so one heater covers the top and one side, while the other covers the bottom and opposite side.

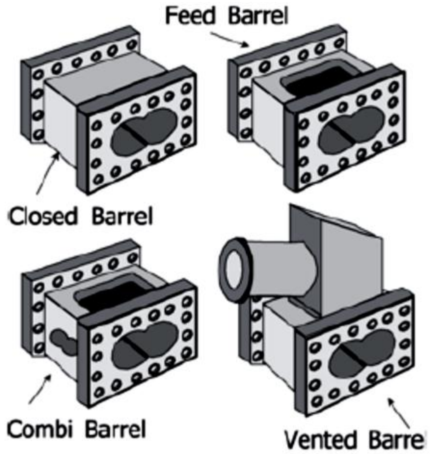


Figure 11.43 is a schematic of the different barrel sections.

Barrels and screw are normally nitrided steel for long life. Through-hardened barrels are available, and some barrels are lined with wear-resistant liners to increase life. Liners provide resistance to corrosion and abrasion. Other metal treatments are available to increase service life.

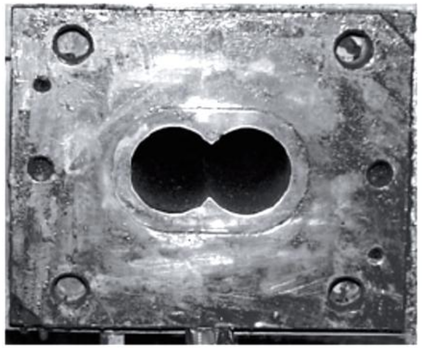
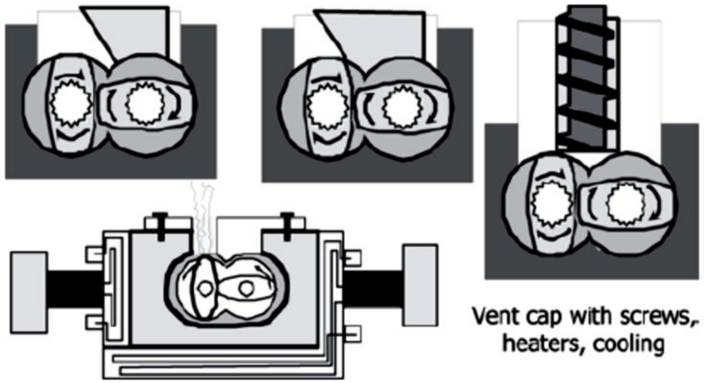


Figure 11.44 shows the end of a 45-mm Theysohn twin screw extruder barrel section with a wear resistant liner.

If an atmospheric or vacuum vent is used, the vacuum port covers half the screw (see Fig. 11.43) to prevent material from flowing out the vent.

Some typical vent caps and configurations are shown in Fig. 11.45 (below) for corotating, intermeshing twin screws.



Different cast barrel heaters are available, depending on the application and temperature requirements. Aluminum heaters have a temperature range to 660°F (350°C), while aluminum/bronze alloy heaters go up to 840°F (450°C). Two cooling designs are available. One uses cooling bores with holes bored around the barrel next to the barrel liner (Fig. 11.46). The second uses water cooling in the heater with a loop running around the heating element (Fig. 11.47). Combining both types of cooling provides the maximum temperature control for the system.

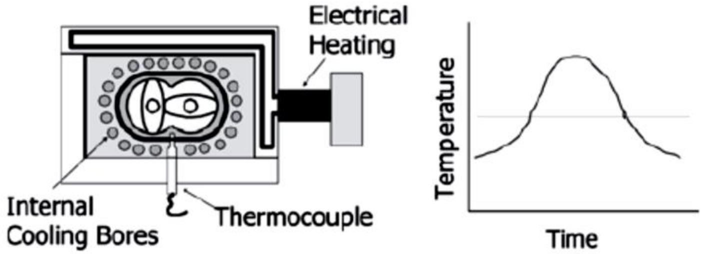


Figure 11.46 shows a barrel cross section with heater and internal cooling bores and the corresponding time–temperature response curve.

This cooling is the least responsive cooling mechanism available, giving the poorest temperature control.

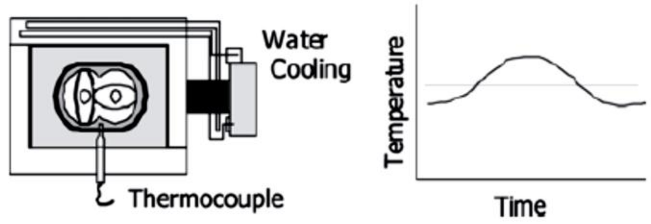


Figure 11.47 shows a single cooling system in the heaters. While this system performs better than the cooling bores, it still is not as good as combining internal cooling bores with water cooled heaters to control the temperature.

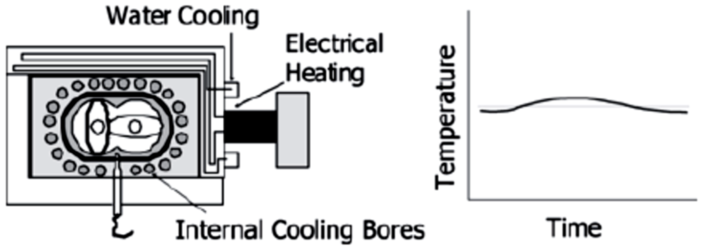


Figure 11.48 shows a system combining cooling methods and the time–temperature response curve.

In some circumstances the screw shafts can be cooled for better temperature control if required. Water or oil is pumped in a tube down the center of the shaft and returned on the outside of the tube. This provides good heat transfer to the outside surface of the screw shaft and inside surface of the screw elements. Maximum cooling occurs at the extruder discharge end. Reversing the flow provides maximum cooling at the extruder feed end.

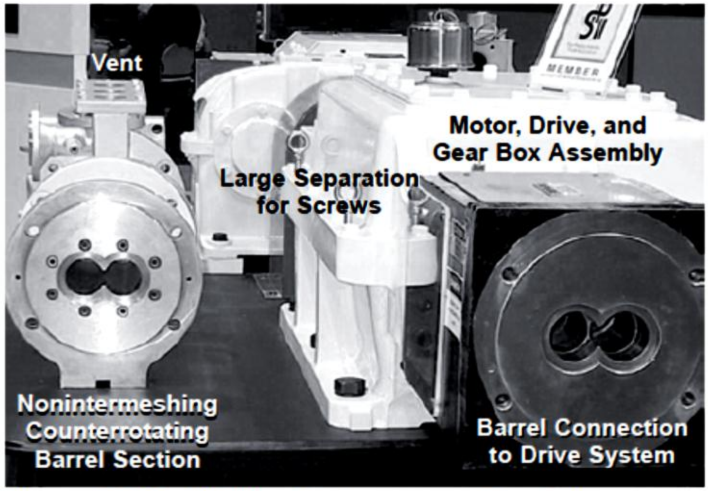


Figure 11.49. Welding Engineers counterrotating nonintermeshing twin screw barrel and drive train.

A Welding Engineers counterrotating, non-intermeshing twin screw extruder drive and barrel section is shown in Fig. 11.49. While this is a non-intermeshing twin screw, the barrel section does not appear radically different from the intermeshing barrels shown previously, and the drive system components are similar. The only slight difference is the barrel apex area, where the metal on top and bottom extend farther toward each other.

It is important to understand the extrusion requirements before assembling the screw.

- Where along the extruder barrel do you want the material to melt?
- What location do you want to add ingredients downstream?
- How much and what kind of mixing is required to produce a homogeneous melt?
- What rate is required?
- Does the product need atmospheric or vacuum venting and at what location? Before assembling a specific screw configuration,
- All elements must be cleaned on both the outside and inside.
- The ends must be lapped to provide a good sealing surface between the elements.
- The shafts, keyways, or splines must be cleaned so elements slide on the shafts easily.
- Anti-sieze must be applied in a thin coat to all surfaces during assembly.

A specific screw design is developed for the process and documented. The design is used to assemble the elements in the correct order.

Figure 11.50. Setup to assemble new screws.

Figure 11.50 shows a typical setup to use when constructing or assembling a new screw design. During screw assembly, anti-sieze application is essential to ensure that the screw can be disassembled later. However, excessive anti-sieze must be avoided. Anti-sieze can build up between the elements, creating a gap where polymer will flow under pressure between the elements down to the shaft. Over time at high temperature, polymer trapped between the screw elements and the shaft degrades and chars, making screw element removal very difficult.

Screw assembly is critical; the elements must be placed on the shafts in pairs (element on shaft 1 must be the same as element on shaft 2). With multiple keyways, splined shafts, or polygon shafts, there is only one correct position to install each element. Each element flight must match the preceding and following element flight to prevent dead spaces along the shaft and create a smooth polymer flow. If an element is misaligned or a lefthanded element is used on one shaft and right-handed one on the other, the screw shafts will not rotate, and the screw elements will have to be removed back to the mistake and then reinstalled. Identical kneading blocks, like conveying elements, have to be installed at the same place on the shafts or the shafts will not rotate. Screws and barrels for conical counterrotating extruders are significantly different from the parallel intermeshing co- and counterrotating extruders. Similar to single screw extruders, the barrel is not segmented and modular, but one piece. Likewise the screws are one piece. Conical twin screws are used primarily for rigid or unplasticized PVC extrusion into profiles (window, siding, gutters, etc.) and pipe. Conical screws and barrels have a large diameter at the feed throat and get progressively smaller toward the die. Conical twin screw extrusion shafts from CPM GmbH were shown in Fig. 11.2.

A conical extruder looks similar to a single screw extruder with heater bands, cooling, and barrel covers installed. Both the root diameter and the flight diameter decrease from the feed section to the die. Material is compressed from the feed end to the die through a decrease in channel volume. With conical twin screws, the feed is often PVC powder, which has a low bulk density compared to the melt density. Consequently, the channel volume change through the extruder is quite dramatic to properly compress and mix the formulation. Maximum channel volume occurs in the feed zone, assuring a uniform material feed and conveying.

Figure 11.52. Cross section of conical twin screw extruder showing zones for (A) feed and plastication, (B) restrictive, (C) devolitilization and (D) metering.

Figure 11.52 shows a conical extruder screw and the process zones in the extruder. The feed and plastication area is where the formulation is fed and converted to a molten polymer. After the plastication flights, a restrictive area with smaller flight volume retards the resin movement, forcing the resin to spend more time in the plastication zone while preparing the melt for devolatilization. Similar to parallel twin screw extruders, this screw section acts as a melt seal for the devolatilization area. The devolatilization zone has a larger pitch to provide maximum polymer surface area to remove volatiles. This zone is only partially filled to assist with the removal of trapped air and volatiles from the melt. Finally, the melt is recompressed and pumped to the die in the metering zone.

Parallel twin screw extruders have more surface area than conical twin screws. However, the flight flanks in a conical have more surface area than in a parallel extruder and can transfer more heat to the material in the channel. The screw surface area is 40% larger compared to a parallel extruder. Due to the larger channel volumes, conical extruders generate less shear heat and more conductive heat compared to parallel twin screw extruders, making them better for processing shear-sensitive materials such as PVC. Conical twin screws with their one-piece design have a distinct advantage in being able to transfer torque through the screws. Since most energy to melt the material is supplied by the motor and screw rotation, conical extruders have more strength where it is required. Most screw wear will occur in the feed, plasticating, and restrictive areas.

Die and Adapter

Dies for any extrusion process can be installed on a twin screw extruder to produce the desired product. Breaker plates with screen packs for filtration or to restrict the polymer flow and build backpressure before the die are used when the process requires them. The largest application for corotating twin screw extruders is compounding different resin formulations or pelletizing polymer by resin suppliers that require either a strand die (Fig. 11.53), die face pelletizer, or underwater pelletizer. While corotating twin screw extruders are excellent melt mixers, producing homogeneous products, they do not generate high die pressures. Gear pumps are often incorporated between the extruder and die to generate sufficient die pressure for sheet, profile, and tubing applications. Gear pumps generate very uniform and high die pressure to produce uniform cross section dimensions in the extrudate.

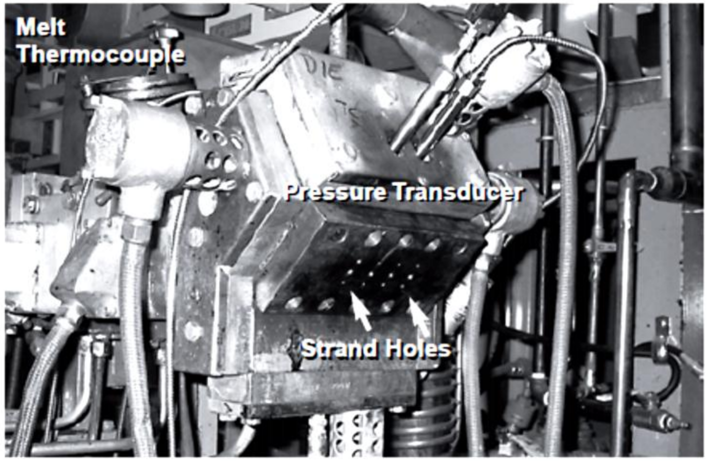


Figure 11.53. Strand die.

Counterrotating twin screw extruders, both parallel and conical, are excellent die pressure generators and are normally run at slower screw speeds with fuller flights than corotating extruders. Consequently, less shear heat is generated. Profile extrusion, particularly with rigid PVC, uses counterrotating extruders to provide

- Good ingredient fluxing during plastication
- Good mixing
- A low shear process that minimizes degradation
- Sufficient die pressure at a constant rate to produce uniform extrudate cross section in the final product

The die or die adapter connects to the barrel figure 8 cross section and converts the melt to a round cross section before entering any other adapter or die. This is normally called an 8-O transition and is required for all twin-screw extruders. Once the 8-O transition is made, dies are similar to those used in single screw extrusion to obtain the desired product profile. Similar to single screw extrusion, all dies and adapters require adequate and uniform heating with no dead spaces in the flow channels to prevent hot or cold spots in the polymer flow that might alter the melt viscosity or lead to resin degradation.

Controls

The extruder is more than a black box where pellets are put in one end and an extruded shape exits the other. It is a complicated process and needs good controls based on understanding what is occurring in the extruder. What happens in different areas of a twin-screw extruder? How do you know the extruder is in control and producing a quality product? How do you know the extruder is running at peak efficiency? The answer to most of these questions is, there are both input and feedback controls to verify that the process is operating properly and at equilibrium. The control process makes a measurement, determines if something needs to be changed, makes a decision, and takes appropriate action. If the system is operating at equilibrium with good product exiting the die at a high rate, the decision might be everything is running properly and no changes are necessary. However, if the product is borderline acceptable or unacceptable, or one process step is outside the SPC control chart limits, the decision is that some function is operating improperly, and a change is required to return the system back into control. With today's computer capability and durability, extruder controls are more sophisticated, resulting in better overall process control. The process can be controlled and monitored with feedback loops from the individual feeder throughputs to the puller speed and all operations in between. Feedback loops plot SPC data at specified time intervals for all temperature controllers, speed controls, puller speeds, in-line gauges for thickness or dimensions, feeder rates, water temperatures in cooling tanks, vacuum levels, windup speeds, roll pressures, and so forth. With the entire process instrumented, a line or multiple lines can be monitored from a remote site to evaluate process reproducibility from run to run and repeatability within a run. Engineers sitting in an office can monitor each plant line, verifying that all lines are running properly, and the processes are in control based on SPC-generated data. In comparison to other plastic processes, an extruder has very few independent control variables that can be changed by an operator to alter the process. Assuming the correct screw design is in the extruder, the proper die is installed, the screen pack is clean, and the equipment is operating properly (all heater bands and thermocouples are functioning properly, air or water cooling on the heating zones is working, and cooling on the feed throat is operating properly), the only extruder variables that can be changed are the temperature setpoints, screw speed rpm, and throughput rates. Parameters that can be monitored to ensure that the process is in control and running properly are:

- Barrel temperatures (actual and set-point)
- Extruder load (percent load, torque, or amps)
- Screw speed
- Melt temperature
- Melt pressure
- Feed throat cooling water
- Raw material temperature entering the extruder
- Vacuum level, if vacuum venting is being used
- Cooling on the individual barrel zones

The other variable with modular twin screw extruders is screw design. If the process is not optimized, the screws can be removed from the extruder and then redesigned to optimize the process and throughput rates. Other parameters in the extrusion line to monitor include:

- Blend ratio
- Feed rates
- Moisture content of hygroscopic and moisture-sensitive raw materials
- Liquid feed rates
- Raw material lot numbers

Downstream equipment parameters to be set and monitored include:
- Roll and/or puller speeds
- Roll gaps
- Cooling bath temperature
- Vacuum level
- Windup speeds

With all this information available, how do you know if the product is good? If process changes are required, how do you make changes? In some instances, not enough information is recorded, raising the question, how do you troubleshoot the process? When setting up the extruder and any other auxiliary equipment in the extrusion process to produce a particular product, the first step is to obtain the standard operating procedures (SOP) for the product. This is a controlled document specifying all processing conditions and settings prior to start-up. Process parameters are normally controlled over a very limited range. If the final product does not meet specifications at start-up, the SOP for the process should be compared with the setup to verify that all equipment is properly set and within the ranges specified by the SOP. If the raw materials are the same as last time and all process conditions are the same, this raises the question, what has changed since the last run to make the product unacceptable? Investigation to determine what has changed requires a systematic approach. Do not start trial and error experimentation, making random changes without an appropriate plan to fix the problem.
Good procedure is to record all operating conditions, both when the process is running properly and when problems exist. The tendency is not to monitor the process when it is running smoothly, only when there are problems. Consequently, when problems occur because something has changed, if baseline data under good processing conditions are not available it is difficult to determine what has changed. It is impossible to record too much data and have too-detailed records. However, it is possible to record too little information and not have the necessary data when problems arise to properly troubleshoot the process.

Temperature Zone Control

Each barrel except the barrel in zone 1, the feed barrel, has at least one heater, and closed barrels have two heaters controlled by a thermocouple. A signal from the thermocouple communicates with the controller, turning the heater on or off. For the controller and heaters to function properly, the thermocouple must operate properly.

A faulty thermocouple with an alternate closed junction at a cold temperature will indicate that the temperature is low, causing the heater to stay on, resulting in substantial overheating. An open thermocouple circuit is usually detected by the controller as a high temperature and the heaters will stay off and the temperature zone cools. If a thermocouple is not responding properly, it needs to be replaced. Thermocouples have to be plugged into the correct temperature controller; otherwise the thermocouple controls the wrong heaters. For example, if the thermocouple from zone 2 is plugged into the zone 3 controller while the zone 3 thermocouple is plugged into the zone 2 controller, and the setpoint temperature for zone 2 is 420°F (216°C) and zone 3 is 450°F (232°C), the actual extruder temperature in zone 2 and in zone 3 will be a complex relationship involving the heat load, the thermal lag, and the controller tuning parameters. Needless to say, this is an undesirable condition. Barrel temperature thermocouples are spring loaded to guarantee good contact with the barrel wall and insulated to minimize heat loss along the thermocouple stem. Melt temperature thermocouples work on the same principles as the zone temperature thermocouples, except the melt thermocouples must protrude into the melt stream to obtain accurate melt temperature. Each heater zone should have an amp meter readout, whether it is on the control panel or an option in a menu-driven computer control system. With all heaters functioning properly, the amps drawn in a particular zone when the heaters are 100% on is a fixed value. Assuming a zone has more than one heater and the ammeter reading is lower than normal, at least one heater is burnt out or not working properly. Nonfunctioning heaters need to be replaced as soon as possible to prevent hot or cold spots along the extruder barrel, resulting in nonuniform polymer heating. Ammeter readings should be checked daily to verify that all heaters are functioning properly. If the actual zone temperature differs from the setpoint, the extruder is saying something is out of control.

Possible scenarios causing the variation of actual versus set temperature are:

- Temperature is not controlling that particular zone.
- Thermocouple is not operating properly and may need replacing.
- Temperature setting for the material being processed is incorrect.
- Excess shear heat is being generated in that zone.
- Extruder cooling is not functioning properly.
- Thermocouple wire to the controller is not connected to the correct controller and/or zone.
- Screw design is incorrect.

Control Summary

Good production practices dictate that all operating conditions and observations need to be recorded to establish a database for troubleshooting product or process problems. New computerized control systems provide continuous process data collection. Any unusual occurrence or abnormality needs to be documented on the control chart to identify cause and effect. It is impossible to record too much information during a developmental trial or a production run.

Documentation includes:

- Setpoint and actual temperatures

- Pressures
- Screw speeds
- Motor load (percent load, amps, or screw torque)
- Melt temperatures
- Product appearance
- Raw material type and lot numbers
- Formulations
- Drying time and temperatures
- Puller speeds
- Cooling medium temperatures
- Takeoff equipment settings

New computerized control and data collection systems contain formulation data and input operating conditions and generate control charts for SPC. Error messages are printed out along with process data at prescribed intervals and can document an entire run.

