

**Vocational Higher Secondary
Education (VHSE)**

Second Year

POLYMER TECHNOLOGY

Reference Book



Government of Kerala
Department of Education

State Council of Educational Research and Training (SCERT),
KERALA
2016

List of Contributors

Participants

1. Ratheesh V
Vocational teacher – RT, GVHSS Odakkali
2. Vijayakumar. A.R
Vocational teacher – RT, GVHSS – THS Pampady
3. Sijuraj MS
Vocational Instructor – RT, GVHSS Odakkali
4. Anju Mohan
Vocational Instructor – RT, GVHSS – THS Pampady

Experts

1. Mr. Sabu. KK
Lecturer in Polymer Technology, Govt. Polytechnic,
Nattakom, Kottayam
2. Jayavani. S
Faculty, CBPST, Kochi

Academic Co-ordinator

Smt. Bindu C
Research Officer, SCERT

Prepared by :

State Council of Educational Research and Training (SCERT)

Poojappura, Thiruvananthapuram 695012, Kerala

Website : www.scertkerala.gov.in *e-mail :* scertkerala@gmail.com

Phone : 0471 - 2341883, Fax : 0471 - 2341869

Typesetting and Layout : SCERT

© Department of Education, Government of Kerala

FOREWORD

Dear Learners,

This book is intended to serve as a ready reference for learners of vocational higher secondary schools. It offers suggested guidelines for the transaction of the concepts highlighted in the course content. It is expected that the learners achieve significant learning outcomes at the end of the course as envisaged in the curriculum if it is followed properly.

In the context of the Right- based approach, quality education has to be ensured for all learners. The learner community of Vocational Higher Secondary Education in Kerala should be empowered by providing them with the best education that strengthens their competences to become innovative entrepreneurs who contribute to the knowledge society. The change of course names, modular approach adopted for the organisation of course content, work-based pedagogy and the outcome focused assessment approach paved the way for achieving the vision of Vocational Higher Secondary Education in Kerala. The revised curriculum helps to equip the learners with multiple skills matching technological advancements and to produce skilled workforce for meeting the demands of the emerging industries and service sectors with national and global orientation. The revised curriculum attempts to enhance knowledge, skills and attitudes by giving higher priority and space for the learners to make discussions in small groups, and activities requiring hands-on experience.

The SCERT appreciates the hard work and sincere co-operation of the contributors of this book that includes subject experts, industrialists and the teachers of Vocational Higher Secondary Schools. The development of this reference book has been a joint venture of the State Council of Educational Research and Training (SCERT) and the Directorate of Vocational Higher Secondary Education.

The SCERT welcomes constructive criticism and creative suggestions for the improvement of the book.

With regards,

Dr P.A. Fathima
Director
SCERT, Kerala

CONTENTS

■	<i>About the course</i>	05
■	<i>Major skills with sub skills</i>	06
■	<i>Syllabus</i>	08
■	<i>Module 3 : Plastic Processing</i>	12
■	<i>Unit 1 - Introduction to plastic processing</i>	13
■	<i>Unit2 - Injection moulding</i>	23
■	<i>Unit 3 - Extrusion</i>	35
■	<i>Unit 4 - Blow moulding and Rotational moulding</i>	47
■	<i>Unit 5 - Thermoforming and calendaring of plastics</i>	57
■	<i>Unit 6 - Testing of plastics</i>	65
■	<i>Module 4 Fibre Reinforced Composites</i>	73
■	<i>Unit 1 - Introduction to composites</i>	75
■	<i>Unit 2 - Reinforcement fibres</i>	79
■	<i>Unit 3 - Matrix materials and additives</i>	90
■	<i>Unit 4 - Manufacturing methods</i>	103
■	<i>Unit 5 - Quality and safety in FRP industry</i>	119
■	<i>List of References</i>	129

ABOUT THE COURSE

Vocational Higher Secondary Education in Kerala is a unique scheme of education which combines both vocational and academic stream of education. Learning vocational skills along with conventional academic education gives the students double advantage of vertical mobility as well as employability. It helps to develop vocational aptitude, work culture, values and attitudes of the learner and enhances his productivity. The vision of Vocational Higher Secondary Education in Kerala is to equip the youth with multiple skills matching the technological advancements and to produce skilled work force for meeting the demands of the emerging industries and service sectors with national and global orientation.

As India is emerging as a manufacturing hub to the world the demand for skilled manpower is on the rise. Kerala, traditionally known for its high quality man power all over the world can embark on this opportunity and equip our students with skills for the manufacturing sector and reduce the unemployment problems of the state.

The polymer technology course in VHSE is one such course from the manufacturing sector. Polymers have wide spread applications in our daily life like simple household articles, automobiles, spacecrafts, medical products etc and is rapidly replacing many conventional materials like metals in many applications. Hence acquiring skills in the manufacturing of polymer products will help the students to get early employment opportunities.

The course is designed for providing knowledge and skills to participants in Rubber, Plastics, and Composite products manufacturing. This course is offered in modular format consisting of four modules with focus on multi skills development. One month On the Job Training and Production cum training centres are also an integral part of the course which gives exposure to real time work environment. Upon successful completion of this course the candidate will be able to join rubber/plastic/composite industries as junior level technicians and are also eligible for attending advanced courses on Polymer Technology or any other course that can be pursued after plus two science stream.

Major skills (with sub skills)

Module - I

- 1) Polymer processing skills
 - a. Identify materials and processes in plastic and rubber processing
 - b. Identify and weigh different materials as per the formulations
 - c. Setting and operation of Hand/Semi automatic injection moulding machines.
 - d. Setting and operation of Compression moulding hand press

Module - II

- 1) Natural rubber crop processing
 - a. Processing of Latex into different marketable forms such as Centrifuged/creamed latex, RSS, Crepe Rubber, and TSR.
- 2) Latex product manufacturing
 - a. Manufacture of latex dipped products such as gloves, balloons etc.
 - b. Manufacture of latex threads and latex forms
- 3) Dry rubber products manufacturing
 - a. Preparation of rubber compounds
 - b. Manufacture of rubber moulded goods
 - c. Manufacture of extruded and calendered rubber products
 - d. Manufacture of tyres and tubes
- 4) Testing and quality control in rubber industry
 - a. Testing of raw rubbers, latex, and rubber compounds

Module - III

- 1) Plastic processing
 - a. Setting and operation of Injection moulding machines
 - b. Setting and operation of blow moulding machines
 - c. Production of extruded plastic products
 - d. Production of rotational moulded plastic products

- e. Production of thermoformed and calendered plastic products
- 2) Plastic testing
 - a. Testing of plastic materials and products

Module - IV

- 1) FRP Processing
 - a. Identification of different materials used in the making of fibre reinforced composites.
 - b. Manufacture of FRP products using different methods such as Hand lay-up, filament winding, pultrusion, etc
- 2) Observing safety precautions and work instructions

SYLLABUS

Module 3

PLASTIC PROCESSING

3.1 Introduction to Plastic Processing

(20 Periods)

Introduction to plastic processing, Different plastic processing techniques. Effect of polymer properties on processing. Moisture absorption, Thermal stability. Important properties, applications and processing parameters of common plastics such as HDPE, LDPE, PP, PS, PMMA, PVC, ABS, SAN, Nylon6, 66, 12, PET, PBT, PC, and POM.

3.2 Injection moulding

(90 Periods)

Injection moulding process - advantages, disadvantages. Injection moulding machine - plunger type, screw type. Different parts of injection moulding machines and their respective functions. Screw Design - feed, transition and metering zones, L/D ratio, compression ratio. Clamping Systems - Manual clamping, Toggle clamping, Hydraulic clamping, and Tie bar less clamping. Moulds - two plate moulds, three plate moulds. Parts of moulds - Runner - cold runner, hot runner, gate, ejection systems, cooling channels. Process parameters - Shot weight, Barrel residence time, Clamping force, - melt and mould temperatures, screw speed, back pressure, injection pressure and holding pressure, injection speed, holding time, cooling time, mould open time. Moulding cycle. Processing defects, causes, and remedies.

3.3 Extrusion

(60 Periods)

Plastic extrusion fundamentals, classification of extruder, different parts and its function of screw extruder - feed hopper, extruder barrel and screw, feed, compression and metering zones, screw nomenclature, types of screws - polyolefin, PVC and Nylon screws, dies, screen pack, breaker plate, heating and cooling elements and drive system. Extrusion dies - solid cross section and hollow cross section dies. Sheet extrusion, profile extrusion, pipe extrusion, blown film extrusion, extrusion of cable. Extrudate swell, melt fracture.

3.4 Blow moulding and rotational moulding

(60 Periods)

Blow moulding - Different types of blow moulding - extrusion blow moulding, injection blow moulding, stretch blow moulding. Problems and trouble shooting in blow moulding. Rotational moulding - Advantages, disadvantages, Rotational moulding vs. blow moulding, applications. Faults and remedies in rotational moulding.

3.5 Thermoforming and calendaring

(60 Periods)

Thermoforming, materials for thermoforming, Different forming processes - Vacuum forming, pressure forming, matched mould forming, plug assisted forming, drape forming. Calendaring of plastics. Different types of calenders, gauge control - roll bending, roll crossing, and roll crowning.

3.6 Testing of plastics

(50 Periods)

Testing of plastics- Need for testing, Specifications and standards, specific gravity, Mechanical - Tensile and flexural properties, Impact strength. Hardness. Thermal - Melt flow Index, Vicat softening point, heat deflection temperature. Environmental stress crack resistance

Module 4

FIBRE REINFORCED COMPOSITES

4.1 Introduction to composites

(30 Periods)

Definition of composites, Basic features of composites, Constituents of composites - Matrix, reinforcement and interphase, Advantages, disadvantages and applications of composites. Classification of composites - based on matrix - Polymer matrix, Metal Matrix, Ceramic matrix, based on reinforcement - Fibrous, Flake filled, particulate filled, laminates, sandwiches, Oriented fibre - Uniaxial, Bi axial, Random fibre, Textile, Knitted, Braided.

4.2 Reinforcement Fibres

(40 Periods)

Functions of reinforcement, requirements of reinforcement fibres, terminology used in fibre science - filament, strand, roving, size, coupling agents, tex, tow, denier,

tenacity, drape etc. Forms of reinforcement - Reinforcing mat - Chopped strand mat (CSM), continuous filament mat, veil, woven roving/fabric.

Glass fibres - E-Glass, S-Glass, C-Glass, Carbon fibre, Aramid fibre, Boron fibre, UHMWHDPE, Natural fibres - Flax, Hemp, Jute, and Sisal

4.3 Matrix Materials and additives

(60 Periods)

Functions of matrix, Thermosets and thermoplastics, Polyester resins, Epoxy resins, Phenolic resins, Vinyl ester resins. Curing reactions, gelation and gel time, cure time, reaction rates. Catalyst or initiators - MEKP, Benzoyl Peroxide, Accelerators - cobalt naphthenate, Inhibitors- Tertiary Butyl Catechol, Curing agents - Amines, anhydrides, Fillers - Calcium carbonate, Talc, Clay, Silica, mineral fillers, Pigments and dyes, Lubricants, UV stabilizers, Anti static agents, heat stabilizers, Colorants Release agents and sealing compounds, Coupling agents. Core materials, Gel coats.

4.4 Manufacturing Methods

(140 Periods)

Introduction, Classification of FRP Manufacturing methods, Open mould processes - Hand lay-up, Spray lay-up, Filament Winding. Closed mould processes - Compression moulding - Dough moulding compound (DMC), Sheet moulding Compound (SMC) and prepregs, Vacuum bag moulding, Pressure bag moulding, autoclave moulding, Injection moulding, Resin transfer moulding, Vacuum assisted resin infusion moulding. Continuous processes - Pultrusion, Braiding.

4.5 Quality and safety in FRP processing

(70 Periods)

Storage of raw materials, Workshop conditions - Reinforcement preparation area, Compounding and mixing area, Mould preparation and moulding area, finishing area. Process care - Curing reaction, gel time, hardening time, maturing time, hot cure, cold cure, resin to glass ratio, degree of cure. Mould care. Preparation of moulds, Repair of composites - repair of gel coat layer, filling dents and cracks.

Module III
PLASTIC PROCESSING

Unit No.	Name of Units	Period
1	Introduction to plastic processing	20
2	Injection Moulding	90
3	Extrusion	60
4	Blow moulding and rotational moulding	60
5	Thermoforming and Calendaring	60
6	Testing of plastics	50
	Total	340

Module IV
FIBRE REINFORCED COMPOSITES

1	Introduction to composites	30
2	Reinforcement fibres	40
3	Matrix materials and additives	60
4	Manufacturing methods	140
5	Quality and safety in FRP processing	70
	Total	340

Module III

PLASTIC PROCESSING

Overview

Plastic material came in to existence by virtue of their superior performance and cost effectiveness over other conventional materials. Over the years application of plastics have been widened with the advent of new generation polymers, blends, alloys and composites. Everyday newer application are being promoted in key sectors of Indian economy like automobiles, agriculture, aerospace, building and construction, infrastructure, telecommunication, IT, medical and biomedical engineering, packaging etc. This in turn necessitates the need for different type of processing methods and machinery to produce quality plastic product at affordable cost.