Problem Solving

How is an extrusion problem solved? Regardless of whether it is in a production, pilot plant, or research and development environment, there are numerous approaches to take, ranging from the trial and error method to implementing systematic investigative procedures. Trial and error is just turning knobs until something happens to correct a specific problem or make it disappear. For some it is a “shot in the dark,” where something is tried without a valid reason, as “all” other ideas have been tried and failed and “something” needs to be done. Another approach is “gut feel”: “I have a lot of experience and I think this is the correct approach to implement to make the process run more efficiently at higher yield.” The “gut feel” approach is usually based on experience and is something that has been done or seen previously. Although the operator or engineer may not know why it works, it does seem to correct the problem. Another approach is to ask a fellow employee if he or she has seen a similar problem and what approach was used to eliminate the problem. In production, if the line is not producing quality product for shipment to a customer, the company is losing money. While it may be ego-building to solve a problem on your own, if the line does not run for an entire shift, the business loses money, which is not good for the company or its employees. Always seek information from other people, probing for methods they have implemented to solve a particular problem, in an effort to get the line operational as quickly as possible. Businesses are run as teams, and cooperation between fellow employees makes the process run more efficiently with higher yields.

The next question to ask is how many variables to change at one time while trying to solve a problem. In a production environment, with time restraints to get the line up and running, the answer is probably one. However, when a problem arises, you often see people turning knobs and changing multiple variables at one time, trying to get the process to run more efficiently or to solve a problem. Once a variable has been changed, how long should the process run under those conditions, allowing it to stabilize or equilibrate before collecting samples to determine the effect of the process changes? The answer is, it depends on the extruder factor or variable changed. For example, if the screw speed is increased or decreased, the thought process is that this happens quickly (30 seconds or less) and the process is in equilibrium immediately. However, if a change is made to the barrel or die temperature profile, equilibrium may take 15 or 20 minutes, depending on extruder size, the delta T, and how long it takes for the actual polymer melt temperature to reach equilibrium. In reality, the time to reach equilibrium and collect a sample after a process change is made depends on the extruder size, whether it was a screw speed change, barrel temperature change, die temperature change, or some other controllable variable (screen pack, raw material, cooling, and so forth). The extruder must be allowed to reach equilibrium before the effect can be determined. As an example, increasing the screw speed from 100 to 120 rpm is almost instantaneous; however, the total effect may not be completely visible for a half hour or more, depending on the extruder size. Increasing the screw speed generates additional

frictional shear heat that must be dissipated by the barrel cooling. Initially the large metal mass comprising the barrel and the screw absorbs the heat. Over time, the barrel and screw temperatures increase as equilibrium is reached. If the barrel cooling is insufficient to remove this additional heat, polymer degradation may occur 45 minutes to an hour after the screw speed change. Barrel temperature changes require as long a time to come to equilibrium because the metal mass involved is still the same. The heaters transmit the heat through the barrel and into the screw through the polymer melt. It takes time to establish equilibrium temperature conditions between the barrel, polymer, and screw. On a small extruder (3.0-inch diameter or smaller), the time to reach equilibrium after a process change is 30 to 45 minutes. For larger extruders with more barrel and screw mass, the equilibration time increases. Process changes on an 8-inch extruder may take two hours to reach steady state or equilibrium. If a process change is made and the system is not allowed to reach equilibrium before a second or third change is made, the effect of the first process change is never realized. If the extruder is not allowed to reach equilibrium before another change is made, the operator is running around in circles and may never solve the problem. Consequently, the answer to the question, “How long do you wait after making a process change to determine the effect of the change?” depends on the extruder size and the change made. In any event, the time is always longer than one to five minutes and in general between 30 minutes and two hours, depending on the extruder size.

The next question is, “How large a process change should you make when changing extrusion variables?” Changing zone 2 on either a single or twin-screw extruder 4°F (2.2°C) is not a significant enough change to observe any effect. If you change zone 2 4°F (2.2°C) and wait 20 minutes for the system to come to equilibrium, then change zone 3 5°F (2.8°C) and allow it to come to equilibrium, it will take too long to make significant changes that affect the processing. Using the same argument for screw speed, increasing screw speed 2 rpm is a change, but it is probably not significant enough to see any effect unless the process setup is on the very edge of the processing envelope and that small process change pushes it over the edge. An example is extruding polybutylene terephthalate (PBT) into sheet using a 3.5:1 compression ratio screw with a Maddock mixer designed for polypropylene. Running polypropylene sheet with the same setup, the extruder is run at 125 rpm, producing quality sheet at a high rate. However, running PBT at 54 rpm degrades the resin, generating gas that blows holes in the PBT sheet. At 52 rpm, defect-free sheet is produced. This 2-rpm change converted a good process and product into the unacceptable range. In most cases, 2 rpm does not greatly alter the process or product characteristics. In this example, a 2-rpm change caused a dramatic effect because the extruder setup was not designed to process PBT. With increased screw speed, the process was pushed over the edge of the processing envelope, resulting in unacceptable product.

When making process changes, the new setting needs to be significantly different from the original setting to determine if the change had an effect.

Table 23.1. Size of Process Changes

Size Change	Screw Speed, rpm	Temperature °F (°C)
Small	1–2	2–4 (1.1–2.2)
Medium	10–15	10–15 (5.6–8.3)
Large	25 or more	30 (17)

Table 23.1 provides some suggestions for process changes. The actual change depends on the extruder, screw design, and the polymer being processed. Assume the current process is running rigid PVC with a barrel temperature profile of 300/340/370/370°F and die temperature of 380°F (149/171/188/188°C and die temperature of 193°C), and the suggestion is made to increase the temperature profile 30°F (16.7°C). The immediate concern is whether rigid PVC can be processed at that temperature without degradation. It is important to use both material and process knowledge to determine the increase and/or decrease when changing processing conditions. Lowering the barrel setpoint temperatures severely can cause the extruder to operate at excessively high torque or, in extreme cases, stop. With crystalline polymers, significantly lower barrel temperatures can cause the polymer to solidify or, with amorphous polymers, become so stiff the extruder torque limit is exceeded. The process change implemented in a specific situation has to be large enough to determine if the change had an effect on the process while remaining within the operating limits of the polymer being processed. If the operating change did not have an effect on the process, go back to the original process setting and change a different variable. In all situations, document the effect the variable change had on the process so the information can be used in the future in making process modifications. If the change had no effect on the process, it is still noteworthy. This knowledge can prevent similar changes if the problem arises again, thus saving time and valuable resources. After a process variable change (screw speed, barrel temperature, cooling tank temperature, roll temperature, and so forth) is completed and the extrusion system is allowed to come to equilibrium, what is the next step if the product or process deficiency has not improved? Is the process variable changed back to its original setting, or are other process variables changed without converting the process back to its original setpoint? Since the first process change had no effect on the process, it doesn't really matter if the process is changed back to its original settings or the current process configuration is used as the baseline for additional process changes. In either situation a baseline is established to determine if future process modifications have an effect. Assuming the process is run using the new baseline data resulting from the process change, a second change is made that shows a very dramatic effect on the product or process. The question becomes, “Is the product or process improvement or deficiency caused by the second process change or the interaction of the first and second process changes working together?” Regardless, experimental data have to be generated to understand the effect of any extruder changes on the product and/or process. When troubleshooting product problems, always save samples made under different processing conditions. Compare the different samples versus the process changes to determine the best direction to take for future process changes. If the product property being optimized continues to show improvement and almost meets the quality requirements but not quite, what is the next step? To a process engineer or operator, small changes in process variables may seem like the correct approach to

optimize the production process. However, if after making numerous small changes the product still does not meet all the specifications, it is time to step back and evaluate the process changes versus product improvements and ask the question, “Can I get there from here?” At some point it becomes obvious that small changes in the process variables will not lead to the desired endpoint. It may be necessary to rethink the process and/or product and make a dramatic change in another direction. If a product or process problem is identified immediately after a production run or trial is started, go back and compare the complete process setup versus the standard operating procedures (SOP). Verify that all operating conditions are properly set, including the auxiliary equipment setup, resin formulation, drying, type of die, barrel and die temperature profile, screw speed, takeoff equipment setup with the proper temperatures, and so forth.

Assume the product or process is running properly with a quality product being produced at a high rate. All of a sudden, the product or process is out of control. What happened or what changed? If the processing conditions are well documented when everything is running well, what changed may be easier to identify. In troubleshooting a process, it is critical to identify what has changed in the product formulation or processing conditions to cause the product or process to be out of control. At start-up the product and process might be running very smoothly, and 45 minutes later, with no process or formulation changes, the product or process is running poorly. The operating conditions at start-up yield good product; however, after the extrusion process has come to equilibrium, the operating conditions do not produce a good product or process. The question is, what has changed between the start-up conditions and the equilibrium conditions (probably temperature difference), and what changes are required to get the extruder and process to perform similarly to the start-up conditions? One last potential scenario is the product or process produced a quality product at a high rate last time it was run, and it is borderline acceptable or unacceptable this time. What has changed? Review the operating conditions and procedures used last time to verify that they are the same this time. Have any equipment changes been made between the two runs? Review the run sheets from the previous production campaign to verify that the operating conditions are the same as the SOP. If the operating conditions from the previous run are different from the previous SOP conditions, the SOP and current processing conditions need to be changed to the operating conditions used in the previous production run. Problem solving and troubleshooting require good documentation comparing what is currently happening in the process to what occurred previously, and to the SOP. A systematic approach and both materials and process knowledge are necessary to solve processing and product problems. Problem solving starts with an understanding of how equipment in the extrusion line functions and how the material interfaces and behaves in the equipment as it is being transformed through the various stages into an acceptable product.

To understand how each piece of equipment operates, the following questions require answers:

- What is the function of a particular piece of equipment in the overall extrusion process?
- How does each piece of equipment operate?
- What function or role does each piece of equipment perform relative to other pieces of equipment in the overall extrusion line?
- What do the various gauges and output displays communicate to the operator?
- How do the controls function and what do they control?

It is necessary to understand how the extruder and the extrusion process operate when they are working together properly. What roles do extruder heating and cooling, downstream equipment heating and/or cooling, puller roll speed to extruder throughput ratio, die operation and adjustments, extruder feed throat temperature, extruder screw design, and so forth, play? Learn to identify any unusual noises or odors, as these may be the first indication some change has occurred in the process or equipment. Die defects may prevent an acceptable product from being produced; be able to identify die damage both internally (assuming die is apart) and externally.

In combination with processing conditions and equipment knowledge, an understanding of the materials and their transformation in each step is necessary.

- What is the formulation rheology and how does it change with temperature and shear?
- What are the proper drying conditions?
- How does moisture affect properties?
- What is the proper melt temperature?
- What is the material shrinkage?
- Is the polymer crystalline or amorphous?
- What are the cooling requirements (material T_g or T_m)?

Complete and well-documented setup sheets or SOPs are required for each product and process. The sheets need to be routinely reviewed and updated as process improvements and modifications are made. Specific setpoints and operating ranges for each process input (independent variable) for all equipment in the extrusion process, from drying to puller speed, are defined. SOPs are dated with revision numbers and contain the process changes made over time as different revisions are generated.

Each extrusion line needs its own logbook documenting any process and equipment changes made by the operator or maintenance. Operators log in at the beginning of each shift and document any changes made to the equipment or process during their shift. Information contained in the process log includes:

- Operator name
- Product changes
- Start-up and shutdown times
- Documentation of any downtime and reason
- Equipment malfunctions or changes
- Product or process deficiencies and corrective action taken to remedy product and/or process issues
- Any unusual observation or occurrence

It is impossible to record too much information, but very possible to record too little. If there is a customer complaint, product traceability and any unusual occurrence that happened during the production run greatly assist in determining if anything out of the ordinary or unusual can account for the complaint. Processing conditions are recorded periodically throughout a particular production run. Statistical process control (SPC) data can be collected continuously throughout a run and stored on disk or CD for later evaluation or if there is a customer complaint. Newer extruder control systems may have built-in SPC documentation that can be used to record process data automatically at specific time frequencies. Process control provides data showing conditions remained constant or within specific upper and lower control limits during the run or when a process upset occurred; control charts identify the time frame during which the process was operating in control and out of control. Extruder load (torque, amps, or percent load), screw speed, and barrel temperatures define the extruder process. Include feed rates and downstream equipment speeds and temperatures in the data collection, because a process snapshot at any particular time is useful to reconstruct. Setpoints versus actual operating conditions provide information on what is changing and how the changes may have affected the product or process. Setpoint information verifies that the temperature controllers are set correctly and, more important, operating properly. These records are critical for product traceability. Any equipment defects or malfunctions identified during a given production run need to be repaired either immediately or after the production is completed and before the next material is started. Maintenance and/or equipment issues should only be put off until the current production run is completed if safety or the product is not affected by the equipment malfunction. An example may be a heater band that burns out during a run. Since most of the energy is from shear heat, the temperature zone may still control within the specified process window at steady state with one heater band out of two or three not functioning properly. On shutdown, the heater band is replaced before the next production run is started. Always make sure any equipment malfunction, the specific time the malfunction is first observed, and when it is corrected are documented in a logbook. Processing conditions and setpoints to be recorded include:

- Actual and setpoint barrel and die temperatures
- Melt temperature
- Feed throat cooling
- Screw speed
- Motor load (torque, amps, or percent load)
- Melt pressures in both the die and barrel
- Throughput rates
- Polymer pretreatment conditions, such as
—drying temperature
—moisture content
—lot numbers
—blend ratios

—feeder speeds prior to the extruder
—moisture level
• Takeoff equipment speed, such as rolls and pullers
• Takeoff equipment temperature, such as water bath, rolls, and air
• Air pressure used in cooling, such as blown film

New equipment (extruder, screw, takeoff equipment) should be run at two or three different speeds with a particular product to obtain baseline operating data. Later in the equipment life cycle, the same processing and product conditions can show if there is a throughput rate or product quality shift. Baseline data comparisons six months, one year, and two years later assist in determining the equipment life expectancy and defining when modifications might be anticipated. Any time a new barrel or screw is installed, a baseline plot of throughput rate (pounds/hour) versus screw speed (rpm) should be generated with a specific polymer for comparison later in the screw and barrel life. These data assist in predicting capital expenses and screw replacement. Good troubleshooting and problem-solving techniques are based on determining what has changed in the process. Without proper documentation, during both good and bad operation, it may be impossible to define what changes have occurred, making problem solving difficult or impossible. At the same time, collecting reams of process and product data that are never analyzed is an exercise in futility, and questions the importance of the data.

Hazards Associated with an Extruder

The three biggest potential safety hazards associated with extruders are burns, electrical shock, and falls. Without proper protective equipment, burns can be commonplace among employees working around extruders. Touching a hot die or handling extrudate without gloves normally causes burns. Long sleeves with properly approved thermal gloves should be worn when working around the die, changing the die, tightening die bolts, or other functions performed on the die. If insulation is placed around the die, make sure it is in good shape and properly installed. Hot extrudate from the extruder will stick to your skin. Since polymeric materials are great insulators, after sticking to the skin they cool very slowly, continuing to burn the skin affected.

Never stand in front of a die when a single screw extruder is starting up. Air in the extruder and possibly gas from degraded products (if the extruder has been sitting at extrusion temperature with material in the barrel for some time) is forced out of the extruder on start-up. If some polymer is left in the barrel, trapped air can be compressed,

blowing the hot polymer out of the die. Standing in front of the extruder creates an unsafe condition where molten polymer can be blown out of the die, land on you, and burn you. Polymer can stick to gloves, where it holds heat for a long time, and can burn you through the gloves if the proper type of glove is not used. When removing the die and/or screw from an extruder (they are normally hot), wear the proper protective equipment (heavy duty gloves and protective thermal sleeves) to prevent burns. Dies can be heavy; therefore, a back brace or other equipment to lift and hold the die can prevent back injuries.

Hazards Associated with Takeoff Equipment

The safety hazards associated with takeoff equipment depend on the extrusion process and takeoff equipment. Pinch points associated with nip rolls, pullers, and roll stacks are one potential safety hazard requiring careful operation. If two operators are running equipment containing nip rolls, they must communicate to verify all operators are clear when nip rolls are closed. Loose-fitting clothing that can be caught in nip rolls or pullers must be avoided. Some lines have rolling knives or knives for edge slitting. These should be guarded, and operators must use caution when working in those areas.

Noise above 80 dB requires that hearing protection be used by all people in the area. If the noise level is below 80 dB, employees may still want to wear hearing protection to prevent long-term hearing loss. Like the extruder, identify potential safety hazards associated with the takeoff equipment. Form a plan to avoid potential hazards. Know where all emergency stop buttons are and verify that they work. Don’t take the approach, **“It Won’t Happen to Me.”**

Material Safety

Understand the materials you are using by reviewing the Material Safety Data Sheets (MSDSs). Improper operating conditions or purging with the wrong materials can have serious consequences. Overheating polyvinyl chloride (PVC) generates hydrochloric acid (HCl), which attacks the lungs and rusts plant equipment. Never mix acetal with nylon, PVC, fluorinated polymers, or ionomer in an extruder, as they will react and give off formaldehyde. PVC has limited thermal stability and should not be left in a hot extruder. PVC degrades in an autocatalytic reaction, generating HCl. Proper purge material should be available to remove PVC from the barrel if the extruder is going to be down for an extended time. Operators who have the flexibility to change extruder temperature profiles need to understand the upper processing limits when extruding PVC or other temperature-sensitive polymers.

Importance of using PPEs

PPE is equipment that will protect workers against health or safety risks on the job. The purpose is to reduce employee exposure to hazards when engineering and administrative controls are not feasible or effective to reduce these risks to acceptable levels.

PPEs:

Name & Usage	Picture of PPE	Name & Usage	Picture of PPE
Safety goggles – used to protect eyes from flying particles (chips, sparks etc.)		Safety shoes – used to protect feet from spatters of welding and impact of other falling objects	
Face shield - used to protect face from welding sparks, radiations, arc and spatters		Face mask – used to protect from inhaling fumes, dangerous gases etc.	
Hard cap – used to protect the head from injury due to falling objects		Leather Apron – used to protect welder's body from welding spark and spatters	
Leather gloves – used to protect hands during welding		Cotton gloves – used to protect hands from sharp edges of sheets and plates	

Importance of housekeeping and safe storage of tools and equipment

The main function of housekeeping is to ensure cleanliness, comfort, convenience, privacy, health and hygiene in a safe environment. It includes keeping work areas neat and orderly. All the tools and equipment must be stored properly.

Importance of making a check list

It ensures you get your daily, weekly and monthly tasks done on time, helps you keep track of projects on deadline and ensures you're organized throughout the day.

PLASTIC PROCESSOR

Module-8

Learner Guide

National Vocational Certificate Level 3

Version 1 - September, 2018

Video Links:

Extrusion machine process (Hindi): https://www.youtube.com/watch?v=tbsApGggYGA
Plastic Extrusion - Safety, Pre-Start and Start-Up Procedures: https://www.youtube.com/watch?v=2rzhevw2Ong
Plastic Extrusion - Operation, Shutdown and Maintenance Procedures: https://www.youtube.com/watch?v=Rf5DQR5qXxU
CLEANING PROCESS FOR EXTRUDER MACHINE: https://www.youtube.com/watch?v=Pvn108_P46w

Module 8: 072200918 Operate Blow Moulding Machine

Objective of the module: The aim of this module to provide skills and knowledge to operate blow moulding machine in accordance with the manufacturer's manual

Duration: 150 hours **Theory:** 30 hours **Practical:** 120 hours

Learning Unit	Learning Outcomes	Learning Elements	Materials Required
LU1: Adjust moulding machine parameters	**The trainee will be able to:** Turn on machine as operation manual. Feed parameters as per PPS and job. Verify all parameters as per job/ data sheet	i) Identify production cycle from feeding to de-molding of product ii) Understand the materials used for moulding iii) Difference between types of heaters, thermocouples & controllers for mould iv) Machine controls • Learn to input processing parameters in the machine and peripheral components v) Ensure working of peripheral equipments such as air compressors, chillers, vacuum pump, printer, dryer, etc. vi) Moulding cycle from feeding to ejection • Set processing parameters as per job card • Ensure desired temperatures are achieved	Blow moulding machine Machine mould Air compressor Vacuum machine De-humidifier Chiller for cold water Utility documentation Service manual Operation manual Basic hand tools

		• Ensure raw material is ready for processing (De-humidified, etc.) • Ensure all peripheral equipments are working properly (oil pump, air filter, hydraulics, motors, pneumatics, etc.) vii) Recognize screw configurations • Check shot size and speed viii) Check injection pressure and other parameters	
LU2: Perform dry run	**The trainee will be able to:** Ensure Mould opening & closing position as per tool Ensure Mould mechanism and Ejection system Verify protection of tool as per operation manual and procedure. Verify material dryness is as per specification	i) Knowledge and understanding of mould and it's mechanism ii) Understanding of hydraulic and pneumatic systems iii) Manual operation of blow moulding machine iv) Ensure operation of clamping mechanism v) Identify and set up part ejection in the mould	Blow moulding machine Machine mould Air compressor Vacuum machine De-humidifier Chiller for cold water Utility documentation Service manual Operation manual Basic hand tools
LU3: Perform semi-auto operation	**The trainee will be able to:** Ensure molding temperatures has achieved according to data sheet Start heating till required material ready for sampling.	i) Recognize machine controls ii) Learn to adjust temperatures from feed zone to injection point iii) Learn to adjust injection pressure iv) Perform Semi-auto operation v) Check for day-light opening	Blow moulding machine Machine mould Air compressor Vacuum machine De-humidifier Chiller for cold water Utility documentation Service manual

	Start moulding cycle as per SOP. Inspect the samples as per data sheet.		Operation manual Basic hand tools
LU4: Perform production	**The trainee will be able to:** Start machine on auto cycle mode as per SOP Perform periodic quality checks as per requirement	i) Machine operation in automatic mode • Up on successfully obtaining required product, switching the machine to auto mode ii) Maintaining product quality as per specifications • Be able to measure components for identification of dimensional defects • Usage of measurement tools is critical: Vernier caliper, micrometer gauge, scale, etc. iii) Recognize different defects and their causes • Be able to visually identify commonly occurring defects, such as flashing, orange-peel, drooling, etc. • Gain knowledge of rectification of commonly occurring defects.	Blow moulding machine Machine mould Air compressor Vacuum machine De-humidifier Chiller for cold water Utility documentation Service manual Operation manual Basic hand tools
LU5: Perform follow up procedure for machine production	**The trainee will be able to:** Ensure product packed in assigned packaging. Check feed level in hopper/bin, etc.	i) Knowledge of product packaging • Understand different types of packaging, e.g.; flexible packaging, packing in cartons, etc. • How to pack final product? ii) Raw material input in moulding machine	Blow moulding machine Machine mould Air compressor Vacuum machine De-humidifier Chiller for cold water

	Ensure machine lubrication as per requirement	• Ensure consistent raw material feed into hopper/feeder • Be able to use overhead crane or moveable lifts/ladders • Understand the importance of cutting tools in opening raw material bags. • Concept of 'clean slits' using sharp tools to ensure particles of bag don't get mixed in raw material iii) Lubrication requirements and procedure of machine • Understand the concept of lubricating moveable parts of machines • Carefully use mould lubricant sprays • Ensure spray cans are stored in a secure location after pre-shot application • Be able to identify different mould release agents as per raw material • Be able to provide first-hand feedback to maintenance department for periodic machine maintenance	Utility documentation Service manual Operation manual Basic hand tools
LU6: Submit production report	**The trainee will be able to:** Record production report as per given format (kg or units / hour). Submit report to concerned department.	i) Production report writing LU.4 Understand the importance of reporting accurate production quantity LU.5 Be able to fill-in relevant production reports LU.6 Be able to identify waste generated along with identification of machine downtime with reasons ii) Data sharing with relevant departments	Job card Production report format

		• Understanding the concept of producing accurate data and benefits of the same on a larger scale • Submission of production reports to production planning department or the supervisor for timely actions.	
LU7: Transport finished product to concerned department	**The trainee will be able to:** Place finished product in designated area Take approval of finished product from Quality control Deliver relevant packaging documents to store personnel.	i) Understand QC protocols • Understand and appreciate the importance of producing products as per specification • Be able to implement the first quality control protocol on machine to ensure elimination of defective products at sight ii) Inter-department co-ordination • Be able to co-ordinate with QC department with produced batches for relevant approvals iii) Be able to hand over final products to store iv) Familiarize with handing-over protocols and paperwork.	Reporting formats Job card Basic Hand Tools Medium of material transport

Examples and illustrations:

For further details, please look at:

Practical Guide to Blow Moulding Technology by Norman C. Lee, © 2006 Rapra Technology Ltd.

Introduction

The basic process is common to all variations of the blow moulding method, which consists of three stages:

1. Melting and Plasticizing – This is accomplished with either extrusion and/or injection moulding machine to produce the melt.
2. Plastic Formation – Through head and die or in an injection mould.

3. Blowing and Moulding – An auxiliary compressor provides air pressure and a clamp unit, which closes over a split mould that is operated with a hydraulic system.

The first step involves the production of a hot tube, known as a parison, a term derived from the glass industry. This may be produced, as indicated, by one of two methods, extrusion or injection. In the injection case it is referred to as preform. The heated parison or preform is placed between two halves of the blowing mould, which closes and clamps around it. The heated tube is blown against the cavity wall and the molten plastic or resin takes the shape of the mould while being cooled. This is illustrated in Figure 1.2. After the cooling stage the part is ejected from the mould. In the case of an extruded part it is necessary to remove the flash (excess plastic around the part) for further finishing.

Drilling, labelling or printing may be required in both methods. Moulding for high volume production parts often uses robots.

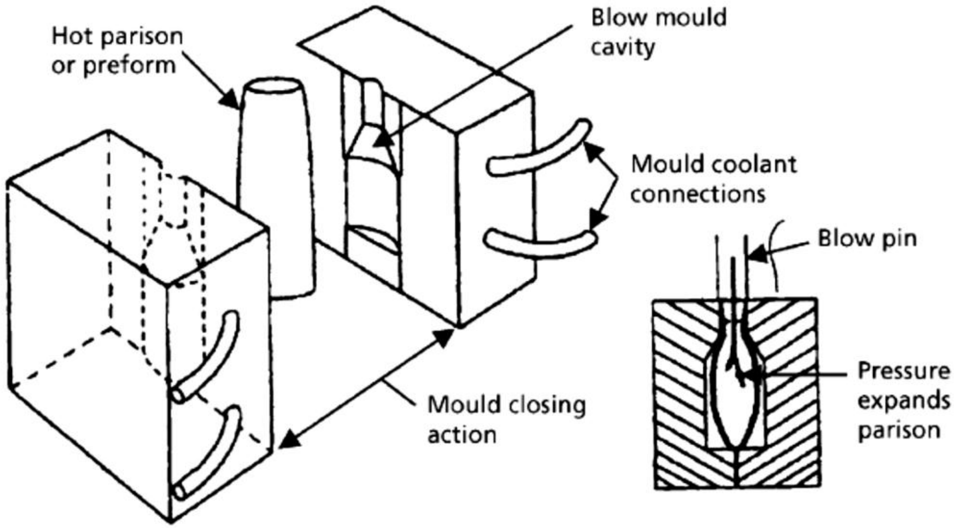
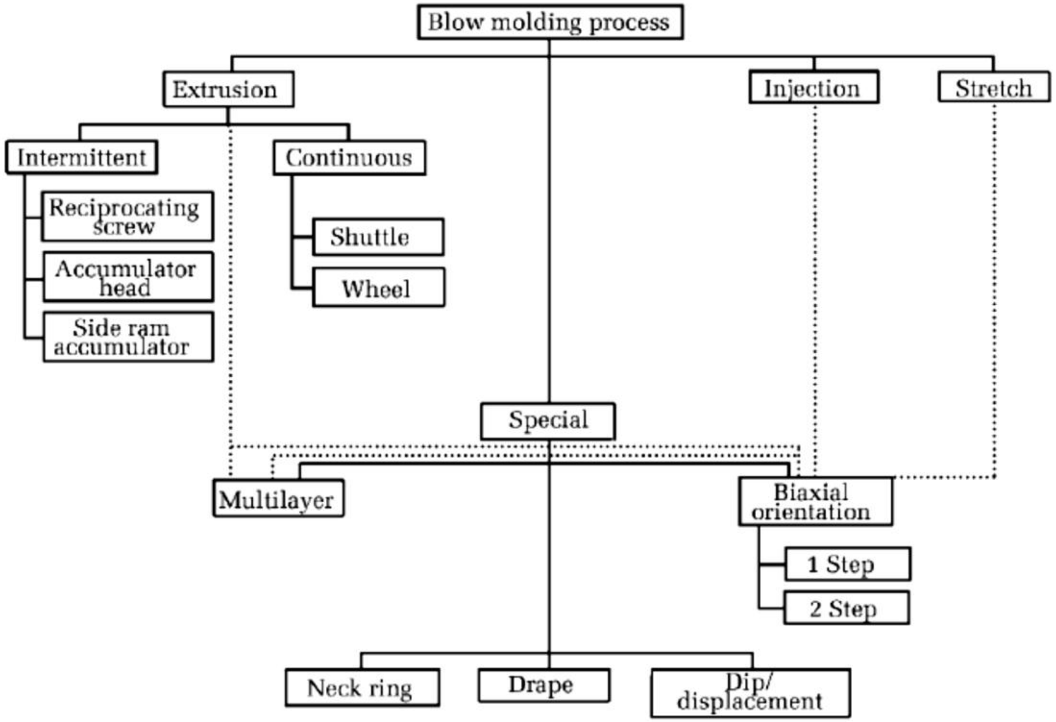


Figure 1.2 Basic blow moulding process

As indicated earlier blow moulding may use either extrusion or injection methods for processing. Figure below shows the breakdown of the subsidiary methods in each case and where they crossover in application.



Injection Blow Moulding

Injection blow moulding produces a parison with bottle neck and threads already formed to final dimensions. This process is used primarily for small pharmaceutical and personal product containers. The economics for such containers dictate multiple (up to ten) cavities - one set each for injection moulding and blow moulding. When tolerances in the neck and closure thread area are critical, injection blow moulding is applicable to larger bottles. An example is pressurized carbonated beverage containers up to 2 liters. Another application is aerosol spray bottles, in which neck tolerances must provide sufficient thickness and taper to meet top load stresses from pressurized filling line equipment, and the closure thread (or lip) must conform to the twist cap (or valve seal). There is essentially no plastic waste or trim generated with the latest injection blow moulding machines, only improperly formed containers from start-up and occasional 'off-spec' parts from production are candidates for regrind.

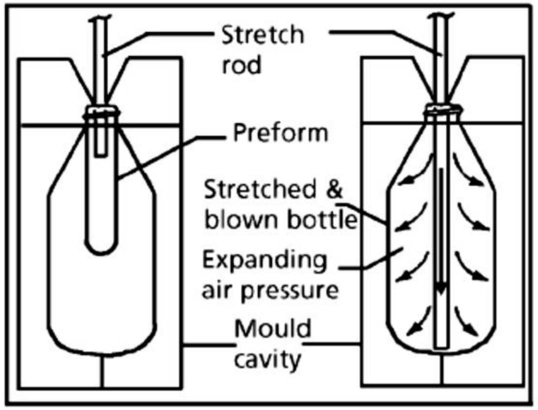
Injection Blow Moulding Process

The injection moulding process produces a moulded parison called a preform. This method is preferred over extrusion blow moulding for making small parts that require high production volumes and closer quality dimensions. Injection blow moulding consists of injecting a thermoplastic material into a cavity and around a core rod producing a hollow test tube like shape (preform). The moulded preform still on the core rod is transferred to the blow mould. The mould is clamped around the preform and air is blown to shape of the cavity. The preform is injected onto a support pin or core, which forms a neck with threads to their required dimensions. The preform is then blown against the cavity wall to its final shape.

Advantages of injection blow moulding are:
• No scrap or flash to trim and reclaim
• High quality neck finish and details
• No process weight variation
• Offers lowest part cost for high-volume bottles 37 grams (12 oz) or less.

Disadvantages of injection blow moulding are:
• Tooling costs are higher than extrusion blow moulding
• Bottle sizes and shapes are limited to an ovality ratio of 2:1 and a blow-up ratio of no greater than 3:1
• Offset necks are possible but not handles.

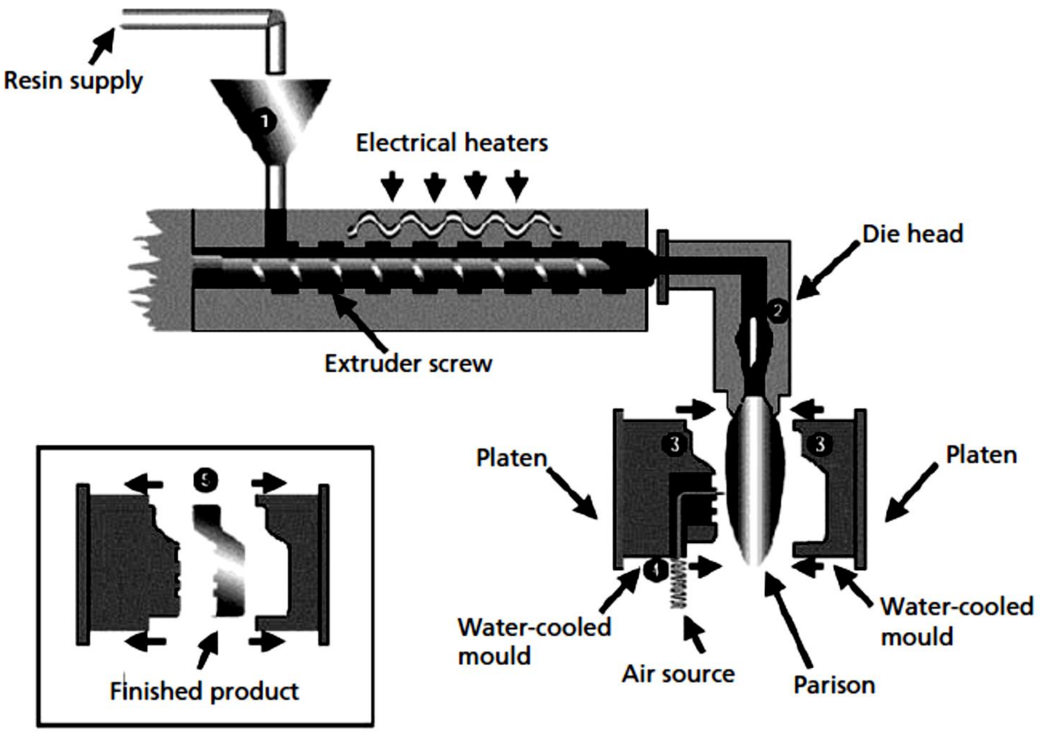
Stretch Blow Moulding
Stretch blow moulding became known in the blow moulding industry with the introduction of the soft drink bottle. Bi-axial stretch blow moulding applies to the method of producing a plastic container from a preform that is stretched in the hoop direction and the axial direction when the preform is blown into its final shape. Stretch blow moulding consists of conditioning (heating) a moulded and cooled preform to a specific temperature. The preform is closed in the blowing mould and is stretched in length and diameter (See figure below).



A temperature conditioned preform is inserted into the blowmould cavity, then is rapidly stretched. Often a rod is used to stretch the preform in the axial direction with air pressure to stretch the preform in the radial direction.

Extrusion Blow Moulding

In contrast to injection blow moulding, all areas of the extruded (free) parison, with the exception of the pinch off, undergo forming during the blowing step. This includes the closure threads on bottles and, in some cases, handles and support lugs. Containers produced by extrusion blow moulding must meet minimum stiffness requirements to undergo filling on automated lines and to avoid, or limit, unsightly bulging under weight of their contents, both alone or when stacked. They must also withstand normal impacts of handling, transport and accidental dropping. Such impact must be absorbed by container walls, weld lines (pinch-off and handle areas), and screw cap closure threads, often under extremes of temperature. HDPE provides most of the requirements noted previously at low cost and is also chemically inert to many fluids used in personal products, food products, and household and industrial chemicals.



Extrusion Blow Moulding Process

Extrusion is the process of applying heat and pressure to melt the resin and force it through an accurately dimensioned die to produce the desired shape. For blowing purposes this is a shape from which the parison is cut. There are several main parts to an extrusion blow moulding machine, which are: screw, barrel, hopper, feed section, compression section, metering section, screen pack, breaker plates, adapter, die head, core, mandrel, and die tip.

Co-Extrusion Blow Moulding

This term refers to products made with several layers in their wall structure and to the method of making them. These layers may be different materials, coloured or not coloured, recycled or virgin. This process makes it possible to combine materials of various properties to create a final product to meet the requirements of a particular application.

Advantages of extrusion blow moulding are:
• Natural process for containers and hollow parts
• Preferred process for high volume containers

Disadvantages of extrusion blow moulding are:
• Uneven wall thicknesses
• Close dimensional tolerances are difficult to achieve
• Relatively low accuracy of surface finishing details.

Start-Up Preparations

An understanding of the settings is needed before starting up a blow moulding machine. Obtain advice from someone who is very familiar with the equipment, or better yet, consult the written procedures. A general procedure is:
• Turn on the main power switches and then select or set the temperatures.
• Ensure that the cooling water is on and check to see that it is flowing through the feed throat.
• Preheat the hydraulic oil to its correct operating temperature.

This may be done either by pumping the oil back into the tank or by using a preheater fitted for this purpose. Once the machine has reached the required temperature, it should be allowed to settle down before any material is introduced into the barrel. The settling-in (equilibration) time, sometimes called ‘soak’ time, is the time needed for the barrel, screw, breaker plate, and die or mould temperatures to stabilize close to the temperature set points. The equilibration or soak time will depend on the size and type of machine. It may take 20 minutes for a small machine and it may take several hours for a larger machine. This time should be used to prepare for the production run.

Other start-up steps include:
• Check the nozzle/die and moulds to see if they are clean and operational.
• Review the production order for colour, quantity, and other requirements.
• Check for necessary tools and equipment and be sure they are in place and working properly.
• Make sure that all auxiliary equipment is clean and operational, to include hopper loaders, conveyors, grinders, vacuum pumps, and leak testers.

Melt Temperature

Two methods are commonly used to measure melt temperature in a blow moulding machine:
• Extrusion or injection of the material onto a suitable surface, then measuring the temperature of the plastic mass with a thermocouple probe.

• Direct reading by a thermocouple that is placed in the barrel and is in direct contact with the melt.

When the temperature of the melt is measured with a probe, care should be taken during the measurement to ensure that the purging of hot plastic does not cause an accident. As has been mentioned previously, molten material will cause serious burns because it is very hot and it adheres to the skin and is very difficult to remove. Burns are a common injury in moulding operations, so long sleeves, gloves and face shields should be worn when handling hot material or where there is danger of being splashed with hot plastic melt, particularly during start-up or purging. As with other situations requiring personal protective equipment, the plant's requirements must be followed.

Warming up an Empty Machine

The machine's warm-up cycle should be programmed so that thermal overshoot does not occur, and heating times are kept reasonably short. Once the machine is at the set temperature, it should be allowed to equilibrate ('heat soak') before material is introduced into the barrel. It is advisable to keep this time as short as possible so that any resin left in the barrel after purging does not degrade. Check the machine for correct temperatures by briefly rotating (jogging or 'inching') the screw. If the screw requires excessively high motor currents or will not rotate, then allow the machine to equilibrate further. The set-up sheets should show the normal heat soak time. Before starting the machine, be sure that the set conditions are satisfactory by purging a few pounds of resin out of the die (or nozzle) at slow screw speeds. Check the melt temperature with a melt probe and also check the general appearance of the melt. It should be smooth and free of dark specks, streaks, bubbles, or other signs of degradation. If no material is delivered when the screw is turned, check to see that plastic feed is available to the screw, check for faulty heater bands, and find out if the feed has 'bridged' (stuck together) in the hopper. Checking for bridging or material blockage in the machine feed throat requires caution and the immediate attention and expertise of trained personnel wearing the appropriate safety equipment. This is because of the potential for serious personal injury from the hot gases, and degraded and overheated plastic that may spray violently back through the hopper.

Warming up a Full Machine

When material is in the barrel or die head, the machine is said to be full. A full, cold machine might result when there is a power failure or when the machine is deliberately shut down because of deterioration of the material by oxidation or depolymerisation. The machine must be heated in a safe way because decomposition produces gases under pressure and can cause serious accidents. To warm a cold machine, set all temperatures just below the melting temperatures of the material, for example, at 135 ºC for low-density polyethylene (LDPE). Allow the machine to reach and equilibrate at these temperatures, and then raise the temperature of the die (nozzle) to the process set point. To reduce the potential for dangerous pressure build-up in the barrel, wait for a period of time to allow the plastic in the die or nozzle to melt, and then raise the other barrel temperatures to the set point. Allow the machine to equilibrate to these temperatures before beginning to purge.

Initial Operation and Purging

When the machine is fully up to temperature, put a small amount of material in the hopper, make sure the hopper lid is in position and the hopper gate is open, and start the screw at 10-15 rpm. Do not allow the screw to turn in an empty machine, because this can damage the barrel and screw. Check to see that the set process conditions are correct by running for a minute or so on an extruder or by running a few purge cycles on an injection machine. A machine with a grooved barrel may require careful hand feeding of material by trained personnel, because it is easy to over-feed the machine.