In simple terms plastic processing is "Get the shape and set the shape". Plastic processing can be defined as the process of converting the plastic raw materials into semi-finished or finished products. Examples buckets, mugs, soap boxes, crates, tanks, pipes, shampoo bottles, carry bags, ropes, bumpers etc.

A sound judgment and experience is required for successful design and fabrication of good plastic product. Design of quality plastic product requires knowledge of advantages and limitation of plastics, familiarity with processing methods.

Worldwide extrusion consumes 36 wt: % of all plastic, injection moulding consuming 32 wt: %. Consumption by other process like blow moulding is 10% and calendaring 8%, compression moulding 3%, others 3%. Thermoforming which is the 4th major process used consumes at least 30% of extruded sheet and films that goes in to packaging.

After completing the module he/she will be able to identify various moulding machines and their parts. He will be able to identify various processing techniques used in plastic industry and he/she acquires hands on experience in semi automatic, automatic plastic processing machineries. He/she will be able to work as plastic compounder, operator, assistant technician of various plastic processing machineries, quality controller in plastic industries.

Unit I

INTRODUCTION TO PLASTIC PROCESSING

It is very difficult to realise how important plastics have become to our everyday lives. Plastics give us the possibility of manufacturing well-designed, beautiful products from the very many different types of plastics materials that are commonly available today. Thermoplastics are generally processed by injection moulding, blow moulding, extrusion, rotational moulding, thermoforming etc. Thermosetting plastics are processed by compression / transfer moulding and others. This unit aims to cover the basic plastic processing techniques and processing related properties of plastics.

Learning outcomes

The learner :

- Explain the basic plastic processing techniques such as injection moulding, blow moulding, extrusion processes
- Analyze the influence of polymer properties on the processing of polymers
- Describe the properties, applications and processing parameters of common plastics such as HDPE, LDPE, PP, PS, PMMA, PVC, ABS, SAN, Nylon6, 66, 12, PET, PBT, PC, PC-ABS Blends and POM.

Introduction

Plastic processing includes the various processing methods used to convert the plastic materials to useful end products. For producing good quality plastic products, first the processor needs to understand the performance requirement for specific end use and accordingly select material. The processing methods can be selected based on the processability of selected material and complexity of the part geometry.

Knowledge of all processing methods, including their capabilities and limitations, is useful to a processor in deciding whether a given part can be fabricated and by which process. Certain processes require placing high operating pressure on plastic such as those used in injection moulding, where pressure may be 2000 to 30000 psi. Lower pressure are used in extrusion and compression ranging from 2000 to 10000 psi; and some processes such as thermoforming and casting, operate at low pressures. Higher pressures allow the development of tighter dimensional tolerance with higher mechanical performance; but there is also a tendency to develop undesirable stress if the process is not controlled.

Plastic Processing Methods

There are a variety of methods used to process plastic. Each method has its advantages and disadvantages and are better suited for specific applications. These methods include: injection moulding, blow moulding, extrusion, rotational moulding, thermoforming, Calendaring, transfer moulding, and compression moulding.

Injection Moulding

The main method used for processing plastic is injection moulding. With this process, the plastic is placed into a hopper. The hopper then feeds the plastic into a heated injection unit, where it is pushed through a long chamber with a reciprocating screw. Here, it is softened to a fluid state. A nozzle is located at the end of the chamber. The fluid plastic is forced through the nozzle into a cold, closed mould. The halves of the mould are held shut with a system of clamps. When the plastic is cooled and solidified, the halves open and the finished product is ejected from the press. Injection moulding is mostly suited for thermoplastics. Thermosetting materials usually are not processed with injection moulding because they will soften, they harden to an infusible state. If they are processed with injection moulding, they need to be moved through the heating chamber quickly so they do not set.

Blow Moulding

Blow moulding is used when the plastic item to be created needs to be hollow. A molten tube called parison is extruded which is then blown using compressed air. The parison expands and conform to the chilled mould. Variations of blow moulding include injection, injection-stretch, and extrusion blow moulding.

Thermoforming

Thermoforming uses a plastic sheet, which is heated to its softening temperature and then shaped by pressing against a male or female mould. The pressure is created by applying vacuum or pressure or through mechanical assistance. The air pressure used can be nearly zero psi, or several hundred psi.

Compression Moulding

Compression moulding is the most common process used with thermosetting materials and is usually not used for thermoplastics. With this process, the material is squeezed into its desired shape with the help of pressure and heat. Plastic moulding powder and other materials are added to the mix in order to create special qualities or to strengthen the final product. When the mould is closed and heated, the material goes through a chemical change that causes it to harden into its desired shape.

Transfer Moulding

Transfer moulding is generally used only for forming thermosetting plastics. It is similar to compression moulding because the plastic is cured into an infusible state through pressure and heat. Unlike compression moulding, however, transfer moulding involves heating the plastic to a point of plasticity prior to being placed into the mould. The plastic is placed in a transfer pot in the mould and a hydraulically operated plunger is used to push and transfer the plastic into the cold cavity. Transfer moulding is used for moulding intricate products, such as those with many metal inserts or with small, deep holes.

Extrusion

The process of extrusion is usually used to make products such as film, continuous sheeting, tubes, profile shapes, rods, coat wire, filaments, cords, and cables. As with injection moulding, dry plastic material is placed into a hopper and fed into a long heating chamber. At the end of the chamber, however, the material is forced out of a small opening or a die in the shape of the desired finished product. As the plastic exits the die, it is placed on a conveyor belt where it is allowed to cool. Blowers are sometimes used to aid in this process, or the product may be immersed in water to help it cool.

Sl.No	Process	Typical Products
Primary Processing		
1	Injection Moulding	Combs, Mugs, Automobiles parts, Soap boxes, Gears, Crates, etc
2	Blow Moulding	Water Bottles, Jerry Cans, Shampoo Containers, Pharmaceutical Containers, etc
3	Extrusion	Pipes, Sheets, Ropes, Monofilaments, Profiles Blown films, Cast Films, Bopp, etc
4	Compression Moulding	Cooker handles, Knobs, Washing Machine Parts, Engine Casings , Plug & Sockets
Secondary Processing		
5	Transfer Moulding	House wares, Switches, Electrical Connectors, Junction Boxes
6	Rotational Moulding	Water Tanks, Dustbins, Double walled trays, Balls
7	Thermoforming	Disposable Cups, Trays, Sign boards, Wall Covering
8	Casting	Acrylic Sheet, Nylon Cast Products, Toys etc.
9	Coating	Artificial Leather Cloth, Coated Playing Cards, etc.,

Processability

Processability means generally the ease or difficulty with which a plastic can be handled during its fabrication into films, moulded products, pipes etc. The main characteristics or properties which determine a plastic's processability are molecular weight, uniformity, additive type and content, and plastic feed rates.

The type of process to be used depend on a variety of factors including product shape and size, plastic type, quantity to be produced, quality and accuracy, design load performance, cost limitation and time schedule. Each of the processes provide different methods to produce different products. As an example extrusion with its many methods produce films, pipe, sheet, profile, wire coating, etc.

Some products are limited by economics of the process that must be used to make them. For example, hollow parts particularly very large ones, may be produced more economically by the rotational process than by blow moulding. Thermosets cannot be blow moulded and they have limited extrusion possibilities. The need for a low quantity may allow certain processes to be eliminated by going to casting.

Compression and transfer moulding processes by virtue of their high cycle time and energy losses due to repeated heating and cooling of the mould are not preferred for moulding of thermoplastic.

Extrusion produces relatively uniform profiles at unlimited length. Casting is not limited by pressure requirements, so large sheets can be produced. Calendered sheets are limited in their width of the roll but are unlimited in length. Vacuum forming is not greatly limited by pressure, although even a small vacuum distributed over a large area can build up an appreciable load. Blow moulding is limited by the equipment that is feasible for the mould size. Rotational moulding can produce relatively large parts with stress free moulding.

Injection moulding and extrusion tend to align long chain molecules in the direction of flow. This produces markedly greater strength in the direction of flow than at right angles to the flow. This can result in stress built up

Effect of polymer properties on processing

When processing thermoplastic melts the following factors should be taken in to account in order to process efficiently and to obtain quality product.

Water absorption

Water/ Moisture is the greatest enemy for processing of plastic.

- Hygroscopic material
- Absorption phenomena -: Nylon, POM, PC.
- Adsorption phenomena -: HIPS, PS, ABS
- All these material should be pre dried
- Non Hygroscopic material -: PVC, Polyolefin's etc.
- Need not be pre dried except when completely wet during monsoon. Action necessary
 1. Use granules as soon as the bag is opened
 2. Pre drying ovens. Hopper drier, dehumidifying drier can be used
 3. For PC dehumidifying drier preferable

Physical form of raw material

- Powder form, granular form, lumpy/slab form
- Slab form - calendaring, compression moulding,
- Granular form - Preferred - uniform pellet size ensure even faster and feeding
- Powder form - Difficulty in feeding - But savings in cost because of the ability to avoid pelletizing stage - Special feeder attachment essential to ensure proper feeding

Thermal stability of polymers

1. PVC thermally sensitive material - Little higher melt temperature may lead to deprecation - HCL is released - - This can leads to corrosion and harmful to human being PID Temperature controller can be used.
2. PMMA, POM upon deprecation liberates MMA & formaldehyde respectively - MMA volatilize and cause bubbles - Formaldehyde gas causes eye irritation
3. PVC & POM should never be processed one after the other, this may lead to explosion

Adhesion of melt to metal

- Wetting of the polymer melt against the metal wall of processing equipment can lead to strong adhesion of polymer to melt. EX: difficulty in removing PVC - Mix from two roll mill.
- PC has strong adhesion to metal. It can take away the skin of barrel if it not properly purged

Common Plastic Materials

Important properties, applications and processing temperatures of common plastics are given below.

LDPE (Low Density Polyethylene)

General Characteristics	LDPE is a low cost semi crystalline polymer with good moisture resistance and flexibility and is very much suitable for general purpose applications
Applications	General purpose goods, Packaging films, bags, containers, electrical insulation, flexible bottles
Processing temperature range	170 - 270°C
Mould temperature range	20 - 40°C

HDPE (High Density Poly Ethylene)

General Characteristics	HDPE is a highly crystalline opaque polymer with low moisture absorption. It has high tensile strength, chemical resistance, and impact resistance.
Applications	General purpose goods, Packaging films, bags, containers, tanks electrical insulation
Processing temperature range	200 - 280°C
Mould temperature range	40 - 90°C

PP (Poly Propylene)

General Characteristics	PP is a semi crystalline polymer with high impact resistance and melt flow rates. PP acts as a living hinge and hence used in hinged packaging applications. PP is difficult to bond with adhesives and has poor low temperature impact strength.
Applications	Automotive, films, containers, General purpose goods, furniture, living hinge applications and industrial products
Processing temperature range	200 - 265°C
Mould temperature range	20 - 60°C

Poly Vinyl Chloride (PVC)

General Characteristics	PVC is an amorphous thermoplastic that is difficult to process. PVC is often plasticized with different levels of plasticizers. Rigid PVC has strong chemical resistance and moderate temperature resistance. PVC has poor UV resistance.
Applications	Wire coating, tubing, pipes, conduits, automotive, electronics, profiles, medical, door/ window frames etc
Processing temperature range	165 - 205°C
Mould temperature range	20 - 50°C

ABS (Acrylonitrile butadiene styrene)

General Characteristics	ABS is an amorphous terpolymer of acrylonitrile, butadiene and styrene. It has good flame retardant properties, high impact resistance and good finish. ABS has poor weathering resistance.
Applications	General purpose, Automotive, electrical and electronics
Processing temperature range	220 - 260°C
Mould temperature range	50 - 90°C

Acetal or POM (Polyoxymethylene)

General Characteristics	POM is a highly crystalline polymer with good creep, fatigue, solvent, and wear resistance. POM has high strength and stiffness and good electrical properties
Applications	Automotive and industrial bearings, gears etc
Processing temperature range	190 - 215°C
Mould temperature range	50 - 90°C

Poly Styrene (PS)

General Characteristics	PS is an inexpensive amorphous polymer with great optical clarity. Unfilled PS is rigid and brittle. PS has poor thermal stability and solvent resistance. It can be processed by most plastic processing techniques
Applications	Toys, packaging, sheets, thermal insulation, food containers, disposable glasses etc
Processing temperature range	175 - 275°C
Mould temperature range	50 - 150°C

Poly Methyl Methacrylate (PMMA)

General Characteristics	PMMA is a low cost transparent amorphous thermoplastic. It has good optical clarity. It is also more environmentally stable than PS and PE
Applications	Automotive lights, TV screens, Furniture, Windows, Medical
Processing temperature range	175 - 260°C
Mould temperature range	40 - 90°C

NYLON - 6

General Characteristics	Nylon 6 is a semi crystalline poly amide with great toughness and elasticity which makes it suitable for textile and industrial fabrics. It has high tensile strength and chemical resistance.
Applications	Textile fibres, gear, surgical sutures, zip fasteners
Processing temperature range	240 - 270°C
Mould temperature range	50 - 95°C

NYLON - 66

General Characteristics	Nylon 12 is a semi crystalline poly amide with good toughness and abrasion resistance.
Applications	Textiles, tyre cords, airbags, carpets.
Processing temperature range	260 - 300°C
Mould temperature range	40 - 95°C

NYLON - 12

General Characteristics	Nylon 12 is a semi crystalline poly amide with great dimensional stability, impact strength and chemical resistance.
Applications	Components of appliances, Automotive parts, Cell phones, gears, medical and sporting goods etc
Processing temperature range	230 - 300°C
Mould temperature range	40 - 90°C

SAN (Styrene Acrylonitrile)

General Characteristics	SAN is an amorphous co polymer of styrene and acrylonitrile. SAN has higher strength, rigidity, and chemical resistance than poly styrene but lacks optical clarity.
Applications	Electrical appliances, cosmetics, medical, containers, and automotive application
Processing temperature range	215 - 260°C
Mould temperature range	45 - 80°C

PET (Polyethylene terephthalate)

General Characteristics	PET is a semi crystalline thermoplastic commonly used for polyester fibres and plastic bottles. It has excellent chemical resistance and temperature resistance of more than 1000C
Applications	Bottles, fibres, films, and packaging
Processing temperature range	250 - 305°C
Mould temperature range	20 - 90°C

PBT (Polybutylene terephthalate)

General Characteristics	PBT is a semi crystalline polyester with good stiffness and toughness. PBT has similar properties to some nylons, but with much less water absorption. PBT can withstand continuous use temperature of 1200C and is often used as an electrical insulator
Applications	Automotive, Industrial, Electronics, housings, Medical
Processing temperature range	230 - 260°C
Mould temperature range	40 - 95°C

PC (Poly Carbonate)

General Characteristics	PC is an amorphous polymer with great impact resistance and optical clarity along with good heat resistance, toughness, and dimensional stability. It has poor chemical and scratch resistance.
Applications	Exterior automotive components, Engineering components, lenses, structural parts, medical components and bullet proof sheeting
Processing temperature range	260 - 325°C
Mould temperature range	70 - 105°C

DETAILING OF PRACTICALS

1) Identification of plastics

Identify the given plastic sample (PE, PVC, and Nylon) through physical and chemical analysis

ASSESSMENT ACTIVITIES

Quiz, Oral Test

Group Discussion on processing related properties of plastics

Theory Evaluation Questions

- 1) Define the term 'Plastic processing'
- 2) Classify different plastic processing methods
- 3) "Compression moulding of thermoplastics is not preferred industrially". Do you agree with this? Give reasons
- 4) Arrange the following plastics in the ascending order of their melting point
Nylon 66, Poly carbonate, HDPE, PBT, PMMA, PVC
- 5) Identify a plastic suitable for producing a moulded hinged product.
 - a) LDPE, b) PP, c) PVC, d) Nylon
- 6) Identify the plastic used for producing Bullet proof materials
 - a) PBT, b) PET, c) PC, d) Nylon
- 7) 'Certain plastic materials like nylon are dried in an oven to remove moisture before processing'. Explain the effect of moisture absorption on the processing of plastics.
- 8) For the production of water tanks which of the following methods can be used?
 - a) Thermoforming, b) Blow moulding, c) rotational moulding, d) Extrusion

Unit II

INJECTION MOULDING

Injection moulding is one of the most common methods of converting plastic raw material to a product. This process is used for thermo plastic material and other polymeric material which may successively be melted, reshaped and cooled. Injection moulded plastic components find applications as components of almost every functional manufactured article in the modern world, from automotive products to food packaging to common house hold articles. This versatile process allows rapid production of high quality, simple or complex components on a fully automated basis. This unit covers the basic features of injection moulding, different types of injection moulding machines, clamping units and moulds, operation cycle and troubleshooting guide.

Learning outcomes

The learner :

- Describe the injection moulding process with its advantages and disadvantages.
- Distinguish different types of injection moulding machines and describe the different parts of injection moulding machines and their respective functions
- Explain the screw design and screw nomenclature of injection moulding screws.
- Explain the different types of injection moulds, their parts and functions and different clamping systems
- Describe the processing variables such as shot weight, barrel residence time, clamping force etc.
- Demonstrate the setting of processing parameters in injection moulding machine and operation of injection moulding machine
- Analyse the processing problems and solutions in injection moulding

Introduction

The injection moulding process is a semi continuous process where, thermoplastic material is softened by heating, formed under pressure and hardened by cooling. In this process, a definite quantity of molten thermoplastic material is injected under pressure into a relatively cold mould where it solidifies in to the shape of the mould.

Advantages of injection moulding

- Parts can be produced at high production rates
- Large volume production is possible
- Relatively low labor cost per unit is obtainable
- Parts require little or no finishing
- Many different surface, colour and finishes are available
- Good decoration is possible
- For many shapes this process is the most economical way to fabricate
- Permits the manufacture of very small parts in large quantities which are almost impossible to fabricate by other methods
- Minimal scrap loss result as runner, gates and rejects can be reground and reused
- Close dimensional tolerance can be maintained
- Parts can be moulded with metallic and non metallic inserts

Limitations of injection moulding

- Intense industry competition often results in low profit margins
- Mould cost are high
- Moulding machinery and auxiliary equipment costs are high
- Lack of knowledge about the fundamentals of the process causes problems
- Lack of knowledge about the long term properties of the material may results in long term failures

Injection moulding machine

Injection moulding machines consist of two basic parts, an injection unit and a clamping unit. Injection moulding machines differ in both injection unit and clamping unit. The name of the injection moulding machine is generally based on the type of injection unit used.

There are four principle type of injection moulding machine

1. Single stage plunger type
2. Two stage plunger type
3. Two stage screw plunger
4. Reciprocating screw

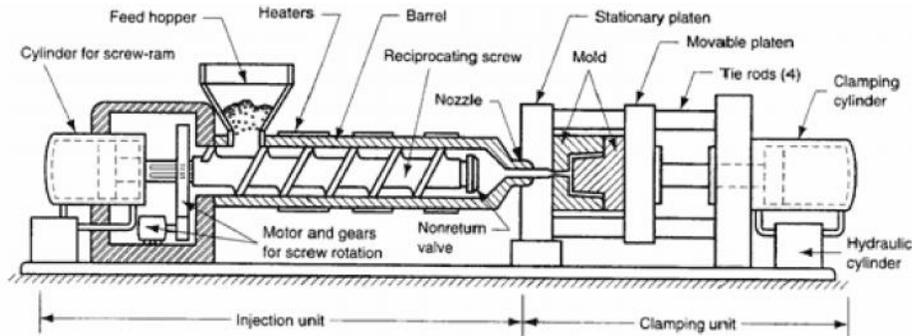


Fig. 3.2.1 Injection moulding machine

Injection unit

The injection unit melts the polymer resin and injects the polymer melt into the mould. The unit may be: ram fed or screw fed.

The ram fed injection moulding machine uses a hydraulically operated plunger to push the plastic through a heated region. The high viscosity melt is then spread into a thin layer by a "torpedo" to allow for better contact with the heated surfaces. The melt converges at a nozzle and is injected into the mould.

Reciprocating screw is a combination of melting, softening, and injection unit in an injection moulding machine. Reciprocating screws are capable of turning as they move back and forth. The reciprocating screw is used to compress, melt, and convey the material. The reciprocating screw consists of three zones (illustrated below):

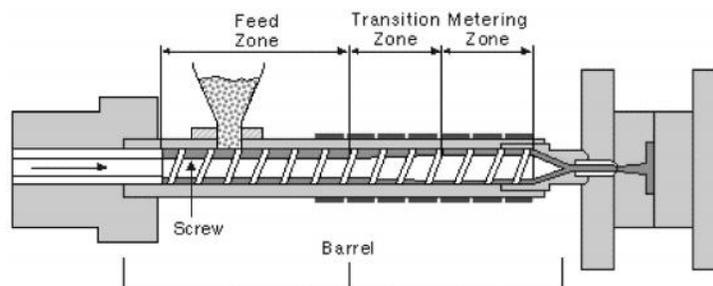


Fig: 3.2.2. Screw Injection moulding machine

Zones of reciprocating screw type injection moulding machine

- Feed zone
- Compression zone/ transition zone
- Metering zone

While the outside diameter of the screw remains constant, the depth of the flights on

the reciprocating screw gradually decreases in the transition zone. These flights compress the material against the inside of the barrel, which creates frictional heat. This heat is mainly responsible for melting the material. The heater bands outside the barrel help maintain the material in the molten state. Typically, a moulding machine can have three or more heater bands or zones with different temperature settings.

In reciprocating type injection moulding, a screw rotates within a cylinder, which is driven by a hydraulic drive mechanism. Plastic material is moved through the heated cylinder via the screw flights and the material becomes fluid. The injection nozzle is blocked by the previous shot, and this action causes the screw to pump itself backward through the cylinder. During this step, material is plasticized and accumulated for the next shot. When the mould clamp has locked, the injection phase takes place. At this time, the screw advances, acting as a ram. Simultaneously, the non-return valve closes off the escape passages in the screw and the screw serves as a solid plunger, moving the plastic ahead into the mould. When the injection stroke and holding cycle is completed, the screw is energized to turn and the non-return valve opens, allowing plastic to flow forward from the cylinder again, thus repeating the cycle.

Feed hopper

The container holding a supply moulding material to be fed to the screw. The hopper located over the barrel and the feed throat connects them.

Injection ram or screw

The ram or screw that applies pressure on the molten plastic material to force it into the mould cavities. The reciprocating-screw machine is the most common. This design uses the same barrel for melting and injection of plastic.

L/D Ratio

The L/D (length/diameter) ratio is an important concept for determining the sizing of an injection unit. In the injection moulding process, screws with L/D ratios of 18: 1 and 20: 1 are typically used.

Compression Ratio

Compression ratio is a term used to give an idea of how much the screw compresses and squeezes the melt-molten material mix in the screw. The depth of the screw channel is used to calculate the compression ratio. The equation to determine the compression ratio is

$$\text{Compression ratio} = \frac{\text{Channel depth in the feed section}}{\text{Channel depth in the metering section}}$$

Typical compression ratio values range from 1.2 to 4.0 for most thermoplastics.

Barrel

Barrel is the cylindrical chamber in which the screw rotates. The resin from the feed hopper is melted in the barrel as it passes between the barrel and the screw. A band heater, which can control temperatures in five sections, is attached outside the barrel. Melted resins are supplied to the mould passing through barrel head, shot-off nozzle, and one-touch nozzle.

Injection cylinder

Injection cylinders supply the necessary power to inject the resin into the mould. It is operated by a hydraulic motor located inside bearing box.

Clamping unit

The clamping unit holds the mould together, opens and closes it automatically, and ejects the finished part. The mechanism may be of several designs, mechanical, hydraulic or hydro mechanical.

Toggle clamps - consists of two bars joined together end to end with a pivot. The end of one bar is attached to a stationary platen and the other end of the second bar is attached to the movable platen. When the mould is open, the toggle is in the shape of V, when the pressure is applied to the pivot, the two bars form a straight line. Toggle clamps are actuated either by hydraulic cylinders or ball screws driven by electric motors. Toggle-clamp units seem most suited to relatively low-tonnage machines. The following figure shows (a) toggle clamp design (1) open and (2) closed; and (b) hydraulic clamping (1) open and (2) closed.