After a short period of operation, check the melt temperature with a melt probe, and also the general appearance of the melt. Dispose of the hot, sticky plastic melt in a safe way once being satisfied that the material is feeding well, and the melt looks satisfactory. On an extruder, also check the drive motor current. It should be with the normal start-up range. If it is too high, there is probably unmelted material in the barrel. If it is too low, there may be feeding problems. On an injection moulding machine, material should fl ow freely from the nozzle. If it doesn't, the nozzle may be blocked by unmelted plastic. Do not attempt to clear a blockage by turning the screw or injecting under high pressure. If all is well, fill the hopper to the normal level for running. Check to see that the monitoring equipment is working, and in extrusion blow moulding, when material starts to extrude from the die, turn on the screw cooling if it is required.

Commencing Moulding – Manual Operation

When purging is complete and satisfactory melt is being produced, moulding may begin. The moulding process usually begins with manual operation, in which the operator initiates each part of the moulding cycle by pushing buttons according to the operation sequence. When the mould is closed, clamping pressure should be checked. To begin extrusion blow moulding, produce a parison and check its temperature and appearance. The parison must be long enough to reach the bottom of the mould for pinch-off. Start moulding, and adjust conditions and settings as needed to obtain a satisfactory part. Increase screw rpm gradually until it reaches the normal operating speed, while constantly checking the parts. A periodic check should be made to ensure that the hopper has enough material and that the melt is not leaking or weeping from around the nozzle/die/adaptor areas. Product quality should be closely watched to see that parts are free from froth or unmelted resin particles, and when the cycle is stable and the parts are good, production can begin. Note: If for some reason a different material was used for purging, it must be removed from the barrel according to procedures required by the material manufacturer, before moulding begins.

Commencing Moulding – Automatic Operation

Automatic operation is only started after satisfactory melt is made, after the purging procedure, and after the machine settings have been established based on experience or process records, or as determined from the manual operating conditions if this is a new product.

Commence moulding on an automatic, or semi-automatic cycle (in which the operator opens and closes the safety gate to start the cycle) using pre-determined cycle times. These may be calculated, based on experience, or determined from the manual operating conditions. Gradually adjust conditions until product of the required quality is obtained at an optimum rate. After each adjustment, allow the machine to settle down for a reasonable time (approximately six cycles) before making further adjustments. With intermittent extrusion machines, adjust the cooling time until the moulding can be ejected without distortion. Screw start delays and screw speed (rpm) can be adjusted to fill this time.

Changing Conditions and Dimension Verification

Any changes must be well thought out in advance and should be made gradually. As an example, any increase in screw rpm may cause not only an increase in output but also an increase in temperature. Changes must be made one at a time. The machine must be allowed to settle down and the effect of the change noted, otherwise no one would know what is going on. Frequent or incorrect changes in the process can cause time to be lost and large amounts of scrap to be made.

Recording Production Conditions
The object of moulding is to make mouldings (parts) to the required specification (quality) and at the quoted cost. To do this, it is essential to keep accurate records. On many machines, data are recorded by computer. This data should be preserved. Critical parts, such as those for medical applications, have bar codes and the data are stored. When this is not possible, an appropriate record sheet should be completed initially and then periodically updated throughout the run. It is also good practice to keep sample mouldings. Logs of key events - the reasons, and observations are also useful.

Safety in Normal Machine Operation

Once the machine has settled in, controls and heaters should operate between an upper and a lower limit. This allows parts to be successfully made to specification. Most machines have process controls that warn when a condition is moving outside of a limit. The operator should advise the process technician so that the cause can be found quickly, and the problem corrected both to minimize the production of bad parts and to reduce the likelihood of hazardous overheating or excessive melt pressure.

Safety Considerations
Machines that are set to run automatically usually eject the parts onto a conveyor for finishing operations, so that the operator does not have to reach into the press. For some large industrial parts, an automated picker or robot picks the part from the press and delivers it to the finishing operations. Many times, particularly on small runs and when using a semi-automatic press cycle, the operator removes the parts by reaching into the press and removing the part from the mould. Redundant safety switches and devices must be in place and working to prevent the press from inadvertently closing on the operator. In all cases, the operator must wear gloves ('cooled' plastic parts are extremely hot to the touch when ejected), safety glasses, and usually earplugs. In plants with several different types of equipment running, the noise generated could damage hearing if protection is not worn. Entrances into plant areas that require sight, hearing, and sometimes helmet protection are usually marked with signs at the entrance indicating the type of safety protection required before entering the area.

Table 7.1 Safety standards for extrusion blow moulding machines	
Clause	**Safety Caution**
Operator's Gate	Operator's gate, window and mounting hardware to keep the operator away from hazards associated with moving parts and hot parison(s) including electric, hydraulic and pneumatic interlocks.
Power Operated Gates	A. Leading edges mounted with pressure sensitive switches to stop or open the gate. B. Closure of the gate shall not initiate cycle start.
Operator's Gate Electrical Interlock with Monitoring	To prevent all clamp, carriage, calibration or take-out motions when the gate is open.
Operator's Gate Hydraulic and Pneumatic Interlock with Monitoring	To prevent hydraulic or pneumatic powered motions when the gate is open including monitoring and alarm.
Emergency Stop Button	At least one emergency button to be provided near the point of operation.
Reset	Resetting a safety interlock shall not directly initiate a cycle.
Rear Guard	A fixed guard for the moulding area opposite the point of operation.
Top Guard	A fixed guard to prevent reaching over another gate or guard.
Additional Safety Requirement for Large Machines only	Presence sensing device; mechanical latch; double acknowledge system.
Emergency Stop	At least one emergency stop button in a walk-in mould area.
Blow Air Release	Monitoring of blow air to prevent mould opening under full blow pressure.
Part Discharge Opening	Guarding required near conveyor openings.
Windows to Moulding Area	All windows to conform to ANSI Z97.1 [2].
Guards	Fixed guards (or movable guards with interlocks) at all other hazardous points.
Guarded Feed Throat Opening	Guarding where access to the rotating feed screw is a hazard.
Extruder Barrel Covers	Cover or barrier to prevent inadvertent contact with high voltage or high temperature.
Window	All windows to conform ANSI Z97.1 [2].
Safety Signs	Safety sign kit to current standard.

Table 7.2 Health and Safety Executive (HSE)

Hazard	Safeguard
Dangerous moving parts in the mould area	Guards interlocking with the drive(s) (pneumatic, hydraulic or electrical) for the dangerous parts and sufficient fixed guards to complete the enclosure. The interlocking system should be dual channel and both channels should be monitored to prevent any further dangerous movement if a fault is detected.
Other dangerous moving parts	If not protected by the guard systems specified for the mould area, use: □ Fixed guards; or □ Distance guards positioned to take account of safety distances to prevent the operator reaching the danger zone; or □ Single-channel interlocked guards, monitored to prevent any further dangerous movement if a fault is detected. And for large machines a monitored, person sensing safety device should be installed, for example: □ A pressure-sensitive mat which extends between the mould; or □ An electro-sensitive device; or □ A mechanical latch which prevents involuntary guard closure and which can only be released from outside the mould area. Having triggered such a device, it should be necessary to do one of the following before initiating another cycle: □ Reset the safety devices □ Close the guards; and □ Actuate an enabling device to confirm the danger area is clear. Reset and enabling device actuation positions should provide a clear view of the danger areas. It should not be possible to actuate the enabling device from the danger area. Accessible emergency stops should be fitted on both sides of the mould. On large rotary machines they should be placed at intervals of 2 m or less inside the danger area.
Dangerous moving parts which can be reached through the delivery aperture	If not protected by the guarding systems specified for the mould area, use □ Fixed guards; or □ Distance guards positioned to take account of safety distances to prevent the operator reaching the danger zone; or □ Interlocked product delivery systems, monitored to prevent any further dangerous movement if a fault is detected. Such product delivery systems would include: – Single-channel interlocked guards, consisting of outward opening doors which are activated to let articles out but otherwise act as an interlocked guard; or – Two electro-sensitive sensing units arranged so they let articles out but prevent access; or – Other equally effective means, for example, pressure-sensitive mats built into the delivery system or scanning devices.
Power-operated guards	Either: □ Sensitive edges (fitted on both sides of the guard) which arrests or reverses guard closure; or □ A reduced-pressure closing system.

Shutting Down

A great deal of money can be saved by using the proper shutdown procedures. For example, if the material could be prevented from degrading or burning, a large amount of purging could be eliminated. Additional money would be saved if a complete machine shut down and cleanout were unnecessary, and start-up would certainly be easier.

Temporary Stops

It is a good idea during a temporary stop to periodically purge the cylinder or barrel by passing material through the machine and/or making air shots. If the plastic material starts to look a bit discoloured, increase the frequency of purging. When a minor machine repair is required, set the heaters on the plasticising cylinder to low values (about 150 °C) to minimise thermal degradation.

Overnight Stops

For overnight stops with thermally stable plastics such as polyethylene (PE) at blow moulding temperatures, close the gate at the base of the feed hopper and turn off the barrel heaters. With the nozzle/die heat on, purge the barrel clean by pumping the screw dry. As soon as nothing more comes from the die/nozzle, stop the screw drive and set the barrel cooling (if equipped) to maximum. When the machine is cool, shut everything off.

High Temperature Work

When extrusion blow moulding at very high temperatures (with a material that does not melt until 265 °C) oxidation and material removal can be a problem. Depending on the material type, it may be purged with a ‘wet' high-density polyethylene (HDPE) (approximately 2% of water is added to the HDPE before use). The water reduces the viscosity. In condensation polymers such as polyamide and polycarbonate (PC), the water further reduces the viscosity because it causes depolymerization. Water also acts as a lubricant with polyamide. To purge, shut the gate at the base of the feed hopper and run the machine until it is free of high temperature material. With an accumulator extrusion blow moulding machine, open the die gap and keep the machine and cylinder temperatures at a high value (270 °C); run ‘wet' HDPE through the system and fi ll the accumulator. The melt will foam and there will be crackling and spitting noises. Keep purging, reduce temperatures to 215 °C, and open the die gap fully. Introduce dry HDPE and then purge the barrel clean by pumping the screw dry. Turn off the heaters when no more material comes through the die, set barrel cooling to the maximum, and then when machine is cool, turn everything off. Note: a 7 kg accumulator machine may require 90 kg of ‘wet' HDPE and 45 kg of dry HDPE to properly purge out a high temperature resin.

Heat-Sensitive Materials

A major problem with heat-sensitive materials is decomposition (‘burning') of the plastic in the machine. The results may be discoloration and rejection of the moulded part. When decomposition occurs, a complete shutdown is usually necessary, although it may be possible to purge the heat sensitive material with another, more heat stable material to clean the machine of contaminated resin.

Purge Materials

Purge compounds are materials used to clean the cylinder (barrel), and may be purchased for this purpose. Instead of a commercial purge compound, a resin such as LDPE may also be introduced into the barrel to push out a thermally unstable material such as polyvinylchloride (PVC). Many purge materials do not melt, or flow as ordinary resins do, so to prevent blockage it is advisable to remove the die assembly before purging. The die should be thoroughly cleaned. Once the purge compound has come through, the shutdown procedure should be followed.

When PE is used as a purge, it may be stored in a small hopper alongside the main hopper, from which it can be introduced rapidly into the machine by a power-operated valve. When PVC degrades, the rapid introduction of purge material is often necessary. With a stoppage of more than 0.5 of an hour when running PVC, the barrel should be purged with PE. Stripping, cleaning and purging should be done when re-starting a PVC run after a power failure or some other unplanned shutdown.

Shutting Down an Injection Blow Moulding Machine

For injection blow moulding machines, retract the barrel away from the parison meld’s sprue bushing. Run the screw dry by allowing the screw to turn just until no more melt exits the nozzle. Do not allow the screw to continue turning, because it may cause unnecessary and possibly damaging wear to the screw and barrel. Follow with a small amount of purge material, the type of which will depend on the type of material that had just been run. In the case of PE, purging is not usually necessary. It is generally safe to simply leave the screw in the forward position and turn off the barrel heats. Other materials may require different purging materials and procedures. For glycol-modified polyethylene terephthalate (PETG) (a material used to make soda bottles and many other types of beverage bottles), polystyrene (PS), low melt index HDPE, or cast acrylic are the typical purging materials. PC are generally purged with a low melt index HDPE or a cast acrylic resin. Polyetherimide resins, which are moulded at very high temperatures (in the 370-400 °C range), are purged in either a one-step or a two-step process. In the one-step process, extrusion grade HDPE (with a low melt index, in the range of 0.3 to 0.35 g/10 min) is run through the machine after as much of the resin as possible has been pumped out. The barrel temperatures are reset to the normal melt processing range for HDPE once the HDPE begins to exit the barrel. HPDE is run through the machine until the purge exiting the nozzle is clear and clean. The screw is left in its forward position inside the barrel, the heaters are turned off, and the machine is shut down. In the two-step process, a material that is intermediate in melt temperature between the high temperature material and the lower melt temperature purge material is used. For example, a PC, which normally processes in the 293 to 310 °C range may serve as an intermediate temperature material that is used for an initial purge. Once the PC begins to exit the nozzle, the barrel temperatures can be reduced to that for moulding PC. The next step is to purge the PC; either with a low melt index HDPE or a cast acrylic resin. Acrylics and PS should not be used as purge materials for resins that are processed at high temperatures, that is, at temperatures above 310 °C. Chemical purging compounds which are designed to work with certain families of materials are often used, usually in conjunction with a plastic purge material. Always check with your supervisor or team leader for the material manufacturer's recommendations regarding purging materials and the safe procedures for their use. Note: When purging materials from the injection barrel, always wear a full face safety purge shield, always move the barrel (injection carriage) to a rearward position, never inject or purge through an open mould, and always make sure the purge safety guard is functioning and closed to avoid a serious burn accident.

Tables 8.1, 8.2 and 8.3 show some causes and effects of problems with finished containers, forming, and parisons.

Table 8.1 Finished container

Observation	Action: Machine ***Running***	Action: Machine ***Stopped***
1. Rough surface	Check for moisture or condensation in the mould, blast with air hose and raise coolant temperature.	Additional mould venting.
2. Excessive shrinkage	Increase blow cycle. Lower melt temperature.	Check die-mandrel concentricity.
3. Warpage	Check mould cooling. Increase blow cycle. Lower melt temperature.	Same as 2
4. Weld-line breaks	Same as 3	Same as 2 Increase pinch-off areas.
5. Thin wall at parting line	Increase mould clamp pressure.	Inspect mould alignment. Inspect mould venting.

Table 8.2 Forming

Observation	Action: Machine ***Running***	Action: Machine ***Stopped***
1. Parison blow out	Lower melt temperature. Reduce blow pressure.	Check mould for 'hot spots'. Check parison alignment. Check for contamination inside tooling.
2. Container sticking	Lower melt temperature. Lower mould coolant temperature.	Check mould design.

Table 8.3 Parison

Observation	Action: Machine ***Running***	Action: Machine ***Stopped***
1. Excessive stretch	Lower melt temperature. Lower die temperature. Increase extrusion rate.	
2. Rough surface	Reduce extrusion rate. Raise temperature.	Clean die tip. Clean tooling. Change tooling.
3. Uneven parison	Reduce extrusion rate.	Align die and mandrel. Inspect for contamination. Inspect for heater band outage.
4. Fisheyes (bubbles)	Lower melt temperature. Lower feed section temperature.	Check resin for moisture and for contamination.
5. Streaks	Raise extrusion back pressure.	Inspect tooling for contamination or damage. Check tooling design.
6. Curl	Increase extrusion rate.	Check tooling temperature profile. Check tooling alignment.
7. Wrinkles	Lower melt temperature.	Check tooling temperature profile. Check tooling alignment.

Safe and Efficient Set-up, Start-up, Operation, Shutdown Procedures and Safety

Note: these procedures represent good practice. In an actual production environment, always follow the procedures for that particular plant.

Start-up

During the start-up of a blow moulding machine, precautions should be taken, for example: no one must stand in front of the die or nozzle and that the hopper should be firmly in place so the screw cannot be accessed. Start-up is the most hazardous time in the process because material left in the barrel from the last run can overheat and degrade, spewing hot gases and degraded plastic from the nozzle or die at high pressure. Another potential hazard is that many steps must be taken, and often quickly.

Start-Up Preparations

An understanding of the settings is needed before starting up a blow moulding machine. Obtain advice from someone who is very familiar with the equipment, or better yet, consult the written procedures. A general procedure is:

- Turn on the main power switches and then select or set the temperatures.
- Ensure that the cooling water is on and check to see that it is flowing through the feed throat.
- Preheat the hydraulic oil to its correct operating temperature. This may be done either by pumping the oil back into the tank or by using a preheater fitted for this purpose.

Once the machine has reached the required temperature, it should be allowed to settle down before any material is introduced into the barrel. The settling-in (equilibration) time, sometimes called ‘soak’ time, is the time needed for the barrel, screw, breaker plate, and die or mould temperatures to stabilize close to the temperature set points. The equilibration or soak time will depend on the size and type of machine. It may take 20 minutes for a small machine and it may take several hours for a larger machine. This time should be used to prepare for the production run. Other start-up steps include:

- Check the nozzle/die and molds to see if they are clean and operational.
- Review the production order for colour, quantity, and other requirements.
- Check for necessary tools and equipment and be sure they are in place and working properly.
- Make sure that all auxiliary equipment is clean and operational, to include hopper loaders, conveyors, grinders, vacuum pumps, and leak testers.

Melt Temperature

Two methods are commonly used to measure melt temperature in a blow moulding machine:

• Extrusion or injection of the material onto a suitable surface, then measuring the temperature of the plastic mass with a thermocouple probe.

• Direct reading by a thermocouple that is placed in the barrel and is in direct contact with the melt.

When the temperature of the melt is measured with a probe, care should be taken during the measurement to ensure that the purging of hot plastic does not cause an accident. As has been mentioned previously, molten material will cause serious burns because it is very hot, and it adheres to the skin and is very difficult to remove. Burns are a common injury in moulding operations, so long sleeves, gloves and face shields should be worn when handling hot material or where there is danger of being splashed with hot plastic melt, particularly during start-up or purging. As with other situations requiring personal protective equipment, the plant's requirements must be followed.

Warming up an Empty Machine

The machine's warm-up cycle should be programmed so that thermal overshoot does not occur, and heating times are kept reasonably short. Once the machine is at the set temperature, it should be allowed to equilibrate ('heat soak') before material is introduced into the barrel. It is advisable to keep this time as short as possible so that any resin left in the barrel after purging does not degrade. Check the machine for correct temperatures by briefly rotating (jogging or 'inching') the screw. If the screw requires excessively high motor currents or will not rotate, then allow the machine to equilibrate further. The set-up sheets should show the normal heat soak time. Before starting the machine, be sure that the set conditions are satisfactory by purging a few pounds of resin out of the die (or nozzle) at slow screw speeds. Check the melt temperature with a melt probe and also check the general appearance of the melt. It should be smooth and free of dark specks, streaks, bubbles, or other signs of degradation. If no material is delivered when the screw is turned, check to see that plastic feed is available to the screw, check for faulty heater bands, and find out if the feed has 'bridged' (stuck together) in the hopper. Checking for bridging or material blockage in the machine feed throat requires caution and the immediate attention and expertise of trained personnel wearing the appropriate safety equipment.

This is because of the potential for serious personal injury from the hot gases and degraded and overheated plastic that may spray violently back through the hopper.

Warming up a Full Machine

When material is in the barrel or die head, the machine is said to be full. A full, cold machine might result when there is a power failure or when the machine is deliberately shut down because of deterioration of the material by oxidation or depolymerization. The machine must be heated in a safe way because decomposition produces gases under pressure and can cause serious accidents. To warm a cold machine, set all temperatures just below the melting temperatures of the material, for example, at 135 ºC for low-density polyethylene (LDPE). Allow the machine to reach and equilibrate at these temperatures, and then raise the temperature of the die (nozzle) to the process set point. To reduce the potential for dangerous pressure build-up in the barrel, wait for a period of time to allow the plastic in the die or nozzle to melt, and then raise the other barrel temperatures to the set point. Allow the machine to equilibrate to these temperatures before beginning to purge.

Initial Operation and Purging

When the machine is fully up to temperature, put a small amount of material in the hopper, make sure the hopper lid is in position and the hopper gate is open, and start the screw at 10-15 rpm. Do not allow the screw to turn in an empty machine, because this can damage the barrel and screw. Check to see that the set process conditions are correct by running for a minute or so on an extruder or by running a few purge cycles on an injection machine. A machine with a grooved barrel may require careful hand feeding of material by trained personnel, because it is easy to over-feed the machine.