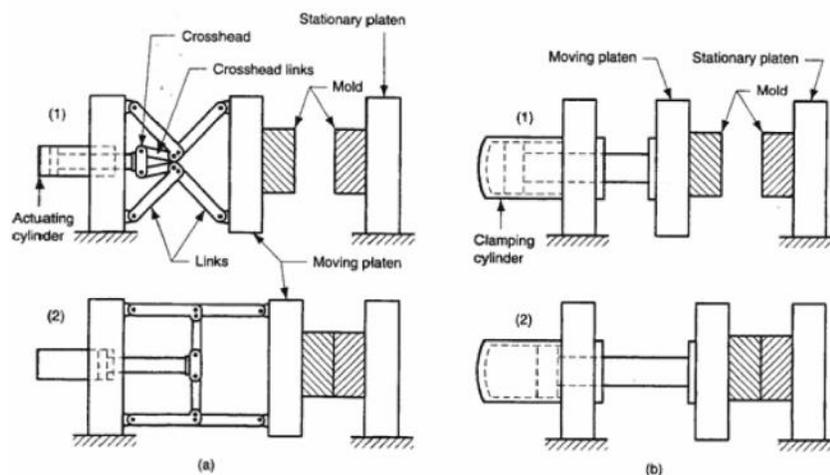


Fig: 3.2.3 Clamping unit (a) Toggle clamps (b) hydraulic clamps

Hydraulic clamps are used on higher-tonnage injection moulding machines, typically in the range 1300 to 8900 kN (150 to 1000 tons). The clamping unit is actuated by a hydraulic cylinder which is directly connected to the moving plate of the mould. When the oil goes to the cylinder it pushes the ram forward and the mould is closed. When the oil is taken back from the cylinder, the ram comes back and the mould is opened.

Advantages of hydraulic clamping.

- Clamp speed can easily be controlled and be stopped at any point
- Direct read out of clamp force
- Easy adjustment of clamp force and mould set up
- Low maintenance as part is self lubricate

Hydromechanical clamps - clamping units are designed for large tonnages, usually above 8900 kN (1000 tons); they operate by (1) using hydraulic cylinders to rapidly move the mould toward closing position, (2) locking the position by mechanical means, and (3) using high pressure hydraulic cylinders to finally close the mould and build tonnage.

Tie- bar less clamping - The tie-bar less clamping system is basically a hydraulic clamping system without any tie bar. The platen is moved on a rail system. The main advantage of this system is that there is no limitation on the mould platen size. Also mounting the mould is easy and is very useful when the products eject from the mould is manually.

Injection mould

Mould is a hollow form or cavity into which molten plastic is forced to give the shape of the required component. Moulds separate into at least two halves (called the core and the cavity) to permit the part to be extracted; in general the shape of a part must be such that it will not be locked into the mould.

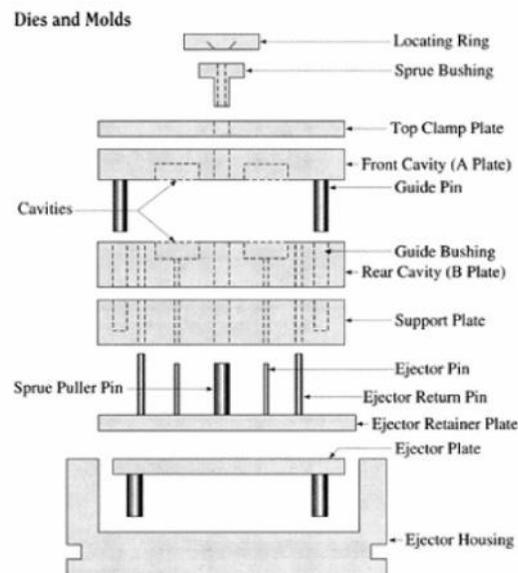


Fig: 3.2.4 Injection mould

For example, sides of objects typically cannot be parallel with the direction of draw (the direction in which the core and cavity separate from each other). They are angled slightly; examination of most household objects made from plastic will show this aspect of design, known as draft. Parts that are "bucket-like" tend to shrink onto the core while cooling and, after the cavity is pulled away, are typically ejected using pins. Parts can be easily welded together after moulding to allow for a hollow part (like a water jug or doll's head) that couldn't physically be designed as one mould.

More complex parts are formed using more complex moulds, which may require moveable sections, called slides, which are inserted into the mould to form particular features that cannot be formed using only a core and a cavity, but are then withdrawn to allow the part to be released. Some moulds even allow previously moulded parts to be re-inserted to allow a new plastic layer to form around the first part. Traditionally, moulds have been very expensive to manufacture; therefore, they were usually only used in mass production where thousands of parts are being produced.

There are two main types of injection moulds: cold runner (two plate and three plate designs) and hot runner - the more common of the runner less moulds.

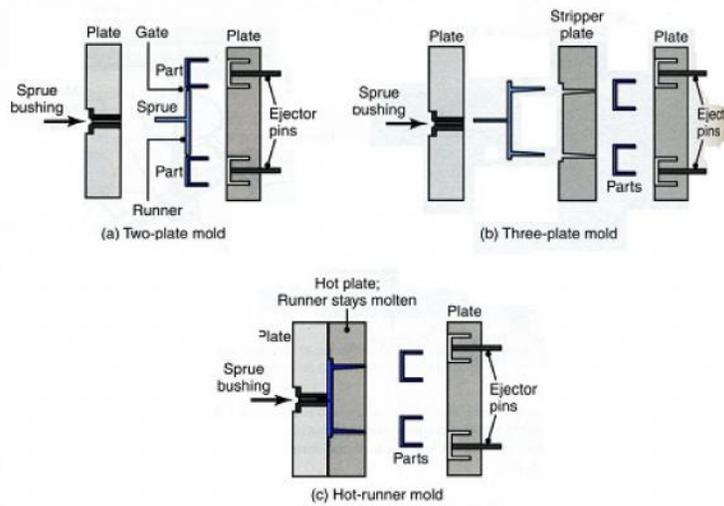


Fig: 3.2.5 Types of mould used in injection moulding

Cold runner

After moulding the cold runner delivery system is trimmed off and recycled. Therefore the delivery system is normally designed to consume minimum material, while maintaining the function of delivering molten plastic to the cavity in a desirable platen

Hot runners

The hot runners (runner less) moulding process keeps the runners hot in order to maintain the plastic in a molten state all times.

Gates

- is an opening found at the entrance of the cavity (end of the runner) which allows the material to enter the cavity. The various types of gates are shown in the following figure

Injection platens

are steel plates on a moulding machine to which the mould is attached. Generally, two platens are used; one being stationary and the other moveable, actuated hydraulically to open and close the mould. It actually provides place to mount the mould. It contains threaded holes on which mould can be mounted using clamps.

Clamping cylinder

A device that actuates the chuck through the aid of pneumatic or hydraulic energy.

Tie Bar

Tie bars support clamping power, and 4 tie bars are located between the fixing platen and the support platen.

Ejection system

The ejection system will push the part out of the mould when it is stopped

- Knockout pins
- Blades
- Stripper
- Air
- Hard stripping

Process Parameters

Back pressure

Back pressure is the amount of pressure exerted on the material volume ahead of the screw, as the screw is pushed back in preparation for the next shot.

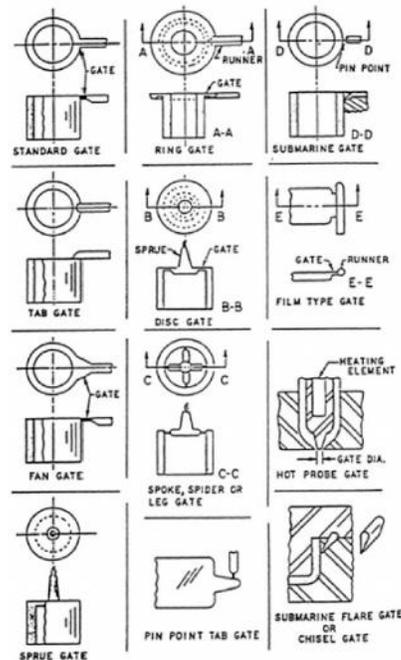


Fig: 3.2.6 Types of gates

Injection speed

The injection speed or (ram speed) is the forward speed of the screw during its injection operation.

Shot weight

This is the maximum weight of plastic that can be injected by a single injection stroke, when the nozzle is free standing. Generally expressed as ounces of polystyrene with a specific gravity of 1.05. For other resins the shot weight is calculated as

Shot weight in terms of resin = $M * b/1.05$

Where b =specific gravity of resin, M = shot weight in terms of PS, $SG=1.05$

Shot weight should not be equal to the combined weight of the article (or article for multi cavity mould) plus runners that could be injection moulded.

The latter is set as the 80% of the shot weight for article with low requirement, 75% of shot weight for the article with high requirement.

Barrel residence time

Barrel residence time is the time for which the plastic material stays inside the barrel before getting injected. It is calculated as

Barrel residence time = (weight the melt in barrel *cycle time)/ actual shot weight

If a big machine is used to make small articles, the melt in the barrel could degrade due long residence time.

Clamping force

It is the maximum force that the machine is capable of to keep the mould closed against the cavity pressure during injection.

Injection pressure

The pressure on the face of the injection screw or ram when injecting material into the mould, usually expressed in psi.

Moulding cycle

The basic injection cycle is as follows

Mould close - injection carriage forward - inject plastic - metering - carriage retract - mould open - eject part(s) Some machines are run by electric motors instead of hydraulics or a combination of both. The water-cooling channels that assist in cooling the mould and the heated plastic solidifies into the part. Improper cooling can result in distorted moulding. The cycle is completed when the mould opens and the part is ejected with the assistance of ejector pins within the mould.

The resin, or raw material for injection moulding, is most commonly supplied in pellet or granule form. Resin pellets are poured into the feed hopper, a large open bottomed container, which is attached to the back end of a cylindrical, horizontal barrel. A screw within this barrel is rotated by a motor, feeding pellets up the screw's grooves. The depth of the screw flights decreases toward the end of the screw nearest the mould, compressing the heated plastic. As the screw rotates, the pellets are moved forward in the screw and they undergo extreme pressure and friction which generates most of the heat needed to melt the pellets. Electric heater bands attached to the outside of the barrel assist in the heating and temperature control during the melting process.

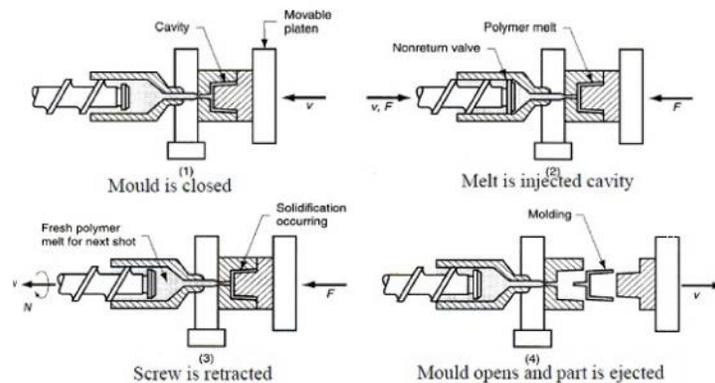


Fig: 3.2.7 Typical moulding cycle

The channels through which the plastic flows toward the chamber will also solidify, forming an attached frame. This frame is composed of the sprue, which is the main channel from the reservoir of molten resin, parallel with the direction of draw, and runners, which are perpendicular to the direction of draw, and are used to convey molten resin to the gate(s), or point(s) of injection. The sprue and runner system can be cut or twisted off and recycled, sometimes being granulated next to the mould machine. Some moulds are designed so that the part is automatically stripped through action of the mould.

Processing defects, causes and remedies

Injection moulding is a complex technology with possible production problems. They can either be caused by defects in the moulds or more often by part processing (moulding)

Table: 3.2.2 Common defects in injection moulding

Moulding Defects	Description	Causes
Blister	Raised or layered zone on surface of the part	Tool or material is too hot, lack of cooling around the tool or a faulty heater
Burn marks Air Burn/ Gas Burn	Black or brown burnt areas on the part located at furthest points gate	Tool lacks venting, injection speed is too High
Color streaks	Localized change of Colour	Master batch isn't mixing properly, or the material has run out
Delamination	Thin mica like layers formed in part wall	Contamination of the material e.g. PP mixed with ABS
Flash Burs	Excess material exceeding normal part geometry	Tool damage, too much injection speed/ material injected, clamping force too low.
Embedded Contaminates	Foreign particle (burnt material or other) embedded in the part	Contaminated material or foreign debris in the barrel, or too much shear heat burning the material prior to injection
Flow marks	Directionally "off tone" wavy lines or patterns	Injection speeds too slow, the plastic has cooled down too much during injection,
Jetting	Deformed part by turbulent flow of material	Poor tool design, gate position or runner. Injection speed set too high.
Polymer Degradation	polymer breakdown from hydrolysis, oxidation etc	Excess water in the granules, Excessive temperatures in barrel
Sink marks	Localized depression (In thicker zones)	Holding time/pressure too low, cooling time too low, with sprueless hot runners this can also be caused by the gate temperature being set too high
Short shot	Partial part	Lack of material, injection speed or pressure too low
Splay marks Splash mark/ Silver streaks	Circular pattern around gate caused by hot gas	Moisture in the material, usually when hygroscopic resins are dried improperly
Stringiness	String remain from previous shot transfer in new shot	Nozzle temperature too high. Gate hasn't frozen off
Voids	Empty space within part (Air pocket)	Lack of holding pressure Mould may be out of registration
Weld line Knit line	Discolored line where two flow fronts meet	Mould/material temperatures too low, the material is cold when they meet, so they don't bond
Twisting	Distorted part	Cooling is too short, material is too hot, the parts bow inwards towards the hot side of the tool.

DETAILING OF PRACTICALS

1) Work practice on hand injection moulding machine

Procedure

Switch on the heater and wait for the required melt temperature to reach. Set the mould in the correct position. When the temperature is reached feed the plastic material into the feed hopper. Repeated plunging is done until we get a new material. Inject the melt into the mould. The pressure is maintained on the plunger for the period during which the material in the mould cools and contracts. After solidification of the melt in the mould the plunger is retracted. The mould is released, opened and the part is taken out. Again the mould is clamped for another cycle.

2) Work practice on semi automatic injection moulding machine

Procedure

Set the mould and align with mould with the injection nozzle and clamp. Set the barrel temperature and switch on the heaters. Set the injection pressure. When the temperature is reached add the plastic granules into the feed hopper. When granules are melted, the plunger is operated for injection into the mould. The pressure is maintained during solidification. After solidification the plunger retracts and the mould is removed and opened.

ASSESSMENT ACTIVITIES

Assignment - diagram of injection moulding machine

Assignment - Screw design and screw types

Chart - Processing defects causes and remedies

Class test

Theory Evaluation Questions

- 1) Compare the advantages and disadvantages of a screw injection machine and plunger machine?
- 2) Compare between toggle clamping and hydraulic clamping
- 3) Suggest a moulding cycle in a fully automatic injection moulding machine
- 4) Name three important parameter that should be inspected by the operator
- 5) With the help of a neat sketch explain the working of injection moulding machine
- 6) Prepare a neat sketch of an injection mould and label the following parts
Cavity, Runner, gate, ejector pins,
- 7) Write four faults and suggest their remedies in injection moulding

Unit III

EXTRUSION

Introduction

The extruder is one of the most important machinery in the polymer processing industry. To extrude means to push or to force out. Material is extruded when it is pushed through an opening. When toothpaste is squeezed out of a tube, it is extruded. The part of the machine containing the opening through which the material is forced is referred to as the extruder die. As material passes through the die, the material acquires the shape of the die opening. The extruded product is referred to as the extrudate. Extrusion is used for producing continuous profiles and pipes. This unit deals with different types of extruders, their parts, functions and operation of extruders, manufacture of pipes, cables, packing films etc

Learning outcomes

The learner :

- Describes the plastic extrusion process
- Distinguishes the different types of Extruders and describe the different parts of extruders and their respective functions.
- Explains the screw design and different types of screws in extrusion
- Describes the production of pipes, profiles, cables, and blown films.
- Demonstrates the extrusion operation
- Analyses the problems and solutions arising in extrusion process

Extrusion

Extrusion is the process by which long continuous plastic products such as pipes, hoses, profiles etc are manufactured. The extrusion process involves forcing the molten plastic materials through a die of specified cross section under controlled conditions. An extruder consists of a barrel and a screw rotating inside the barrel. The plastic granules are fed to the extruder through a feed hopper at the rear end of the extruder. As the screw rotates the material is heated, melted, compacted and forced through a die of desired cross section. The extrudate emerging from the die is cooled and cut into desired lengths. Fig. 3.3.1 shows a schematic representation of the extruder.

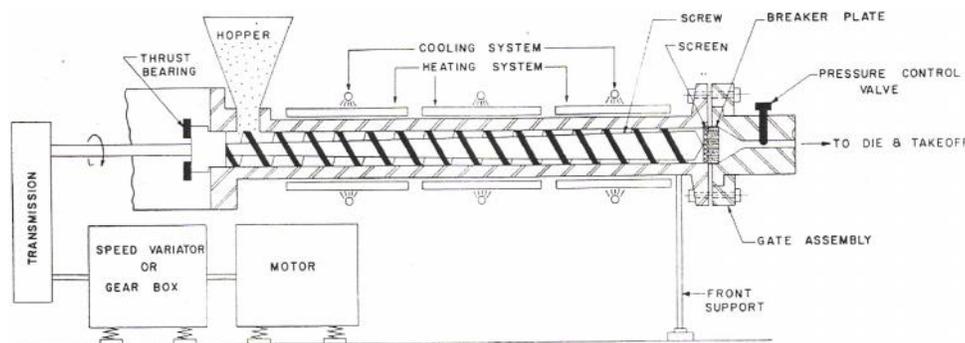


Fig: 3.3.1 Schematic representation of an extruder

Classification of Extruders

Extruders can be classified as

Batch Type

- Ram Extruders
- Reciprocating screw Extruders

Continuous type

- Single screw extruder
- Twin Screw extruder
- Multi Screw Extruder

In the industry, screw extruders dominate, in particular single screw extruders are the work horse of the extrusion industry. Although the twins screw extruders are progressively gaining popularity.

Single-Screw Extruders

Single crew extruders consists of a single screw rotating inside the barrel. Single-screw extruders usually convert granular resin feeds into sheets, films, pellets, and shapes such as pipe. These extruders are described by their screw diameters (in inches or millimeters) and by their L/D ratio, L being the screw length and D the screw diameter. Single-screw extruders are available in almost any size imaginable. Common sizes are 5/8, 3/4, 1, 1 1/2, 2 1/2, 3 1/2, 4 1/2, 5 1/2, 6, 8, 12, 15, and 20 in. L/D ratios range from 5:1 to 48:1, with 20:1 to 30:1 being some of the common choices.

Twin-Screw Extruders

Machines using twin screws are generally large-volume production units used for resin pelletizing in petrochemical plants. They are equipped with various combinations

of intermeshing and nonmeshing screws that can be either the co-rotating or the counter-rotating variety. The following types of processing can be performed in a single machine: 1) melting, 2) mixing and blending, 3) homogenizing, gelling, and dispersing, 4) reacting, 5) pumping, 6) compounding and formulation, 7) devolatilizing and degassing, and 8) drying.

The twin-screw extruder is normally selected as the solution to many compounding and reactive extrusion tasks. Twin-screw extruders can be either intermeshing or nonintermeshing. Nonintermeshing extruders behave like two single screw extruders with only minor interactions between the two screws. A further subdivision of twin-screw types is the direction of rotation. Co-rotating extruders have both screws rotating in the same direction, and therefore the material is exchanged between the screws, while counter-rotating screws transport the process material through the extruder in a figure eight channel.

Compounding requires that the resin be melted and homogenized while incorporating additives or fillers at a given shear level. The key is the isolation of the high, medium, and low shear sections along the screw length, as well as the feeding of additives at the appropriate points. The advantages of twin screws include the capability for mixing, dispersion, and heat control in addition to efficient conveying.

Components of an extruder:

The principal components of an extruder are as listed below

1. Feed Hopper
2. Extruder Screw and barrel
3. Die
4. Heating and cooling elements
5. Screen pack and breaker plate
6. Drive system

Feed Hopper

The purpose of the feed hopper is to transfer the polymer into the extruder barrel. The hopper is designed to have a steady flow of polymer into the extruder. Flow in hoppers depends on their type - gravitational or forced, bulk density of the material, the shape and location of the feed inlet.

Extruder screw and Barrel

The screw and barrel are the heart of the extruder. It takes the feed polymer from the hopper, which is then heated, plasticized and extruded through the die. The

extruder screw is divided into three zones - feed zone, compression zone, and metering zone.

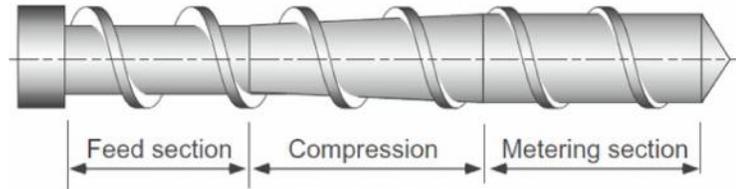


Fig: 3.3.2 Extruder screw

Feed zone: Feed zone comprises of the first 3-10 turns of the screw flight, located directly under the feed throat. Its functions are to collect the granules from the feed hopper, compact the granules and heat them up and convey the material to the next zone

In the feed zone, the screw has a small, constant root diameter. This enables larger intake of the plastic resin enhancing the extruder output. To prevent premature melting of the granules in the feeder throat, the temperature of this zone is kept lower than the others. Usually hopper cooling is also used

Compression or Transition zone: In the metering zone, the channel depth of the screw progressively decreases, thus compressing the plastic resin and forcing the gases and volatiles from the melt to flow back to the feed hopper. Due to the progressive compression of the polymer in this zone, the material starts to soften and melts under the action of heat and shear. The length of this zone depends on the type of material to be processed.

Metering zone: Metering zone is characterized by a constant root diameter and a narrow channel depth. In the metering zone the mix is brought to the correct consistency and uniform temperature and builds up pressure so that the resin can be pushed out through the die. This zone extends to the outlet of the extruder and thus it consists of the screen pack, the breaker plate and the die

Screw

Different types of screws are developed for extrusion of various plastic materials. The important features of the screws are

Screw pitch (P) - is the distance between the centre of two adjacent flights

Channel width (W) - is the gap between two adjacent flights

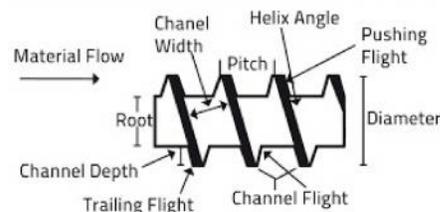


Fig: 3.3.3 Screw Nomenclature

Land width (L) - is the width of the flight

Helix angle - defines the slope of the flight of the screw. It is the angle of the flight to the transverse plane of the screw axis

Screw diameter (D) - is the diameter of the screw including the flight

Flight - is the helical thread on the screw

Root Diameter - is the diameter of the screw excluding the flight.

Channel Depth - is the distance from the bore of the barrel to the root of the screw.

Extruder size - Nominal diameter of the screw is used to specify and extruder

L/D ratio - Ratio of the length of the flighted portions of the screw to the nominal diameter of the screw. Normal L/D ratios are 22 -24 : 1

Higher L/D ratio - gives longer residence time, greater output, uniform output and greater mixing, greater mixing at less shear and more heating from the barrel

Short L/D ratio - results in short residence time that facilitates the processing of heat sensitive materials, less space, lower torque (high strength to screw and less horse power), lower cost

Compression ratio

Compression ratio is the ratio between the channel depth in the flight of the feed zone to the channel depth in the last flight of the metering zone. Depending on the type of the polymer a screw with a compression ratio varying from 1.5 to 4 should be selected.

Screw types

1) Polyolefin screw

In the polyolefin screw the change from the feed to the metering zone is gradual and it is accomplished by increasing the root diameter in the transition zone. Here the root diameter is constant in both feed and metering zones and channel depth is more in feed zone. The feed zone represents 50% of the overall length, transition zone 25% and metering zone 25%

2) PVC screw

PVC is difficult to work with since it is easily degraded by overheating. The material also has a high melt viscosity at its melting temperature and so that the heat necessary for degradation can be easily generated by heating of the stiff material. So the compression zone of the screw is made long and compression occurs gradually so

as to lessen the shear gradation. For the same reason the metering zone is kept short or eliminated fully. The screw should be acid resistant to avoid corrosion by HCl gas liberated on heating.

3) Nylon screw

Nylon 66 has a sharp melting point at 265°C. At this temperature the solid material suddenly melts to a low viscosity melt. The feed zone of the screw is therefore made very long so that the high amount of heat to melt the crystalline material can be reached. Because of the sharp melting point the compression zone is short. To ensure that the screw can pump such low viscosity melt efficiently, the metering zone is of reasonable length. (4D long)

Barrel

Barrel is the cylindrical chamber in which the screw rotates. Hopper is fixed to the top of the barrel at the rear end. The barrel may have one or several vents and feed ports. The barrel is made with hardened steel, lined with wear resistant, corrosion resistant material. Barrel is provided with band heaters for heating.

Drive system

The drive system consists of the drive motor, reduction gears, transmission mechanism, thrust bearing etc.

Heating and cooling elements

The barrel is heated using band heaters. Steam or fluid heating are also in use. Barrel cooling is needed to prevent overheating that may cause degradation. Water cooling is used to cool the hopper throat to prevent bridging of the plastic materials at the throat. Larger screws are bored through for the passage of heat transfer medium, but care must be taken to prevent overcooling which may freeze a layer on the screw root.

Breaker plate and screen pack

Breaker plate is a perforated metal disc with a no. of small diameter holes. The breaker plate is placed in between the screw and the die assembly. Its principal function is to support the screen pack. The breaker plate also helps to convert the spiral flow of the polymer melt leaving the screw into a linear axial flow.