After a short period of operation, check the melt temperature with a melt probe, and also the general appearance of the melt. Dispose of the hot, sticky plastic melt in a safe way once being satisfied that the material is feeding well, and the melt looks satisfactory. On an extruder, also check the drive motor current. It should be with the normal start-up range. If it is too high, there is probably unmelted material in the barrel. If it is too low, there may be feeding problems. On an injection moulding machine, material should fl ow freely from the nozzle. If it doesn't, the nozzle may be blocked by unmelted plastic. Do not attempt to clear a blockage by turning the screw or injecting under high pressure. If all is well, fi ll the hopper to the normal level for running. Check to see that the monitoring equipment is working, and in extrusion blow moulding, when material starts to extrude from the die, turn on the screw cooling if it is required.

Commencing Moulding – Manual Operation

When purging is complete and satisfactory melt is being produced, moulding may begin. The moulding process usually begins with manual operation, in which the operator initiates each part of the moulding cycle by pushing buttons according to the operation sequence. When the mould is closed, clamping pressure should be checked. To begin extrusion blow moulding, produce a parison and check its temperature and appearance. The parison must be long enough to reach the bottom of the mould for pinch-off. Start moulding and adjust conditions and settings as needed to obtain a satisfactory part. Increase screw rpm gradually until it reaches the normal operating speed, while constantly checking the parts. A periodic check should be made to ensure that the hopper has enough material and that the melt is not leaking or weeping from around the nozzle/die/adaptor areas. Product quality should be closely watched to see that parts are free from froth or unmelted resin particles, and when the cycle is stable and the parts are good, production can begin.

Note: If for some reason a different material was used for purging, it must be removed from the barrel according to procedures required by the material manufacturer, before moulding begins.

Commencing Moulding – Automatic Operation

Automatic operation is only started after satisfactory melt is made, after the purging procedure, and after the machine settings have been established based on experience or process records, or as determined from the manual operating conditions if this is a new product. Commence moulding on an automatic, or semi-automatic cycle (in which the operator opens and closes the safety gate to start the cycle) using pre-determined cycle times. These may be calculated, based on experience, or determined from the manual operating conditions. Gradually adjust conditions until product of the required quality is obtained at an optimum rate. After each adjustment, allow the machine to settle down for a reasonable time (approximately six cycles) before making further adjustments. With intermittent extrusion machines, adjust the cooling time until the moulding can be ejected without distortion. Screw start delays and screw speed (rpm) can be adjusted to fill this time.

Changing Conditions and Dimension Verification

Any changes must be well thought out in advance and should be made gradually. As an example, any increase in screw rpm may cause not only an increase in output but also an increase in temperature. Changes must be made one at a time. The machine must be allowed to settle down and the effect of the change noted, otherwise no one would know what is going on. Frequent or incorrect changes in the process can cause time to be lost and large amounts of scrap to be made.

Recording Production Conditions

The object of moulding is to make mouldings (parts) to the required specification (quality) and at the quoted cost. To do this, it is essential to keep accurate records. On many machines, data are recorded by computer. This data should be preserved. Critical parts, such as those for medical applications, have bar codes and the data are stored. When this is not possible, an appropriate record sheet should be completed initially and then periodically updated throughout the run. It is also good practice to keep sample mouldings. Logs of key events - the reasons, and observations are also useful.

Safety in Normal Machine Operation

Operation

Once the machine has settled in, controls and heaters should operate between an upper and a lower limit. This allows parts to be successfully made to specification. Most machines have process controls that warn when a condition is moving outside of a limit. The operator should advise the process technician so that the cause can be found quickly, and the problem corrected both to minimize the production of bad parts and to reduce the likelihood of hazardous overheating or excessive melt pressure.

Safety Considerations

Machines that are set to run automatically usually eject the parts onto a conveyor for finishing operations, so that the operator does not have to reach into the press. For some large industrial parts, an automated picker or robot picks the part from the press and delivers it to the finishing operations. Many times, particularly on small runs and when using a semi-automatic press cycle, the operator removes the parts by reaching into the press and removing the part from the mould. Redundant safety switches and devices must be in place and working to prevent the press from inadvertently closing on the operator.

In all cases, the operator must wear gloves (‘cooled’ plastic parts are extremely hot to the touch when ejected), safety glasses, and usually earplugs. In plants with several different types of equipment running, the noise generated could damage hearing if protection is not worn.

Entrances into plant areas that require sight, hearing, and sometimes helmet protection are usually marked with signs at the entrance indicating the type of safety protection required before entering the area.

In September 2000, the American National Standards Institute (ANSI) issued a new safety standard, SPI B151.15 [1], on extrusion blow moulding machines operating in the US. The clauses in Table 7.1 are from this specification. In the UK, safety at blow moulding machines is addressed in the Plastic Processing Sheets No.3 and 5 [3, 4], published by Health and Safety Executive (HSE) in consultation with the Plastic Processor's Health and Safety Liaison Committee.

The standards outlined in Table 7.2 describe commonly accepted and practicable safeguards for the significant hazards on blow moulding machines supplied before February 1996. On 15 February 1996 the European Standard BS EN 422:1996 [5] was published and came into effect for new blow moulding machines.

Table 7.1 Safety standards for extrusion blow moulding machines	
Clause	**Safety Caution**
Operator's Gate	Operator's gate, window and mounting hardware to keep the operator away from hazards associated with moving parts and hot parison(s) including electric, hydraulic and pneumatic interlocks.
Power Operated Gates	A. Leading edges mounted with pressure sensitive switches to stop or open the gate. B. Closure of the gate shall not initiate cycle start.
Operator's Gate Electrical Interlock with Monitoring	To prevent all clamp, carriage, calibration or take-out motions when the gate is open.
Operator's Gate Hydraulic and Pneumatic Interlock with Monitoring	To prevent hydraulic or pneumatic powered motions when the gate is open including monitoring and alarm.
Emergency Stop Button	At least one emergency button to be provided near the point of operation.
Reset	Resetting a safety interlock shall not directly initiate a cycle.
Rear Guard	A fixed guard for the moulding area opposite the point of operation.
Top Guard	A fixed guard to prevent reaching over another gate or guard.
Additional Safety Requirement for Large Machines only	Presence sensing device; mechanical latch; double acknowledge system.
Emergency Stop	At least one emergency stop button in a walk-in mould area.
Blow Air Release	Monitoring of blow air to prevent mould opening under full blow pressure.
Part Discharge Opening	Guarding required near conveyor openings.
Windows to Moulding Area	All windows to conform to ANSI Z97.1 [2].
Guards	Fixed guards (or movable guards with interlocks) at all other hazardous points.
Guarded Feed Throat Opening	Guarding where access to the rotating feed screw is a hazard.
Extruder Barrel Covers	Cover or barrier to prevent inadvertent contact with high voltage or high temperature.
Window	All windows to conform ANSI Z97.1 [2].
Safety Signs	Safety sign kit to current standard.

Shutting Down

A great deal of money can be saved by using the proper shutdown procedures. For example, if the material could be prevented from degrading or burning, a large amount of purging could be eliminated. Additional money would be saved if a complete machine shut down and cleanout were unnecessary, and start-up would certainly be easier.

Temporary Stops

It is a good idea during a temporary stop to periodically purge the cylinder or barrel by passing material through the machine and/or making air shots. If the plastic material starts to look a bit discolored, increase the frequency of purging. When a minor machine repair is required, set the heaters on the plasticizing cylinder to low values (about 150 °C) to minimize thermal degradation.

Overnight Stops

For overnight stops with thermally stable plastics such as polyethylene (PE) at blow moulding temperatures, close the gate at the base of the feed hopper and turn off the barrel heaters. With the nozzle/die heat on, purge the barrel clean by pumping the screw dry. As soon as nothing more comes from the die/nozzle, stop the screw drive and set the barrel cooling (if equipped) to maximum. When the machine is cool, shut everything off.

Table 7.2 Health and Safety Executive (HSE)	
Hazard	**Safeguard**
Dangerous moving parts in the mould area	Guards interlocking with the drive(s) (pneumatic, hydraulic or electrical) for the dangerous parts and sufficient fixed guards to complete the enclosure. The interlocking system should be dual channel and both channels should be monitored to prevent any further dangerous movement if a fault is detected.
Other dangerous moving parts	If not protected by the guard systems specified for the mould area, use: □ Fixed guards; or □ Distance guards positioned to take account of safety distances to prevent the operator reaching the danger zone; or □ Single-channel interlocked guards, monitored to prevent any further dangerous movement if a fault is detected. And for large machines a monitored, person sensing safety device should be installed, for example: □ A pressure-sensitive mat which extends between the mould; or □ An electro-sensitive device; or □ A mechanical latch which prevents involuntary guard closure and which can only be released from outside the mould area. Having triggered such a device, it should be necessary to do one of the following before initiating another cycle: □ Reset the safety devices □ Close the guards; and □ Actuate an enabling device to confirm the danger area is clear. Reset and enabling device actuation positions should provide a clear view of the danger areas. It should not be possible to actuate the enabling device from the danger area. Accessible emergency stops should be fitted on both sides of the mould. On large rotary machines they should be placed at intervals of 2 m or less inside the danger area.
Dangerous moving parts which can be reached through the delivery aperture	If not protected by the guarding systems specified for the mould area, use □ Fixed guards; or □ Distance guards positioned to take account of safety distances to prevent the operator reaching the danger zone; or □ Interlocked product delivery systems, monitored to prevent any further dangerous movement if a fault is detected. Such product delivery systems would include: – Single-channel interlocked guards, consisting of outward opening doors which are activated to let articles out but otherwise act as an interlocked guard; or – Two electro-sensitive sensing units arranged so they let articles out but prevent access; or – Other equally effective means, for example, pressure-sensitive mats built into the delivery system or scanning devices.
Power-operated guards	Either: □ Sensitive edges (fitted on both sides of the guard) which arrests or reverses guard closure; or □ A reduced-pressure closing system.

High Temperature Work

When extrusion blow moulding at very high temperatures (with a material that does not melt until 265 °C) oxidation and material removal can be a problem. Depending on the material type, it may be purged with a 'wet' high-density polyethylene (HDPE) (approximately 2% of water is added to the HDPE before use). The water reduces the viscosity. In condensation polymers such as polyamide and polycarbonate (PC), the water further reduces the viscosity because it causes depolymerization. Water also acts as a lubricant with polyamide. To purge, shut the gate at the base of the feed hopper and run the machine until it is free of high temperature material. With an accumulator extrusion blow moulding machine, open the die gap and keep the machine and cylinder temperatures at a high value (270 °C); run 'wet' HDPE through the system and fi ll the accumulator. The melt will foam and there will be crackling and spitting noises. Keep purging, reduce temperatures to 215 °C, and open the die gap fully. Introduce dry HDPE and then purge the barrel clean by pumping the screw dry. Turn off the heaters when no more material comes through the die, set barrel cooling to the maximum, and then when machine is cool, turn everything off. Note: a 7 kg accumulator machine may require 90 kg of 'wet' HDPE and 45 kg of dry HDPE to properly purge out a high temperature resin.

Heat-Sensitive Materials

A major problem with heat-sensitive materials is decomposition ('burning') of the plastic in the machine. The results may be discoloration and rejection of the moulded part. When decomposition occurs, a complete shutdown is usually necessary, although it may be possible to purge the heat sensitive material with another, more heat stable material to clean the machine of contaminated resin.

Purge Materials

Purge compounds are materials used to clean the cylinder (barrel) and may be purchased for this purpose. Instead of a commercial purge compound, a resin such as LDPE may also be introduced into the barrel to push out a thermally unstable material such as polyvinylchloride (PVC). Many purge materials do not melt or fl ow as ordinary resins do, so to prevent blockage it is advisable to remove the die assembly before purging. The die should be thoroughly cleaned. Once the purge compound has come through, the shutdown procedure should be followed. When PE is used as a purge, it may be stored in a small hopper alongside the main hopper, from which it can be introduced rapidly into the machine by a power-operated valve. When PVC degrades, the rapid introduction of purge material is often necessary. With a stoppage of more than 0.5 of an hour when running PVC, the barrel should be purged with PE. Stripping, cleaning and purging should be done when re-starting a PVC run after a power failure or some other unplanned shutdown.

Shutting Down an Injection Blow Moulding Machine

For injection blow moulding machines, retract the barrel away from the parison meld's sprue bushing. Run the screw dry by allowing the screw to turn just until no more melt exits the nozzle. Do not allow the screw to continue turning, because it may cause unnecessary and possibly damaging wear to the screw and barrel. Follow with a small amount of purge material, the type of which will depend on the type of material that had just been run. In the case of PE, purging is not usually necessary. It is generally safe to simply leave the screw in the forward position and turn off the barrel heats. Other materials may require different purging materials and procedures. For glycol-modified polyethylene terephthalate (PETG) (a material used to make soda bottles and many other types of beverage bottles), polystyrene (PS), low melt index HDPE, or cast acrylic are the typical purging materials. PC are generally purged with a low melt index HDPE or a cast acrylic resin. Polyetherimide resins, which are moulded at very high temperatures (in the 370-400 °C range), are purged in either a one-step or a two-step process. In the one-step process, extrusion grade HDPE (with a low melt index, in the range of 0.3 to 0.35 g/10 min) is run through the machine after as much of the resin as possible has been pumped out. The barrel temperatures are reset to the normal melt processing range for HDPE once the HDPE begins to exit the barrel. HPDE is run through the machine until the purge exiting the nozzle is clear and clean. The screw is left in its forward position inside the barrel, the heaters are turned off, and the machine is shut down. In the two-step process, a material that is intermediate in melt temperature between the high temperature material and the lower melt temperature purge material is used. For example, a PC, which normally processes in the 293 to 310 °C range may serve as an intermediate temperature material that is used for an initial purge. Once the PC begins to exit the nozzle, the barrel temperatures can be reduced to that for moulding PC. The next step is to purge the PC; either with a low melt index HDPE or a cast acrylic resin. Acrylics and PS should not be used as purge materials for resins that are processed at high temperatures, that is, at temperatures above 310 °C.

Chemical purging compounds which are designed to work with certain families of materials are often used, usually in conjunction with a plastic purge material. Always check with your supervisor or team leader for the material manufacturer's recommendations regarding purging materials and the safe procedures for their use. Note: When purging materials from the injection barrel, always wear a full-face safety purge shield, always move the barrel (injection carriage) to a rearward position, never inject or purge through an open mould, and always make sure the purge safety guard is functioning and closed to avoid a serious burn accident.

Check Recommendations

It is important to fully understand the correct procedures before a machine is started or shut down, or before a resin change. Material suppliers issue process brochures and material data sheets with specifications and a great deal of other information. These should be studied and used to develop plant procedures for each material, particularly for high temperature materials and those that are extremely heat sensitive or thermally unstable.

Importance of using PPEs

PPE is equipment that will protect workers against health or safety risks on the job. The purpose is to reduce employee exposure to hazards when engineering and administrative controls are not feasible or effective to reduce these risks to acceptable levels.

PPEs:

Name & Usage	Picture of PPE	Name & Usage	Picture of PPE
Safety goggles – used to protect eyes from flying particles (chips, sparks etc.)		Safety shoes – used to protect feet from spatters of welding and impact of other falling objects	
Face shield - used to protect face from welding sparks, radiations, arc and spatters		Face mask – used to protect from inhaling fumes, dangerous gases etc.	
Hard cap – used to protect the head from injury due to falling objects		Leather Apron – used to protect welder's body from welding spark and spatters	
Leather gloves – used to protect hands during welding		Cotton gloves – used to protect hands from sharp edges of sheets and plates	

Importance of housekeeping and safe storage of tools and equipment

The main function of housekeeping is to ensure cleanliness, comfort, convenience, privacy, health and hygiene in a safe environment. It includes keeping work areas neat and orderly. All the tools and equipment must be stored properly.

PLASTIC PROCESSOR

Module-9

Learner Guide

National Vocational Certificate Level 3

Version 1 - September, 2018

Importance of making a check list

It ensures you get your daily, weekly and monthly tasks done on time, helps you keep track of projects on deadline and ensures you're organized throughout the day.

Video Links:

What Is blow molding process?? Applications, Types, Advantages & Disadvantages: https://www.youtube.com/watch?v=H04DIgWN3kQ

Extrusion Blow Molding - Lesson 3 - Extrusion Blow Molding Operating Controls: https://www.youtube.com/watch?v=YWzaZYHXS9s

Blow molding – IIT Roorkee: https://www.youtube.com/watch?v=LHquzUSOX0E

Module 9: 072200917 Operate Compression Moulding Machine

Objective of the module: The aim of this module to provide skills and knowledge to operate compression moulding machine in accordance with the manufacturer's manual

Duration: 175 hours **Theory:** 35 hours **Practical:** 140 hours

Learning Unit	Learning Outcomes	Learning Elements	Duration	Materials Required	Learning Place
LU1: Adjust parameters of machine	**The trainee will be able to:** Check raw material to set machine operation Turn on machine as per instruction manual and procedure set by organization Feed parameters as per job/ data sheet.	i) Identify production cycle from feeding to de-molding of product ii) Understand the materials used for moulding iii) Difference between types of heaters, thermocouples & controllers for mould iii) Machine controls • Learn to input processing parameters in the machine and peripheral components	**Total** 40 hours **Theory:** 08 hours **Practical:** 32 hours	Compression mounding machine & mould Weighing scale Plastic raw material Product samples Machine manual Job card	Classroom with multimedia aid and flip charts **EITHER** Visit to Plastic Processing Facilities **OR** Visit to a training institute with relevant facilities

	Verify all pre-start parameters as per job card / data sheet	iv) Ensure working of peripheral equipments such as air compressors, chillers, vacuum pump, printer, dryer, etc. v) Moulding cycle from feeding to ejection • Set processing parameters as per job card • Ensure desired temperatures are achieved • Ensure raw material is ready for processing (De-humidified, etc.) • Ensure all peripheral equipments are working properly (oil pump, air filter, hydraulics, motors, pneumatics, etc.) vi) Recognize screw configurations • Check shot size and speed vii) Check injection pressure and other parameters			
LU2: Perform dry run	**The trainee will be able to:** Ensure Mould opening & closing position	i) Knowledge and understanding of mould and it's mechanism	**Total** 35 hours **Theory:** 08 hours	Compression mounding machine & mould Product samples	Classroom with multimedia aid and flip charts **EITHER**

	Ensure proper functioning of ejector mechanism of the Mould Verify safety of Mould as per SOP.	ii) Understanding of hydraulic and pneumatic systems iii) Manual operation of compression moulding machine iv) Ensure functionality of clamping mechanism v) Identify and set up part ejection in the mould	**Practical:** 28 hours	Machine manual Job card	Visit to Plastic Processing Facilities **OR** Visit to a training institute with relevant facilities
LU3: Perform semi-auto operation	**The trainee will be able to:** Lubricate the Mould and feed plastic as per standard volume and component Start heating of Mould as per data sheet Feed material dose as per data sheet Clamp the Mould as per instruction manual and procedure by organizational standard Wait for the melting of raw material Wait for the cooling cycle before ejection	i) Recognize machine controls ii) Learn to adjust temperatures from feed zone to injection point iii) Learn to adjust injection pressure iv) Perform Semi-auto operation v) Check for day-light opening	**Total** 30 hours **Theory:** 06 hours **Practical:** 24 hours	Compression mounding machine & mould Product samples Machine manual Job card	Classroom with multimedia aid and flip charts **EITHER** Visit to Plastic Processing Facilities **OR** Visit to a training institute with relevant facilities

LU4: Perform production	**The trainee will be able to:** Start machine on auto cycle mode as per operation manual. Perform periodic quality checks as per requirement.	i) Maintaining product quality as per specifications • Be able to measure components for identification of dimensional defects • Usage of measurement tools is critical: Vernier caliper, micrometer gauge, scale, etc. ii) Recognize different defects and their causes • Be able to visually identify commonly occurring defects, such as flashing, pin-holes, short-shots, etc. • Gain knowledge of rectification of commonly occurring defects.	**Total** 30 hours **Theory:** 06 hours **Practical:** 24 hours	Compression mounding machine & mould Weighing scale Plastic raw material Product samples Machine manual Job card	Classroom with multimedia aid and flip charts **EITHER** Visit to Plastic Processing Facilities **OR** Visit to a training institute with relevant facilities
LU5: Perform follow-up procedure for machine production	**The trainee will be able to:** Ensure product packed in assigned packaging. Check feed level in hopper /bin as per requirement.	i) Knowledge of product packaging • Understand different types of packaging, e.g.; flexible packaging, packing in cartons, etc. • How to pack final product?	**Total** 5 hours **Theory:** 01 hours **Practical:** 08 hours	Compression mounding machine & mould Weighing scale Plastic raw material Product samples Machine manual Job card	Classroom with multimedia aid and flip charts **EITHER** Visit to Plastic Processing Facilities **OR**

	Ensure machine lubrication as per requirement.	ii) Raw material input in moulding machine • Ensure consistent raw material feed into hopper/feeder • Be able to use overhead crane or moveable lifts/ladders • Understand the importance of cutting tools in opening raw material bags. • Concept of 'clean slits' using sharp tools to ensure particles of bag don't get mixed in raw material iii) Lubrication requirements and procedure of machine • Understand the concept of lubricating moveable parts of machines • Carefully use mould lubricant sprays • Ensure spray cans are stored in a secure location after pre-shot application • Be able to identify different mould release agents as per raw material			Visit to a training institute with relevant facilities