Screen Pack is usually multilayered, sandwich of metallic wire screen. It is placed between the screw and the breaker plate using the latter for physical support. The main function of screen pack is to strain out particulate contaminants from the plastic. The screen pack should be cleaned or changed periodically.

Extrusion Dies

The role of the die is to form the melt into linear products like fibres, films, sheets, profiles, rods, pipes etc. The die is a channel whose profile changes from that of the extruder bore to an orifice which produces the required form.

The dies can be classified depending on the cross section of the extrudate as

- Solid cross sections - The dies for solid cross sections are simple straight through dies with the desired cross sections
- Hollow cross sections - The dies for hollow sections consists of a cylindrical die with a mandrel at the centre. The outer diameter of the tube is determined by the diameter of the outer die ring orifice. The inner diameter is determined by the mandrel diameter. The mandrel is held in position by a spider. Centering screws are used to make the mandrel and outer die ring concentric.

Another classification scheme is based on the die attachment to the extruder barrel

- Straight through dies - die is arranged in line with the direction of the barrel. Used for the extrusion of pipe, rod, profiles, and sheet
- Cross head dies - Die is arranged at an angle 90, 45, or 300 to the barrel. Used for the production of insulated wires, cables etc
- Offset dies - Combination of straight through and offset dies. Used for the production of pipes

Sheet extrusion

Sheet extrusion is a technique for making flat plastic sheets from a variety of resins.

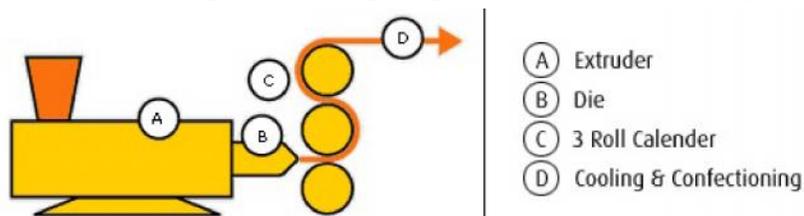


Fig: 3.5.4 Sheet Extrusion

Solid sheet extrusion units consist of at least one extruder and one sheet extrusion die. They are followed by the polishing stack, in general comprising 3 calenders, calibrating and cooling the sheet with their surfaces or calender nips. Behind this the roller conveyor and the draw-off rolls for air cooling are located. The sheet is finally cut and stored.

Plastic sheets with width in excess of 2 meters and thicknesses ranging from approx. 0.5 to 15 mm in continuous lengths are manufactured by this process. Advanced machines can extrude multilayer sheets with functional surfaces, grain/structured surfaces etc.

Polystyrene is the most common polymer used in sheet extrusion. It is the dominant material for thermoformed packaging and competes with ABS and PP in technical markets. End use applications include tubs and pots for yogurt, margarine, and desserts. Thermoformed packaging is also used in many other applications in the food industry.

There are three primary techniques used to manufacture thermoplastic sheet. These are:

1. Extrusion through a flat die onto casting rolls.
2. Extrusion through an annular die onto a sizing mandrel. The pipe-like cross section that is extruded will be slit in one or more places and then flattened and handled as sheet.
3. Resins and additives will be plasticized between large rolls and then sized through a series of additional rolls into a flat sheet. This process is known as Calendaring.

Applications

Extruded PS sheet are used for thermal insulation materials for walls, roofs, and under floors. In automobiles, sheets are used to produce interior trim, panels, and dashboards. Foamed polyolefin sheet, both cross-linked and non-cross-linked, is also used in automotive applications. Other applications include luggage, refrigerator liners, and shower units etc.

Profile extrusion

This process is used to manufacture plastic products with a continuous cross-section such as; drinking straws, decorative moulding, window trimming and a wide variety of other products. The plastic is fed in pellet form into the extruder hopper. The material is softened by both friction & heat and conveyed continuously forward by a rotating screw inside a heated barrel. The softened plastic is then forced out through a die and directs into cool water where the product solidifies. Subsequently it is conveyed into the take-off rollers which pulls of the softened plastic from the die.

Applications

Window profiles, sealing sections, Modular drawer profiles, Decorative trim Etc.

Pipe extrusion

Pipe extrusion is defined as a process of forcing the polymer melt through a shaping die. The extrudates from the die is sized, cooled and the formed pipe is pulled to the winder or a cut off device with the aid of haul off device. Prior to this, the plastic material in the form of polymer granules is fed into the hopper, conveyed by a rotating screw through a long cylindrical barrel. This is subjected simultaneously to high temperature and pressure, forcing the melt through the die at a predetermined rate. To get hollow cross sections a spider die is used in which a central core is fixed concentric in the interior of the die and is fixed in position through spider arrangements. Polyvinyl chloride (PVC), and Polyethylene's (PE) are the most widely used thermoplastic piping material.

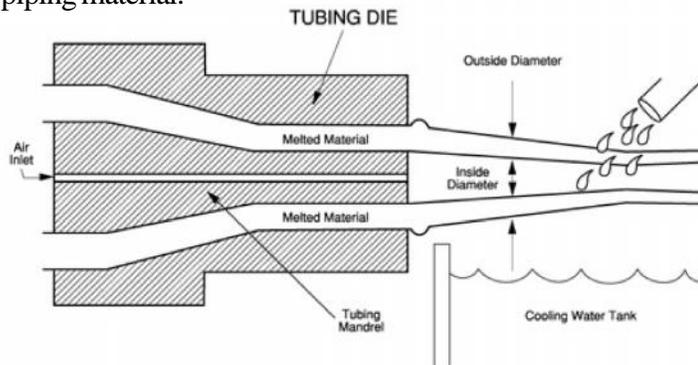


Fig: 3.3.5 Pipe Extrusion

Pullers-Cutters - Cutter-pullers are used in the production of pipes and thin-wall tubes. As their name implies, they pull the extrudate through a vacuum sizer/cooler and cut the tube or pipe to the desired length. The speed of the puller is set by a controller to correspond to the speed of the extruder. Reciprocal movement of the cutting head is synchronized with the linear speed of the sleeve or pipe, and at a preset length, a blade cuts the sleeve and retracts. Then the cutting head moves back by the distance equal to the required tube or pipe length.

Blown film extrusion (film blowing)

The plastic melt is extruded through an angular slit die placed vertically to form a thin walled tube. Air is introduced via a hole in the centre of the die to blow up the tube like a balloon. A high-speed air ring blows onto the hot film to cool it. The tube of film then continues upwards, continually cooling, until it passes through nip rolls where the tube is flattened to create what is known as a 'lay-flat' tube of film. This lay-flat or collapsed tube is then taken back down the extrusion 'tower' via more rollers. On higher output lines, the air inside the bubble is also exchanged. This is

known as IBS (Internal Bubble Cooling). The lay-flat film is then either kept as such or the edges of the lay-flat are slit off to produce two flat film sheets and wound up onto reels. If kept as lay-flat, the tube of film is made into bags by sealing across the width of film and cutting or perforating to make each bag. This is done either in line with the blown film process or at a later stage.

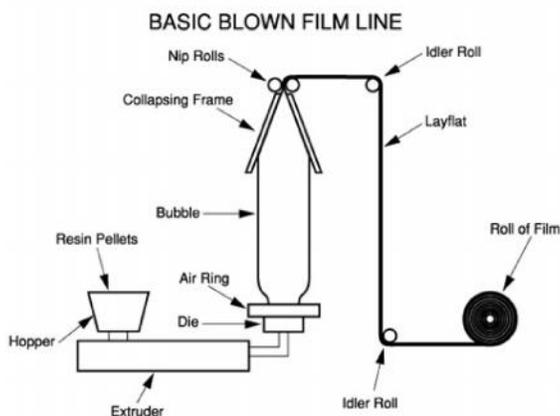


Fig: 3.3.6 Blown film extrusion

The expansion ratio between die and blown tube of film would be 1.5 to 4 times the die diameter.

$$\text{Blow ratio} = \frac{\text{Bubble diameter}}{\text{Die diameter}}$$

The drawdown between the melt wall thickness and the cooled film thickness occurs in both radial and longitudinal directions and is easily controlled by changing the volume of air inside the bubble and by altering the haul off speed. This gives blown film a better balance of properties than traditional cast or extruded film which is drawn down along the extrusion direction only. The film width and thickness can be regulated by control of the volume of air in the bubble, the output of the extruder and the speed of the haul-off. The extruded films can also be biaxially oriented. Common materials for blown film extrusion are Polyethylenes (HDPE, LDPE and LLDPE) are the most common resins in use, but a wide variety of other materials can be used as blends with these resins or as single layers in a multi-layer film structure including PP, PA, EVOH.

Applications:

- Blown film can be used either in tube form (e.g. for plastic bags and sacks) or the tube can be slit to form a sheet.
- Industry packaging (e.g. shrink film, stretch film, bag film or container liners),
- Consumer packaging (e.g. packaging film for frozen products, shrink film for transport packaging, food wrap film, packaging bags, or form, fill and seal packaging film), Laminating film (e.g. laminating of aluminium or paper used for packaging for example milk or coffee)

- Barrier film (e.g. film made of raw materials such as polyamides and EVOH acting as an aroma or oxygen barrier used for packaging food, e. g. cold meats and cheese),
- Films for the packaging of medical products,
- Agricultural film (e.g. greenhouse film, crop forcing film, silage film, silage stretch film).

Cable Extrusion

For the production of cables a cross head type extruder is used. The molten resin is extruded using a cross head type die through which the conductor wire is fed. The melt coats the conductor wire, forming an insulator layer. The finished product is cooled, tested and wound up

Die swell

The contraction of the extrudate in the direction of extrusion and expansion in cross section while emerging from the die is called extrudate swell. It is also called as die swell.

$$\text{Die swell} = \frac{\text{Outer extrudate diameter}}{\text{Diameter of the die}}$$

Extrudate swell may be reduced by

- 1) Decreasing extrusion rates
- 2) Increasing the melt temperature and die land
- 3) Increasing the draw down ratio

Melt fracture

The presence of rough surface, especially short cracks or ridges in the extrudate surface in the machine direction is called melt fracture. Melt fracture can be controlled by

- 1) Die streamlining
- 2) Lowering the extruder speed
- 3) Reducing the friction coefficient of die walls
- 4) Reducing the viscosity of the melt

DETAILING OF PRACTICALS

- 1) Work practice in an extruder
- 2) Field visit to an extruding unit

ASSESSMENT ACTIVITIES

Field visit

Case study

Chart preparation

Theory Evaluation Questions

- 1) Single screw extruders are the work horse of extrusion. List the different parts of a single screw extruder. Explain the functions of each.
- 2) While extruding a plastic product the product coming out of the die is found to be larger than the die size. Explain this phenomenon? List the steps to minimize this defect.
- 3) Plastic carry bags are made by blown film extrusion. Explain blown film extrusion process with the help of a neat diagram?

Unit IV

BLOW MOULDING & ROTATIONAL MOULDING

Blow moulding is a manufacturing process in which air pressure inflates heated plastic in a mould cavity. It is used for the production of hollow plastic parts with thin walls, such as beverage bottles, cosmetic containers and pharmaceutical packaging. Another method used for the manufacture of hollow articles such as water tanks rotational moulding. This unit details the different blow moulding and rotational moulding operations used in plastic industry.

Learning outcomes

The learner :

- Describes the different blow moulding operations like extrusion blow moulding, injection blow moulding and stretch blow moulding
- Analyses the problems, causes and remedies in blow moulding operation
- Describes the rotational moulding of plastics
- Analyses the defects, causes and remedies in rotational moulding

Blow Moulding

Blow moulding is a manufacturing process in which air pressure inflates heated plastic in a mould cavity. It is used for the production of hollow plastic parts with thin walls, such as beverage bottles, cosmetic containers and pharmaceutical packaging. There are three types of blow moulding: extrusion, injection and stretch blow moulding. Many thermoplastics, including polystyrene, PC and polyvinylchloride (PVC), can be blow moulded. However, the most common resins are high-density polyethylene (HDPE), low-density polyethylene (LDPE) and polyethylene terephthalate (PET).

Extrusion Blow moulding

In extrusion blow moulding, a molten tube of plastic called parison is extruded into a mould cavity. The mould sides are then clamped together, pinching and sealing the parison tube at the bottom. Air is blown into the tube from the top, which expands the hot resin wall into the shape of the cavity; the mould is cooled with water solidifying the resin into the shape of the part. Once cooled, the part is ejected from the mould and trimmed. A typical blow moulding operation show in the figure below.

The basic extrusion blow-moulding cycle is as follows.

The thermoplastic resin is melted in the extruder and is extruded out of the die head between two mould halves. The tube of melted plastic is called a parison. The mould halves come together

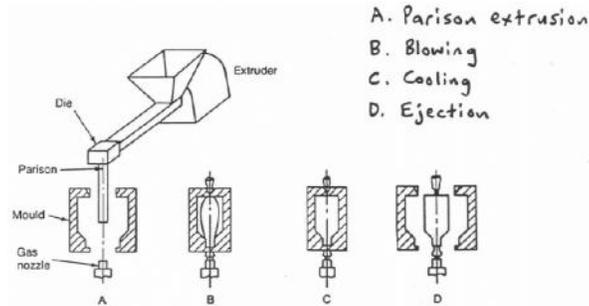


Fig: 3.4.1 blow moulding operation

when the parison has reached the correct length. Pinch bars at the bottom of the mould close off the tube and maintain some air in the parison to prevent the walls of the parison from sticking together prematurely. The moulds are closed completely, sealing the parison and creating flash on the edges of the mould. Air is blown through the blow pin mounted in the head of the machine, forcing the soft plastic of the parison out against the walls of the mould. The part is cooled in the mould, under pressure, until it can maintain its shape and required dimensions. Before the mould is opened, the blowing air is stopped and the air is vented to prevent part distortion. The mould is opened and the part is stripped from the blow pin by either mechanical devices or by blowing it off. The blow pin may also be retracted into the head.

The extrusion blow-moulding process is primarily used for smaller, high-quality bottles, such as those required by the cosmetics industry, or whenever a good neck finish is important. It is also used for open containers such as plastic drinking cups, which could be moulded in conventional injection moulds, except that blow moulding yields walls that are substantially thinner and lighter than those made by injection moulding, without sacrificing any significant properties.

Most of the cycle time is taken up by the blowing and cooling step. Therefore blowing and cooling control the machine cycle. The speed of the machine that melts the resin and makes the parison must be configured to conform to the blowing/cooling time.

Injection blow moulding

Injection blow moulding is a two-step process. A contoured preform is injection moulded and then transferred to a blow mould cavity where it is inflated. The injection blow-moulding process is limited to smaller sizes of parts than extrusion blow moulding. The injection blow moulding process produces parts to tight dimensional or weight tolerances that might not be achievable with the extrusion blow moulding process.

Injection blow moulding is also used to mould parts out of materials such as PET or polystyrene (PS) which are difficult to mould by the extrusion blow moulding process. Injection blow-moulded parts can be produced without flash or trimming. Tooling is more expensive for injection blow moulding, but the cycle times are faster than for extrusion blow moulding.

During the injection stage, the melt is injected into a split parison cavity and around a predetermined core rod. Once the melt is conditioned, the moulds open and then rotate 120° to transfer the pre-form into a split blow-mould cavity (blow-mould station). Compressed air enters through the core rod, blowing the conditioned parison melt against the blow-mould cavity wall. After the material has cooled in the blow-mould cavity, the moulds open and the finished container is then rotated 120° for transfer to the pickoff (eject) station for removal from the core rod. In the pick-off station, bottles are automatically removed from the core rods and fall directly into a shipping carton or are placed in an upright position on a conveyer belt for post handling.

Advantages

Some of the advantages of injection blow-moulded containers are:

- Precise neck finishes
- No trimming or reaming of excess flash.
- Repeatability.
- Excellent surface appearance.
- Greater range of rigid materials, such as polystyrene, SAN and ABS.
- Opportunity for parts consolidation.
- Multi material capability.

These advantages make injection blow moulding suitable for producing containers to the cosmetic, pharmaceutical, and food.

Stretch blow moulding

Stretch blow moulding uses the same procedures as injection blow moulding, but prior to inflation, a ram stretches the pre-form. The stretching aligns the polymer chains, creating stronger parts

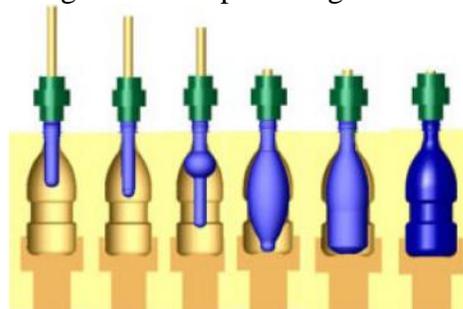


Fig: 3.4.1 blow moulding operation

with better clarity and gas barrier properties. There are two methods of stretch blow moulding, ISBM (injection stretch blow moulding) and RHB (reheat and blow). With ISBM, the injection moulded pre-form is immediately transferred to the blow moulding tool. RHB uses pre-forms that are injection moulded and inventoried. The pre-form is then reheated and blow moulded.

Table 3.4.1 Comparison between extrusion and injection blow moulding

Extrusion blow moulding	Injection blow moulding
Parison is expanded against the walls of the blow mould by air pressure to take the shape of the mould	Injection moulded preforms are expanded against the walls of the blow mould by air pressure
Pinch has to be cut from the part	No. pinch off
Secondary operations is necessary	Can be used directly
Programming of the parison is necessary to get accurate weight of the part	High quality neck moulding provides dimensional accuracy
Can be used for making bottles with handles	Cannot be used for making bottles with handles
Low tooling cost	Comparatively high

Blow moulding defects

Parison Sag

This creates in an uneven wall thickness in the parison. During the formation of parison it gets longer and heavier. As its gets heavier gravity starts to extend the parison this is called parison sag. Material with high melt strength are needed in extrusion blow moulding to reduce the amount of sag in parison.

Axial thickness variation on parison

Surface defects: Mottle, Extrusion die liens

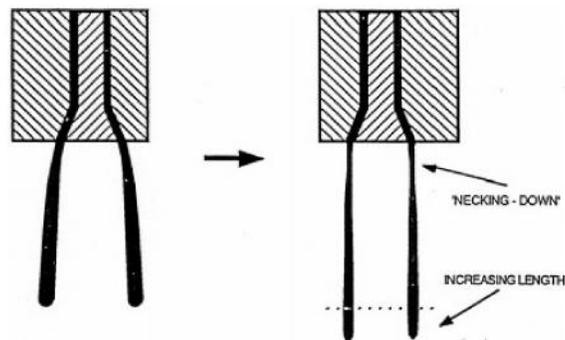


Fig: 3.4.3 Parison sag

Table 3.4.2 Faults causes and remedies in blow moulding

Fault	Cause	Action
Parison too long	Excess extrusion output Low melt viscosity leading to parison sag	Reduce screw speed Reduce barrel temperature Reduce die head temperature
Parison too short	Insufficient extruder output Too low melt temperature	Increase screw speed Check heater functioning
Parison diameter too large	Incorrect die selection Excess die swell	Check Raise melt temperature
Parison diameter too small	Incorrect die selection Excess parison sag	Check Lower melt temperature
Excess parison wall thickness	Incorrect setting of parison thickness controller Excess die swell	Check Raise melt temperature
Parison wall too thin	Incorrect setting of parison thickness controller Excess parison sag	Check Lower melt temperature
Parison curls outward as it leaves the die	Die temperature too low	Raise die temperature
Parison curls inwards as it leaves the die	Die temperature too high	Lower die temperature
Shark skin (rough inside)	Die head temperature too low Melt temperature too low	Raise die head temperature Raise Melt temperature
Burn Marks	Decomposition	Check melt temperature Check no dead spots Check tip of the screw is not too hot
Poor neck/ flash separation	Blow pin badly set Damaged cutting sleeve	Check and adjust Replace
Displaced pinch weld	Bent parison Blunt parison knife	Check parison faults Replace
De formed moulding	Moulding ejected too hot	Increase cooling time Check cooling water supply to the mould
Part sticks to the mould	Mould too hot Moulding too hot	Check mould temperature Increase cooling time Reduce melt temperature
Moulding does not fully inflate	Insufficient air	Raise air pressure Increase blowing time

Rotational moulding

Rotational moulding or rotomoulding is a method of moulding plastics which is ideal for the production of hollow articles, particularly large size products. It involves the slow tumbling, heating, and melting of a thermoplastic powder in a bi-axially rotating mould to produce seamless, hollow plastic parts. This process is typically used to mould hollow parts, especially those with complex and varied shapes not easily

obtainable by other hollow-art processes. It is a virtually shear-free and pressure-free process.

Process Steps:

The Rotational Moulding process is essentially split into four operations:

Step 1: Loading resin into the mould

- A pre-measured amount of plastic material (in either liquid or powder form) is placed in a cavity.
- The mould is then closed and indexed into an oven where materials are brought up to the moulding temperature.
- As the mould is heated, it is rotated continuously about its vertical and horizontal axes.
- This biaxial rotation brings all surfaces of the mould in contact with the plastic material.

Step 2: Heating and fusion of resin

- The mould is rotated within the oven until all the plastic material has been picked up by the hot inside surfaces of the cavity and densifies into a uniform layer.
- The machine moves the mould out of the oven and into the cooling chamber.

Step 3: Cooling before unloading

- Air or a mixture of air and water, cools the mould and the layers of molten plastic material. This cooling process continues until the part has cooled sufficiently to retain its shape.
- The machine then indexes the mould to the loading and unloading station.

Step 4: Unloading/Demoulding

- When the polymer has cooled sufficiently to retain its shape and be easily handled, the mould is opened and the product removed.
- At this point powder can once again be placed in the mould and the cycle repeated.



Fig: 3.4.4 Rotational moulding



Fig: 3.4.5 Rotational Moulding machine

Raw Materials

To obtain the desired end product, the choice of a quality powdered resin is essential in rotational moulding. One reason is the high temperatures used risk chemical degradation in a less-than-quality product. Today, approximately 84 percent of all resin used in rotational moulding is polyethylene (Table 3.4.1). A wide variety of poly-ethylene powders with a wide range of properties, including melt index and density are available in the market. While the effects of particle size on end-product properties and processability are less critical, those of melt index and density are considerable. The commonly used raw materials for rotational moulding are LDPE, LLDPE, PP, EVA, and PVC

Table 3.4.3 Rotational moulding resin consumption

Resin	Market share
Polyethylene	84%
Polycarbonate	15%
Nylon	
PVC	
Polyesters	
Polypropylene	
OTHERS	1%

Rotomoulding Process variables are:

- Oven temperature
- Oven residence time

- Amount of polymer in the mould
- The speeds of rotation of the mould
- Nature of the cooling medium
- Duration of the cooling periods
- De-moulding temperature

The other factors affect the quality of product; although they may not be under the direct control of moulder include:

- Power particle size
- Power particle size distribution
- Melt flow behaviour of the polymer
- Density of the polymer
- Mould material
- Shape of the mould
- Thickness of the mould
- Efficiency and type of oven
- Efficiency and type of cooling bay

Advantages of rotational moulding

- Very large parts can be manufactured
- Chemical waste and storage tanks up to 2,500 gallons
- Minimum design constraints
- Very low tooling costs
- No polymer weld lines
- Stress-free products

Disadvantages

- Slow cycle times mean high piece prices
- Narrow range of raw materials.
- Some geometrical features (such as ribs) are difficult to mould

Applications

Industrial & Commercial:

Industrial and commercial applications include Specialty tanks and containers for fuel, water, and chemical processing, Livestock feeders, Drainage systems, Food service containers, Instrument housings, Vending machines, Highway barriers and road markers

Consumer Products:

Rotational moulding is used to make consumer products such as Recreational, Special Application, Toy & Transportation, Boats and kayaks, Childcare seats, Light globes, Tool carts, Playing balls, Playground equipment, Truck/cart liners, Air ducts etc.

Table 3.4.4 Comparison of rotational and Blow moulding methods

Rotational moulding	Injection blow moulding
Ideal for larger volume products	Ideal for smaller volume products
Ideal for moulding perfect hollow objects like ball	Ideal for hollow objects with an opening at one end
Low cost for a given size capacity when compared to blow moulding	Moulding process is costly Costly moulds are used
Processability limited to thermoplastics like poly ethylene, PVC etc	Able to process wide variety of thermoplastics including ABS

Table 3.4.5 Faults causes and remedies in rotational moulding

Fault	Cause	Action
Warped parts	Inadequate venting Non uniform cooling	Use 13 mmdiameter vents per cubic meter of mould volume Check mould rotation during cooling
Part stick in the mould	Insufficient release agent, degradation of release agent, Roughness or porosity on mould surface	Re apply or use more release agent Refinish damaged mould surfaces
Uneven wall thickness	Improper mould rotation	Correct the mould rotation
Excessive flashing at mould parting line	Inside pressure high	Provide venting Remate mould parting line Adjust clamping pressure
Highly underfused parts, with many small bubbles in wall or rough, powdery inside surface	Oven temperature low Heat transfer rate not adequate Resin powder too coarse	Increase oven temperature Increase heat transfer using thinner moulds Use finer mesh powder

DETAILING OF PRACTICALS

1) Work practice on blow moulding machine

The operation of blow moulding machine requires mould setting temperature control, air pressure and material

1. Mould setting: normally mould setting is done by adjusting the barrel up and down and matched so that no gap exists between. It should be air tight, or else the blowing air will escape
2. Temperature setting: the temperature of the melt is controlled indirectly by using the timer switch on or off the time. The duration of the heater on the period is maintained is constant
3. Air pressure: air compressor is required to produce air. To regulate the pressure a gauge is fitted on to the air compressor. Normally the pressure ranges from 2kg/cm² to 3 kg/cm²
4. Material :most material are produced with HDPE whose processing temperature ranges from 160 -250°C

Operation

Set the machine and mould ready for operation as per the setting procedures described above, switch on the machine and waited until it reaches the required temperature. After that feed the plastic material in the barrel by bringing down the plunger. The operation is repeated till the right form of parison is obtained. The parison is having excess length than the cavity of the mould. Close the mould and lock it. Allow the air for blowing. After cooling the mould is opened and product is removed. This process is repeated again and again for further production.