		Be able to provide first-hand feedback to maintenance department for periodic machine maintenance			
LU6: Submit production report	**The trainee will be able to:** Record production report as per given format (kg or unit/ hour). Submit report to concerned department	i) Production report writing • Understand the importance of reporting accurate production quantity • Be able to fill-in relevant production reports • Be able to identify waste generated along with identification of machine downtime with reasons ii) Data sharing with relevant departments • Understanding the concept of producing accurate data and benefits of the same on a larger scale • Submission of production reports to production planning department or the supervisor for timely actions.	**Total** 5 hours **Theory:** 01 hours **Practical:** 08 hours	Job card Production report format	Classroom with multimedia aid and flip charts **EITHER** Visit to Plastic Processing Facilities **OR** Visit to a training institute with relevant facilities
LU7: Transport finish product to	**The trainee will be able to:**	i) Understand QC protocols • Understand and appreciate the	**Total** 5 hours	Reporting formats Job card	Classroom with multimedia aid and flip charts

concerned department	Place finished product in designated area. Take approval of finished product from Quality control Deliver relevant packaging documents to store personnel.	importance of producing products as per specification • Be able to implement the first quality control protocol on machine to ensure elimination of defective products at sight ii) Inter-department co-ordination • Be able to co-ordinate with QC department with produced batches for relevant approvals iii) Be able to hand over final products to store	**Theory:** 01 hours **Practical:** 08 hours	Basic Hand Tools Medium of material transport	**EITHER** Visit to Plastic Processing Facilities **OR** Visit to a training institute with relevant facilities

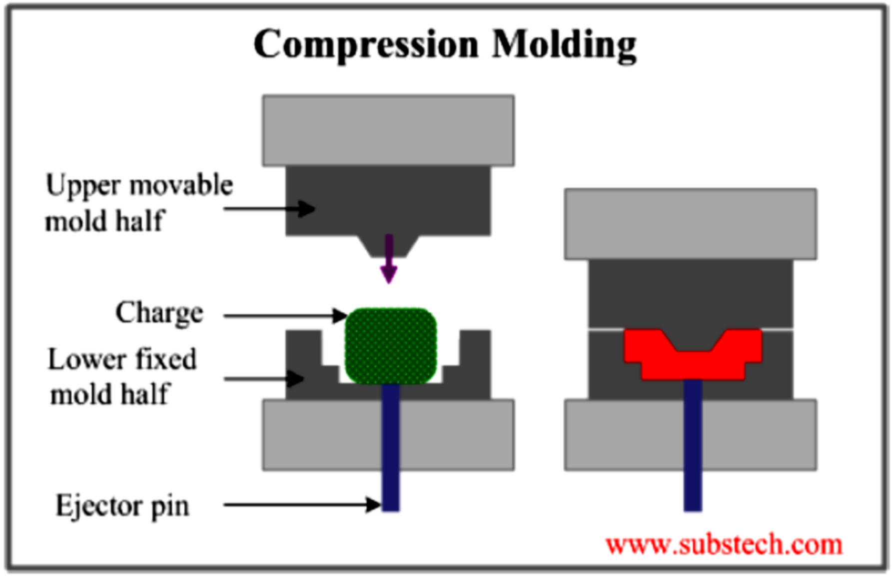
Examples and illustrations:

For further details, please refer to:

1) Handbook of Troubleshooting Plastics Processes by © 2012 Scrivener Publishing LLC, Chapter 18: Compression Moulding
2) Presentation on Compression Moulding, 2008 AMD 2927, IIT Delhi, by Chandra Shekhar Thakur

Introduction:

Compression molding is widely used in the automotive industry to produce parts that are large, thin, lightweight, strong, and stiff. It is also used in the household goods and electrical industries.



Compression molded parts are formed by squeezing a glass fiber reinforced charge inside a mold cavity, as depicted in Fig. 7.25. The matrix can be either a thermoset or thermoplastic. The most common matrix used to manufacture compression molded articles is unsaturated polyester sheet reinforced with glass fibers, known as sheet molding compound (SMC). The 25 mm long reinforcing fibers are randomly oriented in the plane of the sheet and make up for 20−30% of the molding compound's volume fraction. A schematic diagram of an SMC production line is depicted in Fig. 7.26. When producing SMC, the chopped glass fibers are sandwiched between two carrier films previously coated with unsaturated polyester-filler matrix. A fiber reinforced thermoplastic charge is often called a glass mat reinforced thermoplastic (GMT) charge. The most common GMT matrix is polypropylene. During processing of thermoset charges, the SMC blank is cut from a preformed roll and is placed between heated cavity surfaces. Generally, the mold is charged with 1 to 4 layers of SMC, each layer about 3 mm thick, which initially cover about half the mold cavity's surface. During molding, the initially randomly oriented glass fibers orient, leading to anisotropic properties in the finished product. When processing GMT charges, the preforms are cut and heated between radiative heaters. Once heated, they are placed inside a cooled mold that rapidly closes and squeezes the charges before they cool and solidify.

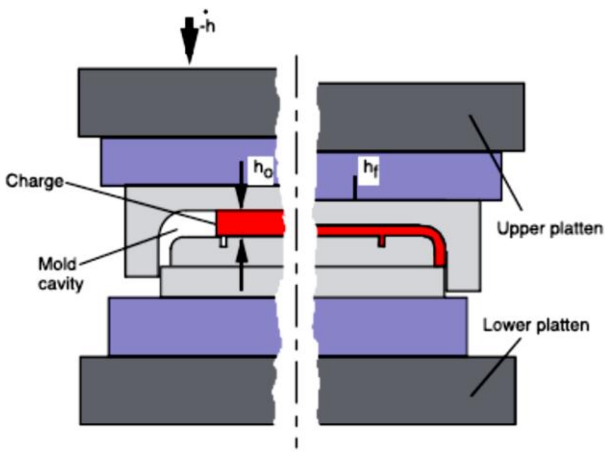


Figure 7.25 Compression molding process (h_0 = charge thickness, h_f = part thickness and $\dot{h}$ = closing speed)

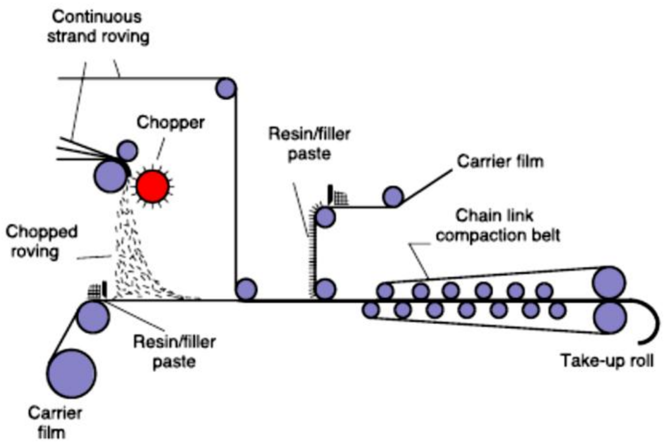


Figure 7.26 SMC production line

One of the main advantages of the compression molding process is the low fiber attrition during processing.Here, relatively long fibers can flow in the melt without the fiber damage commonly seen during plastication and cavity filling in injection molding. An alternate process is injection-compression molding. Here, a charge is injected through a large gate followed by a compression cycle. The material used in the injection compression molding process is called bulk molding compound (BMC), which is reinforced with shorter fibers, generally 10 mm long, with an unsaturated polyester matrix. The main benefit of injection compression molding over compression molding is automation. The combination of injection and compression molding leads to a lower degrees of fiber orientation and fiber attrition compared to injection molding. As in any polymer process, in compression molding there is a direct relationship between deformation and final orientation in the part. Figure 7.27 depicts the fiber orientation distribution within a plate where the initial charge coverage was 33%. Such distribution functions are very common in compression or transfer molding and lead to high degrees of anisotropy throughout a product. To illustrate the effect of fiber orientation on material properties of the final part, Fig. 7.28 shows how the deformation and resulting orientation from 33, 50, 66 and 100% mold coverage affects the stiffness of the plate. Similar to injection molding, there are commercially available codes that can be used to predict mold filling, fiber orientation, and warpage of compression molded parts. To predict fiber orientation in realistic parts, the Folgar–Tucker model has been implemented into commercially available compression mold filling simulation programs. The predicted fiber orientation distribution field for a compression molded automotive fender is shown in Fig. 7.29. To calculate the residual stress development during the manufacturing process and shrinkage and warpage of the finished product, commercially available programs use models where the heat transfer equation is coupled to the stress–strain analysis through constitutive equations. Figure 7.30 compares the mold geometry with the part geometry for the truck fender shown in Fig. 7.29 after mold removal and cooling, computed using numerical models.

High degrees of fiber orientation are common in compression molded parts

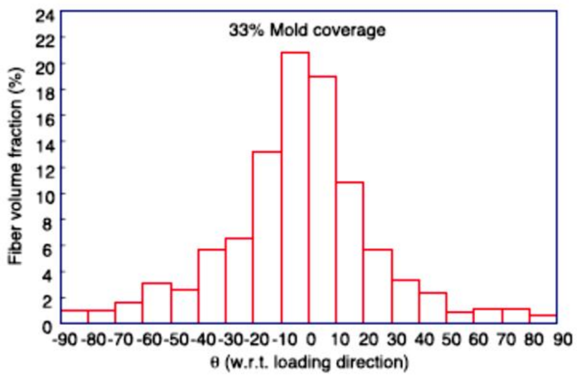


Figure 7.27 Measured fiber orientation distribution histogram in a plate with 33 % initial mold coverage and extensional flow during mold filling

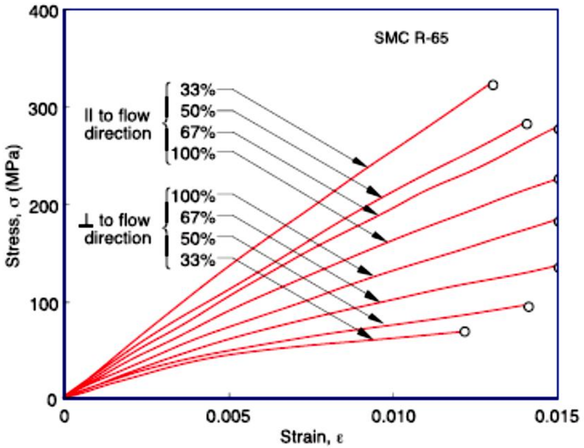


Figure 7.28 Stress–strain curves of 65 % glass by volume SMC for various degrees of deformation

Fiber orientation results in parts with large variations in thermomechanical properties

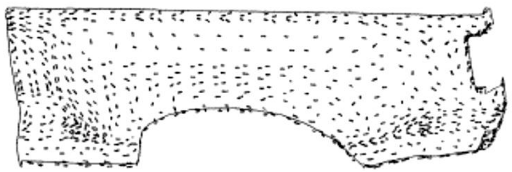
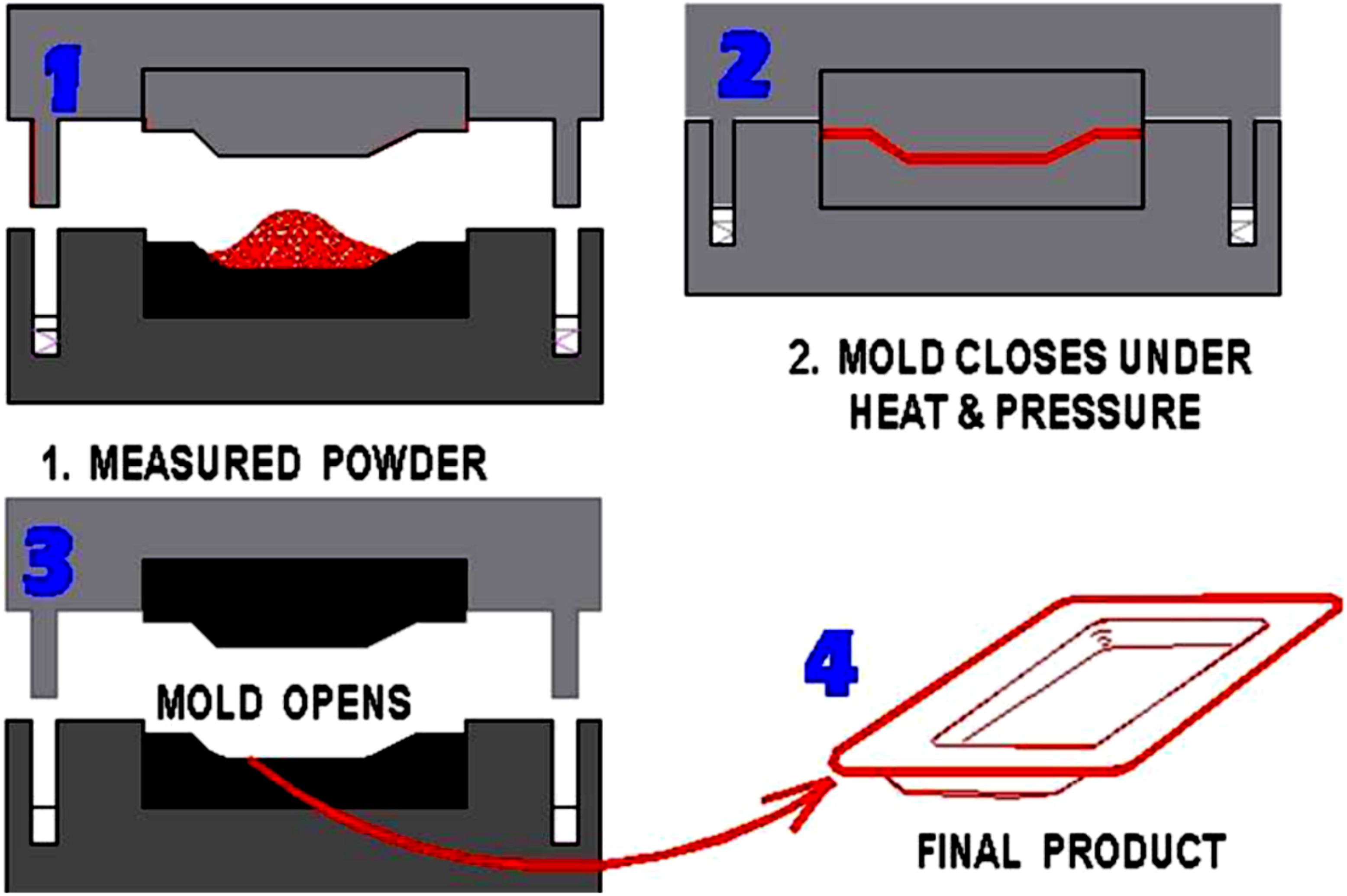


Figure 7.29 Fiber orientation distribution in a compression molded automotive fender

Process Description



Parameters

1. The quantity of charge(molding material)put into the mold

2. Pressure of the molding process:

   • Range of pressure 2000-3000 psi(13.8-20.7 MPa)

3. Mold temperature:

   • Temperature range 300ºF to 375ºF (149^0 C- 191^0 C).

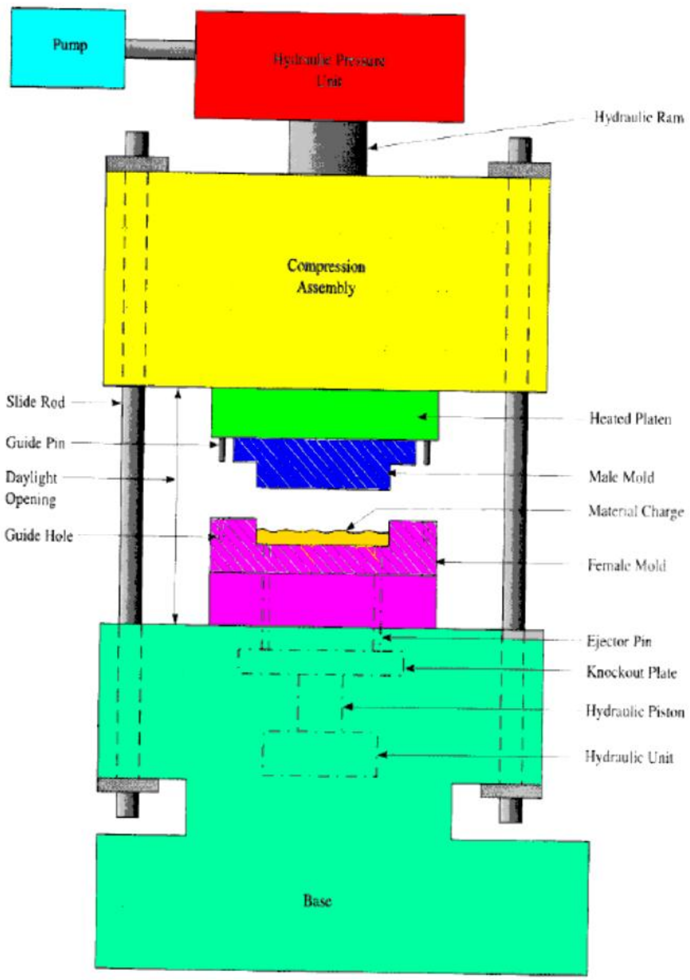
4. Cure time variables:

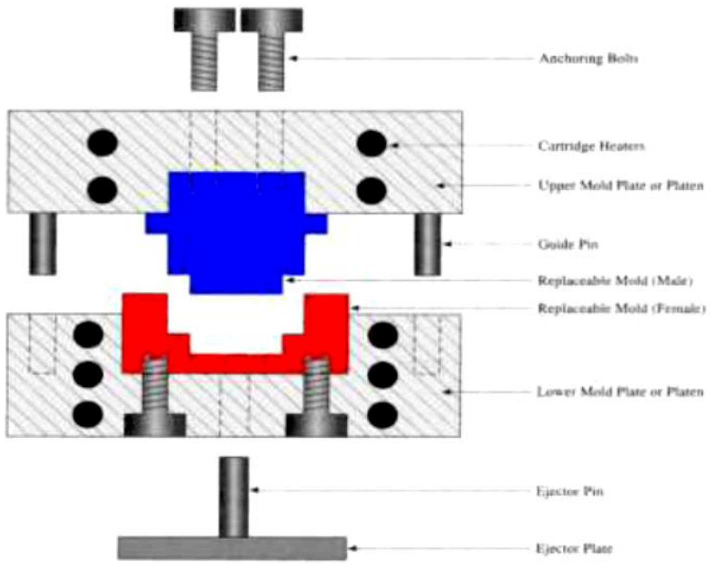
   • The period required to harden thermosetting material to partial and complete polymerization is called cure time.

Advantages

- Lowest cost
- More uniform density
- Uniform shrinkage due to uniform flow
- Improved impact strength due to no degradation of fibers during flow
- Dimensional accuracy
- Internal stress and warping are minimized

Illustration of a Press Mechanism used for Compression Moulding
(Image courtesy http://course1.winona.edu)





Mold

Disadvantages

- Curing time large
- Uneven parting lines present
- Scrap cannot be reprocessed.

Applications & products

- Dinnerware
- Buttons
- Knobs
- Appliance Housings
- Radio Cases
- Automotive exterior panels especially for commercial vehicles
- Ash trays & electrical parts

Materials used in this process

- Thermosetting polymers:
- Fiber reinforced composite
- Thermoplastic:
    - Ultra-High Molecular Weight Polyethylene (UHMWPE)
    - Long Fiber Reinforced Thermoplastics, etc.

For further details, please refer to: Compression Moulding Presentation by Chandra Shekhar Thakur, 2008, AMD 2927

Materials

Each monomer used for compression molding has its own special cure chemistry. Successful materials enhance properties such as heat resistance, impact, tensile strength, etc. In compression molding the selected polymer resin and the glass fibers are premixed with other additives. The premix or prepreg is made initially before compression molding the desired shape. Thermoset and thermoplastic materials have very different processing methods.

Thermoplastics and Compression Molding

Glass fiber matrix thermoplastic (GMT) processing was invented twenty years after sheet molding compound (SMC) was established. Long fiber thermoplastic composites were developed in the 1990s. The main process difference is that these compounds are melted in a heating station or extruder and put in the "cold7' mold (60-80°C). Due to the withdrawal of heat in the mold the material starts to freeze right after deposition and during the flow in the mold. Thus, the material properties are influenced by the thermal process parameters and the local pressure/velocity gradients, analogous to thermoset materials. Hence, the compression molding manufacturer has a great responsibility to find the optimal process parameters. In compression molding thermoplastic laminates, blanks smaller in area than the part size, are heated in a continuous belt drive oven above the melting temperature. The blanks are manually or robotically transferred to the compression molding tool where pressure is applied to fill the tool. During the compression process, the material begins to solidify since the tool temperature is controlled with water or oil to a temperature well below the resin matrix solidification point. The compression speed and tool temperature effect how the polymeric material flows during processing [10-11]. Continuous Fiber Reinforced Thermoplastics (CFRT) can replace other materials, such as thermoset composites, in many commercial engineering applications. Their principal advantages are:

- excellent toughness
- durability and damping properties
- easier storage
- possibility of continuous processing
- reshaping
- reparability
- and more favorable recycling and processing routes that do not involve chemical reactions.

However, the high cost of continuous fiber thermoplastic composite impregnation, arising from melting the polymer or using solvents, still restricts their use in commercial applications. Hence, cost reduction largely depends on developing more efficient fiber impregnating methods with high-viscosity thermoplastics and processing final composite parts. A recently developed technology for coating continuous fibers with polymer powders at low cost [12-14] can allow the efficient production of thermoplastic towpregs which are prepregs fabricated from powder coated tow which can be converted to woven and braided fabric. The consolidation is a critical phase of the towpreg processing into a final composite part by compression molding. Using thermoplastic resins to toughen thermosets is a relatively new technology. Polyethersulfones, polyimides, polyetherimides, and nylons are often used. These toughen thermosets have a morphology with ductile particles that are able to create microcracks and bridge the crack surface. The toughness increase is much more modest than their counterparts for lightly crosslinked thermosets, but such increases allow these highly crosslinked thermosets to be successfully applied to high performance composites.

Thermosets and Compression Molding

Compression molding fiber reinforced thermosets is well established. There are two main compound types such as prepregs (SMC) that were established in the early 1960s. For thermoset resins compression molding is the critical and productivity controlling step. The thermoset cure process cross-links the linear macromolecules with complications. Closed mold techniques are used to make complex parts from bulk molding compounds (BMC). During processing of thermoset charges, the SMC blank is cut from a preformed roll and is placed between heated cavity surfaces. Generally, the mold is charged with 1^4 layers of SMC, each layer about 3 mm thick, which initially cover about half the mold cavity's surface. During molding, the initially randomly oriented glass fibers orient, leading to anisotropic properties in the finished product. When processing glass mat reinforced thermoplastic (GMT) charges, the preforms are cut and heated between radiant heaters. Once heated, they are placed inside a cooled mold that rapidly closes and squeezes the charges before they cool and solidify. One advantage of the compression molding process is the low fiber attrition during processing. Here, relatively long fibers can flow in the melt without the fiber damage common during plastication and cavity filling during injection molding. An alternate process is injection-compression molding. Here, a charge is injected through a large gate followed by a compression cycle. The material used in the injection compression molding process is called bulk molding compound (BMC), which is reinforced with shorter fibers, generally 10 mm long, with an unsaturated polyester matrix. The main benefit of injection compression molding over compression molding is automation. The combination of injection and compression molding leads to lower fiber orientation and fiber attrition compared to injection molding.

Premix or Prepreg Preparation

Open tool processing is often employed to process fiber-reinforced parts. The simplest open mold process is called hand lay-up, which involves manual placing impregnated fibers mats with thermosetting resin on an open mold. Room temperature and elevated cure temperature resins can be used. A spray-up method is used for faster production rates, but it is limited to chopped fibers. The combination of viscous resins and high fiber loads requires a vacuum bag technique to eliminate voids and increase compaction. In extreme circumstances, laminates enclosed in a vacuum bag can be place in an autoclave to cure under high pressure and temperature.

Fiber Alignment

The alignment of fibers can be made in different types and typical premix systems include:

- Sheet molding compound commonly known as SMC is resin and chopped fibers placed randomly on the sheet plane with appropriate uniform thickness to fabricate the articles. SMC process is similar to thermoforming process.

- Dough molding compound commonly known as DMC is a resin and chopped fiber mixture that looks like dough. It is used for molding three dimensional articles. The fibers are randomly placed throughout the article.
- Tape uses continuous fibers impregnated with resin and the fibers may be placed uniaxially or woven. The woven fabric provides biaxial direction strength.

Pre-form

Pre-forming is accomplished with a mechanical or hydraulic press into which a hardened steel die set is mounted. The die has a cavity section and an upper and lower punch. The press compresses a compound fed from a hopper and transforms the loose powder into densely packed shape in a very rapid cycle. Pre-form weights are accurately controlled. It can be done with single or multi-cavity die. Pre-form process is dusty, and it requires a separate area to reduce contamination.

Prepreg

Traditionally prepreg has been used to fabricate high performance composites for aerospace components, high performance yachts, racing cars, sports equipment and so on. A prepreg is a semi-finished, machine made product in which a reinforcement material has been impregnated with a pre-catalyzed resin. Prepreg quality will greatly influence the molded product properties. During prepreg manufacture, the resin content, the soluble resin content and the volatile content are the key factors to ensure quality.

Sheet Molding Compound – Production

SMC is frequently used material composed of reinforcing chopped glass fibers combined with a very complex specialty resin, formulated in an almost infinite number of ways. In SMC, the long reinforcing fibers are randomly oriented in the sheet plane and make up 20-30 percent of the molding compound's volume fraction. The product size to be molded is limited by available equipment size and tonnage. Figure 18.1 illustrates a SMC production line. Chopped strands have low formability, low wettability, and low cost. So, the mats made from them are used for making medium strength objects with uniform cross-sections by compression molding and hand lay-up. Fabrics are made from yarns which are produced from twisted fine strands. Woven fabrics can easily handle strength orientations and increase mechanical properties. They exhibit high biaxial strength, and good formability. They are used in wet lay-up and compression molding processes. Fillers must be clean and free of oily materials, dirt, dust and especially moisture. Moisture complicates problems in compression-molding. When processing thermoset charges, the SMC blank is cut from a preformed roll and is placed between heated cavity surfaces. During molding, the initially randomly oriented glass fibers orient, leading to anisotropic properties in the finished product. When processing GMT charges, the preforms are cut and heated between radiative heaters. Once heated, they are placed inside a cooled mold that rapidly closes and squeezes the charges before they cool and solidify.

The SMC sheets can be formed in a belt press. Such sheets are allowed to mature for several days before they are cut into appropriate pieces that are stacked to form a charge that is put in an open heated mold. The mold is then closed to form a charge that is put in an open heated mold. The mold is then closed with certain force to fill SMC in the formed cavity. During the filling there is an extensive built-up in the SMC due to its initially high viscosity. As the SMC is heated up by the tooling its velocity naturally decreases at the same time as the thermosetting starts. The latter is usually a slower process that only affects the resin viscosity after the mold is closed. It is also possible to design the processing tools and conditions so that a high pressure remains on the SMC after the mold has been closed. The curing takes place and when the mold is opened; the final SMC product can be removed. The procedure is well known and has been used effectively a number of decades. When producing SMC, the chopped glass fibers are sandwiched between two carrier films previously coated with unsaturated polyester-filler matrix. A fiber reinforced thermoplastic charge is often called a glass mat reinforced thermoplastic (GMT) charge. The most common GMT matrix is polypropylene. More recently, long fiber reinforced thermoplastics (LFT) have become common. Here, one squeezes sausage-shaped charges deposited on the mold by an extruder.

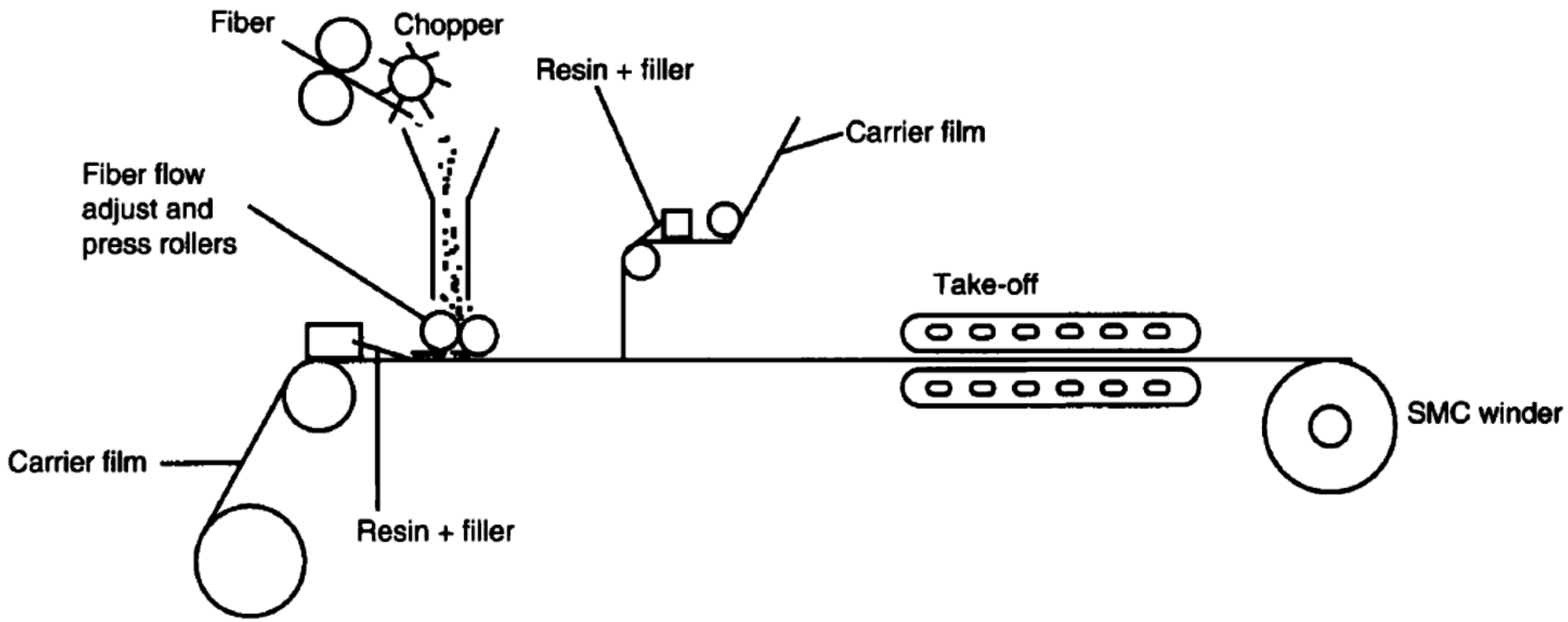


Figure 18.1 Sheet molding compound production process.

Mold

Several different mold designs can be used in compression molding. However, all designs utilize the same molding press. Compression molding uses stiff to medium flow compounds because it involves the best flow during its process. A properly designed compression mold will produce molded parts of excellent overall mechanical properties.

Technology - Compression Molding

In the compression molding process, it is very importance that the void content is low on the surface and in the bulk. Sheet molding compound is a fiber reinforced polymer material consisting of thermosetting resin, chopped fibers, fillers, and additives. An appropriate amount of compound in the form of premix or prepreg to be molded is placed into the cavity which is the lower half of the heated mold. During compression molding cycle, the mold halves are then brought together to squeeze the material and fill the mold. Compression molding starts with an appropriate prepreg shape. The mold is heated at its curing temperature and brought together under pressure. During processing, the compound softens by heat and transforms to the cavity shape. The softened melt hardens further under heat and pressure. After sufficient hardening the part can be removed without distortion when the mold is opened. The heated mold in the compression molding process, initiates the curing process for the resin. In compression molding, the desired molded article shape is defined by the two-piece mold. The pressure is maintained while the material cures. The charge temperature is about room temperature, the mold temperature ranges from 120-150°C. The compound temperature rises during the flow due to heat transferred from the cavity surfaces. Due to this the viscosity declines before the cross-linking reaction starts. Much attention is given to improve compression molding costs by reducing the cycle time required to produce acceptable parts in steady production. In compression molding, the cure time is the longest part of the cycle time. However filling time play an important role. With shorter filling times, a more reactive material can be used and thus a shorter the cure time. In particular one important area for compression molding is being able to predict the pressing force needed to close the mold at a given speed. Figure 18.2 illustrates the molding cycle in compression molding. Local pressure gradients in the mold cause different local velocities and fiber orientations during flow. These orientations affect the part anisotropy. Besides the thermal process parameters, it is the flow that has a major influence on the part properties. Compression molding cycle starts with:

- Opening of the mold.
- Insert(s), if any, to be placed in the cavity.
- Molding compound loaded in the cavity in the form of powder or pre-form or pre-heated.
- Closing of hot mold, breathe if needed. Heating to be continued until complete cure of the thermoset material under pressure.
- Ejection of molded part and the part to be placed in shrink or cooling fixtures if needed or whenever necessary to maintain close dimensional tolerances.
- Removal of foreign matter and flash usually by air blast from the mold.

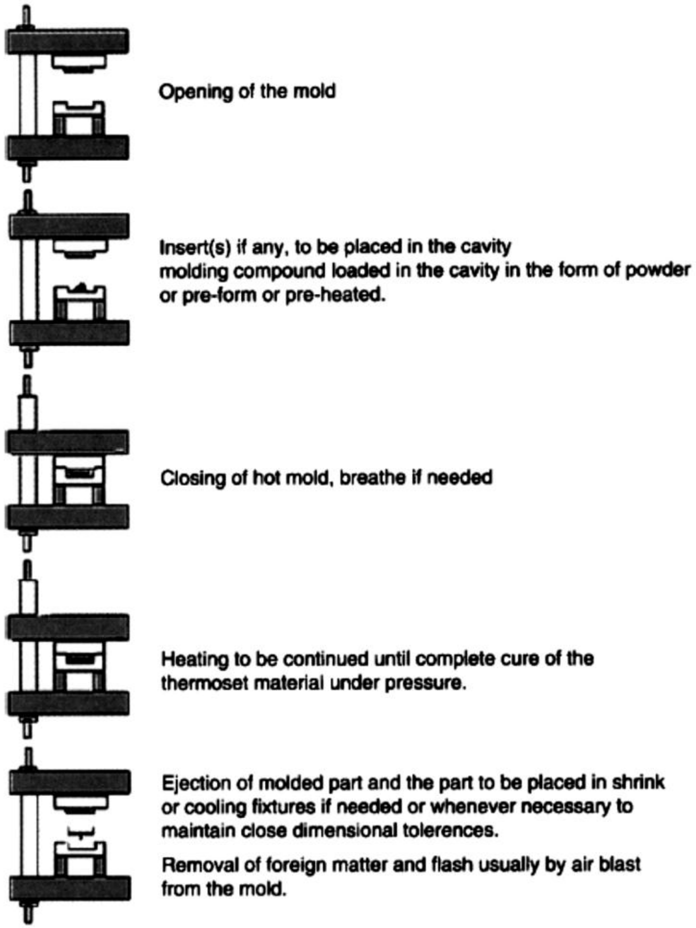
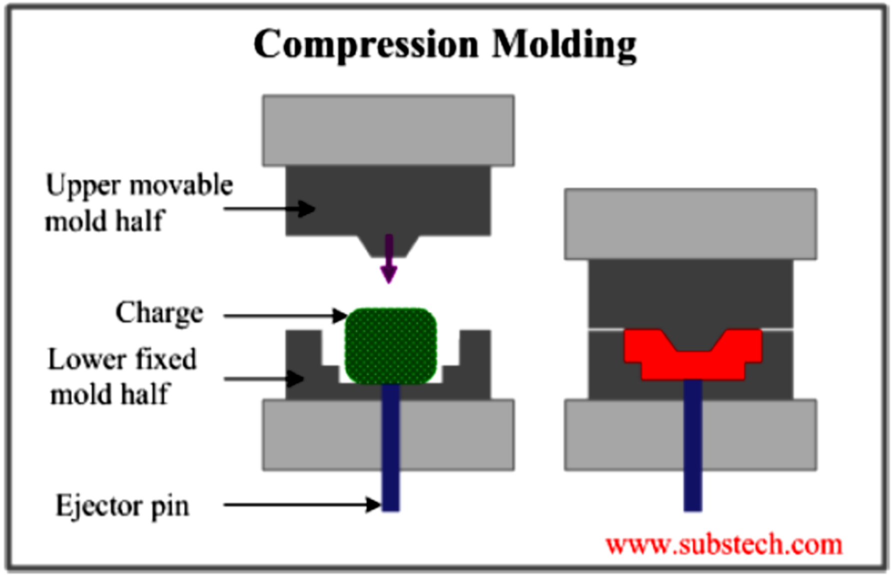


Figure 18.2 Compression molding cycle.

Compression molding is widely used in the automotive industry to produce parts that are large, thin, lightweight, strong, and stiff. It is also used in the household goods and electrical industries.



For e.g., compression molded parts are formed by squeezing a glass fiber reinforced charge inside a mold cavity. The matrix can be either a thermoset or thermoplastic. The most common matrix used to manufacture compression molded articles is unsaturated polyester sheet reinforced with glass fibers, known as sheet molding compound (SMC). The 25 mm long reinforcing fibers are randomly oriented in the plane of the sheet and make up for 20−30% of the molding compound's volume fraction. A schematic diagram of an SMC production line is depicted in Fig. 7.26. When producing SMC, the chopped glass fibers are sandwiched between two carrier films previously coated with unsaturated polyester-filler matrix. A fiber reinforced thermoplastic charge is often called a glass mat reinforced thermoplastic (GMT) charge. The most common GMT matrix is polypropylene. During processing of thermoset charges, the SMC blank is cut from a preformed roll and is placed between heated cavity surfaces. Generally, the mold is charged with 1 to 4 layers of SMC, each layer about 3 mm thick, which initially cover about half the mold cavity's surface. During molding, the initially randomly oriented glass fibers orient, leading to anisotropic properties in the finished product. When processing GMT charges, the preforms are cut and heated between radiative heaters. Once heated, they are placed inside a cooled mold that rapidly closes and squeezes the charges before they cool and solidify.

Important Variables during Processing

In compression molding, thermoset materials determine the pressure required to produce molding with minimum cycle time. Important variables such as

- Product design in terms of:
  - projected area and depth
  - wall thickness
  - obstructions such as sharp corners, pins, etc.
- Press speed, slow versus fast
- Self-contained versus hydraulic system
- Ability to maintain holding pressure during molding
- Material plasticity being processed:
  - pre-heating conditions
  - compound density (pre-form or powder)
  - material position placed in die.
  - compound flow properties under pressure
  - filler material and concentration.
- Overall mold temperature and its uniformity
- Mold surface condition
- Mold pressure.

Troubleshooting

Today process parameters are often found by trial and error rather than by process simulation because simulation software is often considered suitable for industrial applications. Compression molding is facing many challenges to meet a rapidly changing and diversifying market environment. There are many problems encountered in the process with associated inherent complexities in terms of:

- Kinetics
- Mechanisms
- Physical changes
- Transport effects such as:
  o viscosity increase
  o particle formation
  o inter-facial mass and heat transfer limitations.

The end-use applications are often represented by non-molecular parameters such as:

- Tensile strength
- Impact strength
- Color
- Crack resistance
- Thermal stability
- Density, etc.

These must be somehow related to fundamental polymer properties such as:

- Composition
- Branching
- Cross-linking
- Stereo-regularity, etc.

Unfortunately, process variables affect properties and the relationship between the process variables and end-use properties is generally very difficult and not well established. In situ real-time monitoring of compression molding is of crucial importance to polymer scientists and engineers engaged in efforts to optimize processes and products. Moreover, many process variables that affect product quality namely non-ideal mixing and conveying, and strong process non-linearity related to limited cycles and multiple steady states. Two big expenses for any processing are:

- Failure to quickly and accurately troubleshoot process upsets and equipment problems
- Failure to realize the operating potential of its process through optimization
- Minor upsets and equipment problems which are not identified and resolved quickly can progress into much larger problems potentially resulting in:
    - lost production
    - off-spec product
    - equipment loss
    - catastrophic accidents.

Additionally, operating a process at suboptimal performance results in elevated operating costs due to:

- Increased energy costs
- Equipment reliability costs
- Lower yields

- Longer startups, etc.

Therefore, the ability to troubleshoot and optimize process operations are two of the most valuable skills operation personnel can possess. Troubleshooting requires a comprehensive analysis of:

- The process
- Mold design
- Material

Compression molding tends to focus on process modifications to solve problems. There may be longer cycle times, secondary rework operations or formulation modifications that negatively impact profits. Thorough and systematic analysis can pinpoint the exact problem cause and identify the most cost and time-effective solution.

Problems and Solution(s)

Compression molding is widely used in the automotive industry for producing exterior body panels. For the last two decades, and in spite of many cosmetic problems, compression molded parts usage has increased for exterior body panels such as hoods, deck lids, and door panels. The cosmetic problems most commonly observed in compression molded parts are sink marks over ribs and bosses, long term waviness, and surface porosity. Painting or coating the molded part can be very effective in providing a cosmetic surface free from substrate porosity. A low-profile agent such as thermoplastic material mixed with the resin just prior to compounding has been found to reduce the polymerization shrinkage as it cures in the mold and in turn reduces sink marks and long-term waves observed on the part surface. Using coatings and low-profile additives has reduced sink marks. However, sink marks can still exist in the molded parts. To solve the sink mark problem, one must style and design surface contours so that sink marks are concealed. Jutte et al. studied the role of polymerization and thermal shrinkage and concluded that the polymerization shrinkage can be minimized by using low profile agents. Thermosets are inherently brittle, organic additives can be used to improve the fracture toughness of these materials. For thermosets, that are lightly cross-linked, reactive oligomers that phase separates during cure help and for highly cross-linked thermosets, thermoplastic toughening agents can be used. During pressing the temperature and the pressure are substantially increased. This means that even large voids can be dissolved in a very short time. If the pressure is large enough within the resin most enclosed gas should dissolve and SMC products ought to be completely free from voids. It is well known that these items can have a relatively high void content. There are several reasons for this. Still some issues are unresolved such as fiber reorientation during processing, which strongly affects the final SMC strength and residual void formation which can cause large surface defects after painting and lower the electrical insulation capacity of the part manufactured.

The voids located in the SMC during pressing may have entered the SMC via:

- the constituents when they are mixed to form the SMC
- being enclosed during the lay-up procedure

• or formed as the charge flows in the mold during pressing.

It may also happen that during the curing process the pressure becomes too low and SMC constituents such as styrene start to boil. Regardless of how the voids form, their final size and location are strongly affected by the fluid pressure in the SMC during compression. Specifically, it has been observed that the formation, movement, and number of voids are strongly related to the temporal and spatial distribution of the pressure and the pressure gradients, where high pressures, and pressure gradients, generally gives a low residual void content since it enables the voids to move forward through fiber networks or dissolve into the resin. The SMC consists of fibers, caulk, and some additives that may considerably slow down the dissolution of gas. Low-pressure zones are formed during pressing. This may be due to uneven filling or, complex shaped molds or uneven solidification. A substantial amount of gas is dissolved during the compression which saturates the resin much faster than predicted in the model. This could be a reasonable explanation if air is trapped between the sheets during charge lay-up. Molding cycles are longer with the need to remove flash from the parting line and holes. Difficulties in molding side holes or sections, and problems with molding in flash free metal inserts have all contributed to reduced use of compression molding.

Summary

In summary following are the fundamentals, advantages and disadvantages of compression molding:

Fundamentals

• The simplest closed mold method is casting which involves pouring the liquid into a mold. For more viscous systems, compression molding is used to squeeze the material into two halves of a heated mold.
• Cold powder or pre-form can be loaded in compression molding
• Mold is open when the material is loaded.
• Material positioned for optimum flow.
• Least shrinkage observed in compression molding.
• In compression molding, inserts might be displaced during the compression molding cycle.
• With compression molding parting line flash generally prevents metal – metal closing of the mold halves. It makes dimensions perpendicular to the parting line greater by the flash thickness.
• Transfer molding is similar to compression molding except the plunger pushes the reactive resin through a mixing nozzle to mix the reactants before injecting them into a closed cavity.

Advantages

• Sprue, runners, and transfer-culls can be avoided without any gate erosion problems.
• Minimize stress by short and multidirectional flow in the mold.

• With reinforcing fibers, high impact strength is gained due to more randomly positioned fibers.
• Multiple cavities can be used without a sprue and runner system.
• Possible to automatically load material and remove molded articles.
• Thin wall parts without warpage or dimensional change.
• Molds for compression molding are less expensive.
• Can mold heavily reinforced materials
• Best method for moldings with large surface area related to thickness
• Greatest uniformity in molded properties
• Most versatile process with relation to quantities and component complexity
• Relatively simple to understand and control.

Disadvantages

• Thermosets have poor fracture resistance.
• Thermoset materials are brittle, hence recommended minimum part wall thickness are necessary.
• Relatively labor intensive, with more material handling involved.
• Material losses due to the flash allowances and general waste.
• Secondary operations for flash removal are generally required.
• Poor part thickness and weight control.
• Cannot mold around delicate inserts or pins.

For further details, please refer to the book: Handbook of Troubleshooting Plastic Processes: A Practical Guide, Chapter 18.

Importance of using PPEs

PPE is equipment that will protect workers against health or safety risks on the job. The purpose is to reduce employee exposure to hazards when engineering and administrative controls are not feasible or effective to reduce these risks to acceptable levels.

PPEs:

Name & Usage	Picture of PPE	Name & Usage	Picture of PPE
Safety goggles – used to protect eyes from flying particles (chips, sparks etc.)		Safety shoes – used to protect feet from spatters of welding and impact of other falling objects	
Face shield - used to protect face from welding sparks, radiations, arc and spatters		Face mask – used to protect from inhaling fumes, dangerous gases etc.	
Hard cap – used to protect the head from injury due to falling objects		Leather Apron – used to protect welder’s body from welding spark and spatters	
Leather gloves – used to protect hands during welding		Cotton gloves – used to protect hands from sharp edges of sheets and plates	

Importance of housekeeping and safe storage of tools and equipment

The main function of housekeeping is to ensure cleanliness, comfort, convenience, privacy, health and hygiene in a safe environment. It includes keeping work areas neat and orderly. All the tools and equipment must be stored properly.

Importance of making a check list

It ensures you get your daily, weekly and monthly tasks done on time, helps you keep track of projects on deadline and ensures you're organized throughout the day.

Video links:

Processing of Plastics- Compression and Transfer Moulding: https://www.youtube.com/watch?v=A1XKGUH7wRQ
What is Compression moulding process in hindi: https://www.youtube.com/watch?v=NlJqDPInDXY
Compression Moulding Process: https://www.youtube.com/watch?v=sus8arkJOeA

Summary – overview of the curriculum

Module Title and Aim	Learning Units	Timeframe of modules
Module 1: Apply Work Health and Safety Practices (WHS) **Aim:** This unit describes the skills to work with safety and participate in hazard assessment activities, follow emergency procedures and participate OHS practices in process	**LU1.** Implement safe work practices at work place **LU2.** Participate in hazard assessment activities a work place **LU3.** Follow emergency procedures at workplace **LU4.** Participate in OHS consultative processes	30
Module 2: Identify and Implement Workplace Policy and Procedures **Aim:** This unit describes the skills and knowledge required to develop and implement a workplace policy & procedures and to modify the policy to suit changed circumstances. It applies to individuals with managerial responsibilities who undertake work developing approaches to create, monitor and improve strategies and policies within workplaces and engage with a range of relevant stakeholders and specialists.	**LU1.** Identify workplace policy & procedures **LU2.** Implement workplace policy & procedures **LU3.** Communicate workplace policy & procedures **LU4.** Review the implementation of workplace policy & procedures	20
Module 3: Communicate at Workplace **Aim:** This unit describes the performance outcomes, skills and knowledge required to develop communication skills in the workplace. It covers gathering, conveying and receiving information, along with completing assigned written information under direct supervision.	**LU1.** Communicate within the organization **LU2.** Communicate outside the organization **LU3.** Communicate effectively in workgroup **LU4.** Communicate in writing	30

Module Title and Aim	Learning Units	Timeframe of modules
Module 4: Perform Computer Application Skills **Aim:** This unit describes the skills and knowledge required to use spreadsheet applications, prepare in page documents, develops familiarity with Word, Excel, Access, PowerPoint, email, and computer graphics basics. It applies to individuals who perform a range of routine tasks in the workplace using a fundamental knowledge of spreadsheets, Microsoft office and computer graphics in under direct supervision or with limited responsibility	**LU1.** Prepare In-page documents as per required information **LU2.** Prepare Spreadsheets as per required information **LU3.** Use MS Office as per required information **LU4.** Perform computer graphics in basic applications **LU5.** Create Email account for communications	40
Module 5: Manage Personal Finances **Aim:** This unit of competency describes the outcomes required to manage develop, implement and monitor a personal budget in order to plan regular savings and manage debt effectively.	**LU1.** Develop a personal budget **LU2.** Develop long term personal budget **LU3.** Identify ways to maximize future finances	30
Module 6: Operate Injection Moulding Machine **Aim:** This competency standard is designed to provide skills and knowledge to operate injection moulding machine in accordance with the manufacturer's manual.	**LU1.** Adjust Moulding machine parameters **LU2.** Perform Dry Run **LU3.** Perform Semi Auto Operation **LU4.** Perform Production **LU5.** Perform follow up procedure for machine production **LU6.** Submit production report **LU7.** Transport finish product to concerned department	175

Module Title and Aim	Learning Units	Timeframe of modules
Module 7: Operate Pipe Extrusion Machine Operation **Aim:** This competency standard covers specific knowledge related to operation of pipe extrusion machine and explaining parameters setting, running procedure, and reporting procedure of machine.	**LU1.** Inspect extrusion machine pre-start parameters **LU2.** Carry out operation **LU3.** Start production as per requirement **LU4.** Perform follow up procedure **LU5.** Submit Production Report **LU6.** Transport Finished Product	150
Module 8: Operate Blow Moulding Machine **Aim:** The standard covers specific knowledge related to operation of blow moulding machine and explaining parameters setting, dry run procedure, and reporting procedure of machine.	**LU1.** Adjust Moulding Machine parameters **LU2.** Perform Dry Run **LU3.** Perform Semi-auto Operation **LU4.** Perform Production **LU5.** Perform Follow up procedure for Machine Production **LU6.** Submit Production Report **LU7.** Transport Finished Product to Concerned Department	175
Module 9: Operate Compression Moulding Machine **Aim:** The standard covers specific knowledge related to operation of compression moulding machine and explaining parameters setting, dry run procedure, and reporting procedure of machine.	**LU1.** Adjust parameters of machine **LU2.** Perform Dry Run **LU3.** Perform Semi-auto Operation **LU4.** Perform Production **LU5.** Perform Follow up procedure for Machine Production **LU6.** Submit Production Report **LU7.** Transport Finished Product to Concerned Department	150

Short Questions/Answers

Q1. Which plastics are used in injection molding?	Thermoplastics
Q2. What types of polymeric materials (plastics and elastomers) are there?	Amorphous and Semi-crystalline
Q3. What is the difference between parallel and conical twin screw extruders?	Conical twin screws are used for better throughput and parallel twin screws are used for better mixing.
Q4. Complex shape of parts or components cannot be formed by the injection moulding process.	False
Q5. Components from injection moulding process are made very expensive due to the application of very costly equipment.	False
Q6. The moulding directions in injection moulding can affect the cost of equipments used in the process.	True
Q7. The flow of plastic in the mould cavity is more proper and smoother if the thickness of the component made is very small.	False
Q8. Shrinkage of the plastic parts in mould cavity can results in generation of sink holes in the plastic.	True
Q9. A heavy surface finishing is always required for components made in injection moulding machine.	False
Q10. In injection moulding process, ribs are generally provided for the reinforcement to avoid sink marks from the component.	True

Q11. The barrel is used for opening and closing of the mold.	False
Q12. There is a varied pressure provided in the solidification unit of injection molding process.	False
Q13. Calendering is mostly suited for making PVC	True
Q14. Tubes having U shape cannot be manufactured by polymer extrusion process.	False
Q15. Extrusion is a process which uses an electric system for processing various polymers.	False
Q16. Thermosetting polymers can be processed by extrusion process by forming cross-linking in the extruder.	True
Q17. In processing polymers, injection moulding process is almost similar to extrusion process except for the screw operation.	True
Q18. Extruder is a device used for the finishing of processed polymer products in the extrusion process.	False
Q19. Continuous type of extruder is generally equipped with rotating parts in the extrusion process.	True
Q20. Multiple screw extruders are mostly preferred than the single screw extruders in the extrusion process.	False
Q21. In the extrusion process, a cast type barrel is mainly used for the heating of polymer material.	False

Q22. Extruder die is a machine part that gives final shape to the polymer material used in the extrusion process.	True
Q23. In the extrusion process, a water-cooling system is used which automatically controlled by a sensor.	True
Q24. Speed of production in transfer molding is higher than that of compression molding?	True
Q25. Thermosetting materials are the polymeric materials which get soften on heating with or without pressure.	False
Q26. Thermosetting plastics are generally used for making products of high strength and rigidness.	True
Q27. Polyurethanes plastics can be made in flexible foams even after belonging to thermosetting polymers.	True
Q28. Polyethylene, polypropylene and polyvinyl chloride (PVC) are the main example of thermosetting polymers.	False
Q29. Thermosetting plastics like epoxies can be used for filament wound rocket motor casings in missiles by combining with glass fibers.	True
Q30. Polyurethane plastics are highly reactive to chemical compounds due to lack of elasticity in this plastics.	False
Q31. Phenolic plastics can also be used as binder for holding plies of wood in making of plywood.	True

Q32. Thermosetting plastics can be used for manufacturing of windshield for airplane.	False
Q33. Mechanical properties of any plastics are mainly dependent on the temperature, force and time of load applied.	True
Q34. The heater in vacuum forming process is heated up to 90°C.	True
Q35. The initial cost in blow molding is low.	True
Q36. Blow moulding is a very slow process, however economical for producing products with better quality.	False
Q37. In extrusion blow moulding process, it is very difficult to trim away excess of plastics	True
Q38. Single stage stretch blow moulding is always preferred than two stage stretch blow moulding for increase in production rate.	False
Q39. Single stage stretch blow moulding process is mostly used for small level production.	True
Q40. Thermoforming process involves injecting of molten plastic into a mould cavity by application of compressed air.	False
Q41. In thermoforming process, it is very difficult to control thickness of moulded parts or sheets.	True
Q42. In thermoforming, it is very easy to mould the plastic materials which are of crystalline nature.	False

Q43. Thermoforming is basically a cheap process as compared to injection and blow moulding process.	True
Q44. Which material is mostly used for making of thermoforming moulds?	Aluminum

Test Yourself (Multiple Choice Questions)

MODULE	**6**			
Question	**1**	Three overall classes of plastics are distinguished from one another. They include thermosets, thermoplastics and __________________	A	Monomers
			B	Synthesis
			C	Elastomers
			D	Fibers
Question	**2**	Thermoplastics are soluble and ________	A	Densely cross-linked
			B	Fusible
			C	Non-fusible
			D	Crystalline

Question	**3**	Amorphous thermoplastics are ________ when they are not combined with fillers or similar additives.	A	Transparent
			B	Milky opaque
			C	Translucent
			D	Black
Question	**4**	Polycarbonate (PC), from which Compact Disks are molded, is a(n) _________ thermoplastic.	A	Amorphous
			B	Semi-crystalline
			C	Liquid Crystal
			D	Immiscible
Question	**5**	___________ cannot be fused or dissolved but can be swelled.	A	Thermoplastics
			B	Elastomers
			C	Thermosets
			D	Composites

Question	**6**	Thermosets are non-fusible and ____________	A	Soft
			B	Densely cross-linked
			C	Dense
			D	Irregular shaped
Question	**7**	The intermolecular forces which operate in the crystalline state are considerably __________ than those in the amorphous state.	A	Weaker
			B	Stronger
			C	Complex
			D	Diverse

Question	**8**	The abbreviation for polyamide, as specified by IS0 1043, is __________________	A	PS
			B	PA
			C	PC
			D	PVA
Question	**9**	Processing temperatures are _________ for thermoplastics than for metals.	A	Higher
			B	Lower
			C	Left
			D	Right

Question 10 Viscosity is a measure of the __________ of a melt.

A Hardness

B Flow properties

C Density

D Visco-elasticity

Question 11 As temperature decreases, the viscosity of the melt ___________________

A Increases

B Decreases

C Varies

Question 12 The injection Moulding process can be divided into the following phases: injection, holding pressure, cooling, feeding and ________________.

A Locking

B Removal

C Cleaning

D Closing

Question	**13**	The nozzle is ____________ during the injection phase.	A	Closed
			B	Open
			C	Perforated
			D	Ejected
Question	**14**	The screw moves towards the ______________ during the injection phase.	A	Hopper
			B	Nozzle
			C	Pump
			D	Motor
Question	**15**	Compensation for shrinkage occurs during the _____________ phase.	A	Injection
			B	Holding pressure
			C	Feed
			D	Metering

Question	**16**	The point at which no more melt can be forced into the molded part is called the _________________.	A	Melting point
			B	Holding point
			C	Sealing point
			D	Melting point
Question	**17**	The holding pressure is generally ____________ than the injection pressure.	A	Lower
			B	Double
			C	Equal
			D	Higher
Question	**18**	A ________ amount of material is conveyed into the cavity during the holding pressure phase.	A	Large
			B	Small
			C	Equal
			D	Twice
Question	**19**	The cycle time _______ be determined by the plasticating time.	A	Must
			B	Must not

Question	**20**	The ________ phase runs concurrently with the feed phase.	A	Cooling
			B	Injection
			C	Holding pressure
			D	Metering
MODULE	**7**			
Question	**21**	Which of the following material is not used in extrusion?	A	Wax
			B	Granules
			C	Powder
			D	Pellets
Question	**22**	In extrusion process, extra shearing occurs in which part of the system?	A	Feed section
			B	Pumping section
			C	Collapse section
			D	Transition section

Question 23 Melting section is another name for which section?

A Feed Section

B Transition section

C Transition section

D Collapse section

Question 24 How are extruded materials cooled?

A Water

B Contact with chilled surface

C Air

D Oil

Question 25 Which of the following is not an important factor of cooling in extrusion?

A Reduction in shrinkage

B Reduction in distortion

C Ease of adding colors

D Rate of cooling

Question	**26**	Which of the following is not an application of polymer extrusion?	A	Door insulation
			B	Chewing gums
			C	Cables
			D	Circuit boards

Question	**27**	Film extrusion process, best involves film having thickness below what length?	A	0.2mm
			B	0.3mm
			C	0.4mm
			D	0.5mm

Question	**28**	In cable extrusion process, what is the speed of product winding?	A	40m/s
			B	50m/s
			C	60m/s
			D	70m/s
Question	**29**	Which of the following equipment is used for controlling the temperature of polymer material in the extrusion process?	A	Thermoresister
			B	Thermometer
			C	Thermocouple
			D	Glasstube
MODULE	**8**			
Question	**30**	In blow molding, to inflate soft plastic, which medium is used?	A	Air
			B	Water

			C	Oil
			D	Alcohol
Question	**31**	Which of the following plastics is not used in blow molding?	A	Terephthalate
			B	Polypropylene
			C	Polyethylene
			D	PVC
Question	**32**	What is the minimum air pressure required in blow molding process?	A	350KPa
			B	400KPa
			C	450KPa
			D	500KPa

Question	**33**	What can be the maximum pressure to be given to a plastic for blow molding process?	A	700KPa
			B	750KPa
			C	800KPa
			D	850KPa
Question	**34**	Which of the following is not a type of blow molding process?	A	Injection blow moulding
			B	Extrusion blow moulding
			C	Multi-smaller blow moulding
			D	Multi-larger blow moulding

Question 35 Which of the following is not an application of blow molding process?

A Toy bodies

B Door liners

C Bottles

D Pipes

Question 36 What is the maximum thickness that can be allowed for a plastics sheet in vacuum forming process?

A 3mm

B 3.1mm

C 3.2mm

D 3.3mm

Question	**37**	What is the minimum thickness required by the plastic for vacuum forming?	A	0.125mm
			B	0.25mm
			C	0.375mm
			D	0.5mm
MODULE	**9**			
Question	**38**	What is the minimum pressure required in a compression molding process?	A	0.5MPa
			B	1MPa
			C	1.5MPa
			D	2MPa

Question	**39**	What is the minimum temperature required in a compression molding process?	A	120°C
			B	125°C
			C	130°C
			D	135°C
Question	**40**	What is the maximum pressure required in a compression molding process?	A	35MPa
			B	40MPa
			C	45MPa
			D	50MPa

Question	**41**	What is the maximum temperature required in a compression molding process?	A	240°C
			B	245°C
			C	250°C
			D	255°C

Question	**42**	In compression molding, the curing time does not depend on which of the following factors?	A	Material
			B	Curing temperature
			C	Geometry
			D	Thickness

Multiple Choice Questions Answer scheme

Module 6:

Q1: C
Q2: B
Q3: B
Q4: B
Q5: C
Q6: B
Q7: B
Q8: B
Q9: B
Q10: B
Q11: A
Q12: B
Q13: B
Q14: B
Q15: B
Q16: C
Q17: D
Q18: B
Q19: B
Q20: A

Module 7:

Q21: A

Q22: B
Q23: B
Q24: B
Q25: C
Q26: B
Q27: D
Q28: B
Q29: C

Module 8

Q30: A
Q31: A
Q32: B
Q33: C
Q34: C
Q35: D
Q36: C
Q37: A

Module 9

Q38: A
Q39: B
Q40: D
Q41: C
Q42: B

National Vocational and Technical Training Commission (NAVTTC)

Plot 38, Kirthar Road, Sector H-9/4, Islamabad, Pakistan
+92 51 9044 322
+92 51 9044 322
info@navttc.org
www.navttc.org