2) Field visit to blow moulding unit

3) Work practice on rotational moulding machine

Weigh required amount of LDPE/HDPE powder .It is then transferred in to an open cold mould which is already coated with a mould releasing agent, silicon emulsion. After loading mould is closed manually by clamps. The mould is then fixed with arms and is rotated biaxially in a closed heating chamber where intense heat is supplied .Rotational speed is 0-40 rpm for the minor axis and 0-12 rpm for major axis . The temperature of the oven should be 200-500c depending on the product. After the desired cycle time (2 to 20 minute) the mould is cooled quickly by spraying cold water over the mould. Later, the mould is opened and the product is taken out.

ASSESSMENT ACTIVITIES

Field visit, Case study, Chart preparation

Theory Evaluation Questions

- 1) Write the flow chart of rotational moulding process?
- 2) Compare and contrast rotational moulding with blow moulding?
- 3) Why vent is given to the rotational moulds

Unit V

THERMOFORMING & CALENDARING

Over view of the unit

This unit deals with two major processing processes- thermoforming, used for manufacturing a range of products from cups to boat hulls and rotational moulding widely used to produce hollow articles like tanks.

Learning outcomes

The learner :

- Explain the different thermoforming processes and their respective features.
- Identify the different thermoforming materials and applications.
- Explain the plastic calendaring process and distinguish between different types of calenders.
- Describe the different gauge control methods in calendaring.

Thermo forming

Introduction

Thermoforming is a plastic manufacturing process in which the thermoplastic sheets are formed with the application of heat and pressure in a mould. The thermoplastic sheet is held horizontally over a mould surface and clamped with a holding device. The sheet is heated up until it is soft it is pressed into or stretched over the mould surface by application of air pressure or by any other means. The softened sheet conforms to the mould shape and it is held in place until it cools. The mould cavity is opened and the thermoformed part is released.

Thermoforming set-up usually consists of the clamping unit, heaters, mould, and air cooling system. The moulds should be cleaned after every cycle, as materials in the mould can cause change in the shape of the finished goods. There are different types of thermoforming process depending upon the pressure required i.e., vacuum forming, pressure forming, matched die forming, Plug assist forming and drape forming.

Vacuum Forming

In this process, the vacuum pressure is used to form the heated thermoplastic sheet into the desired shape. The thermoplastic sheet is placed on the mould surface and

fixed with the help of clamping unit. The sheet is heated until it softens and thereafter vacuum needs to be applied quickly. A surge tank is used to quickly pull the air out between the mould cavity and the sheet. When the vacuum is created, the sheet conforms to the shape of the mould cavity. The formed part is cooled and then ejected from the mould cavity. The schematic of vacuum forming process is shown in the following figure

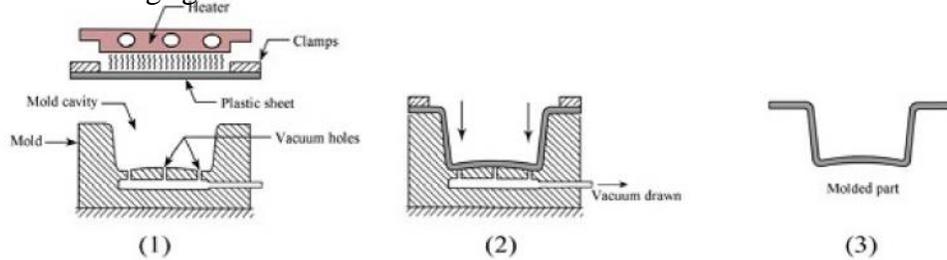


Fig: 3.5.1 Vacuum Forming

Pressure Forming

The pressure forming process is closely related to vacuum forming. In this process, the air pressure required is much higher as compared to the vacuum forming. The preheated plastic sheet is

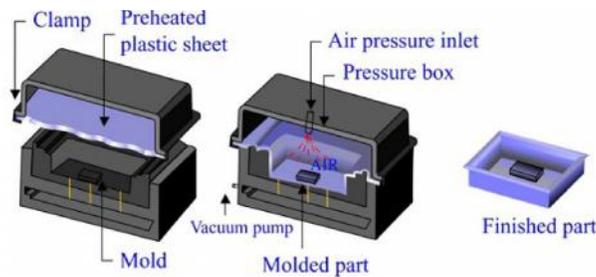


Fig: 3.5.2 Pressure Forming

placed on the mould surface, and then air pressure is applied quickly above the sheet as shown in figure. The high pressure is developed in between the softened sheet and the pressure box. Due to high pressure, the preheated plastic sheet can be deformed into the mould cavity in a fraction of a second. The formed sheet is held in the mould cavity for cooling for a few seconds. The formed part thereby solidifies and is ejected from mould cavity. Prototype parts can also be made using pressure forming process.

Matched die forming

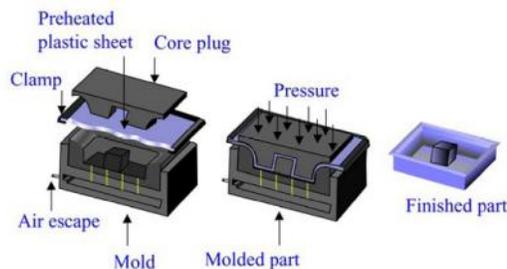


Fig: 3.5.3 Matched Die Forming

Matched die forming is also called mechanical forming. In this process, mould consists of two parts i.e. die and punch as shown in figure. The thermoplastic sheet is heated with the application of heat until it softens. The preheated sheet is placed into

the mould surface (that is called die) and through punch pressure is applied on the hot sheet. The air in between the die and softened sheet is evacuated by using vacuum pump, and therefore the thermoplastic sheet conforms to the mould shape. The formed part is cooled and ejected from the mould cavity.

Plug Assist Forming

Plug assist thermoforming is one of the process variant of vacuum or pressure forming. Its purpose is to pre-stretch the heated polymer sheet prior to the application of pressure and/or vacuum during the final part formation. In this type of forming, the plastic sheet is mechanically pre-stretched by a plug that is pushed into the hot plastic before the application of vacuum/pressure to the mould. The plug has a geometry that is usually 10 - 30 percent smaller than the interior of the female mould cavity. A pressure is then applied to draw the material against the cavity walls and complete the forming operation. The major advantage of plug-assist forming is that it gives a better wall thickness uniformity than can be obtained by other forming processes, especially for conical cup or box shapes.

The plug can be used to carry material towards the areas that would have been too thin if just straight pressure/vacuum forming is used. The plug is constructed of materials with low thermal conductivity to keep the plastic sheet from cooling when the sheet comes in contact with it. Materials such as wood, syntactic foam and cast thermoset plastics can be used to make a low thermally conductive plug. Aluminium with temperature controlled electric heaters can also be used. Aluminium plugs produce excellent results but are usually more costly.

Plug Assist vacuum forming

After the plastic sheet is heated and sealed across the mould cavity, a plug shaped roughly like the mould cavity (but smaller) is plunged into the plastic sheet, pre-stretching the material. When the plug platen has reached its closed position, a vacuum is drawn through the mould to complete the formation of the sheet.

Plug Assist Pressure Forming

Plug assist pressure forming is similar to plug assist vacuum forming, except that as the plug enters the sheet, air under the sheet is vented to the atmosphere. When the plug completes its stroke and seals the mould, air pressure is applied from the plug side.

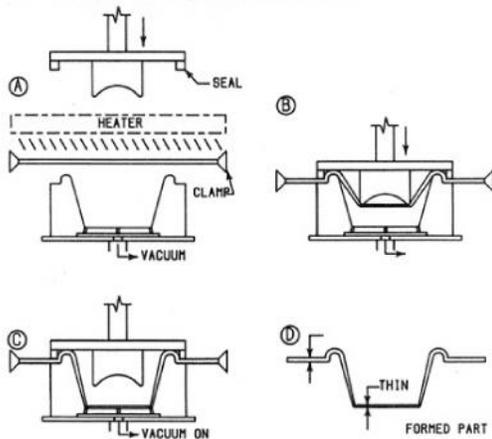


Fig: 3.5.4 Plug assisted vacuum forming

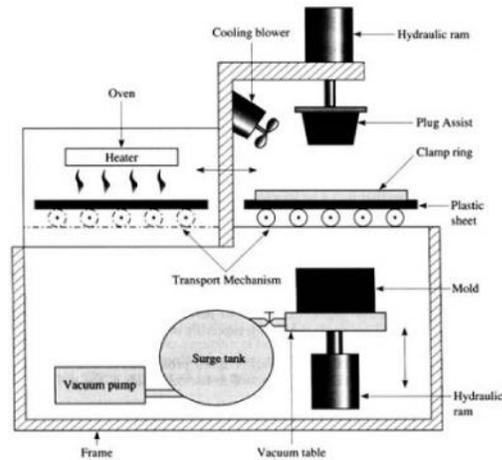


Fig: 3.5.5 Plug assisted vacuum forming machine

Drape forming

Drape forming is similar to straight vacuum forming except that after the sheet is framed and heated, it is mechanically stretched and a pressure differential is then applied to form the sheet over a male mould. However, the sheet touching the mould remains close to its original thickness. It is possible to drape-form items with a depth-to-diameter ratio of approximately 4: 1

Process steps

Step 1: The plastic sheet is clamped in a frame and heated. Heating can be timed or electronic sensors can be used to measure sheet temperature or sheet sag.

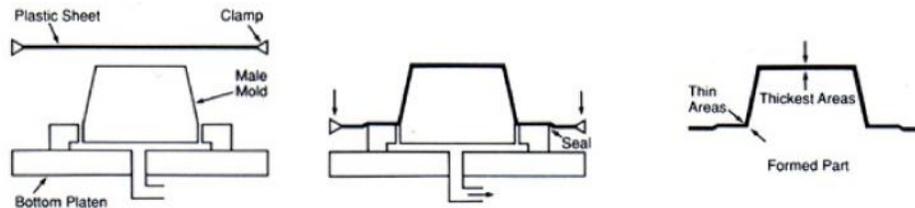


Fig: 3.5.6 Drape forming

Step 2: Drawn over the mould: either by pulling it over the mould and creating a seal to the frame or by forcing the mould into the sheet and creating a seal. The platen can be driven pneumatically or with electric drive.

Step 3: Then vacuum is applied through the mould, pulling the plastic tight to the mould surface. A fan can be used to decrease sheet cooling time.

Step 4: After the plastic sheet has cooled, the vacuum is turned off and compressed air is sent to the mould to help free it from the plastic. The platen then moves down

pulling the mould from the formed part. The formed sheet is unclamped, removed and a new cycle is ready to start.

Advantages

- Better part dimensional control on inside of part
- Lower mould costs
- Ability to grain surface (tubs, showers, counter tops, etc)
- Faster cycle times.

Disadvantage: More scrap due to larger clamps and trims area.

Applications:

- Large panels that require retaining a simple non-flat shape as in a curved display wall.
- Constructions of wide sections of odd-shaped walls that will still retain overall even material thickness.

Materials Used for thermoforming

The different types of thermoplastic materials which can be processed using thermoforming process are: Acrylic (PMMA), Acrylonitrile butadiene styrene (ABS), Cellulose acetate, Low density polyethylene (LDPE), High density polyethylene (HDPE), Polypropylene (PP), Polystyrene (PS), Polyvinyl chloride (PVC)

Applications

Thermoforming process is used for variety of applications, for example, food packaging, automotive parts, trays, building products and aircraft windscreens. Thick gauge parts are used as cosmetic surfaces on permanent structures such as trucks, medical equipment, material handling equipment, electrical and electronic equipment, spas and shower enclosures, vehicle door and dash panels, refrigerator liners, utility vehicle beds, and plastic pallets. Thin gauge parts are primarily used to package or contain a food item, disposable cups, containers, lids, blisters and clamshells.

The advantages and disadvantages of the thermoforming process are given below:

Advantages:

- Extremely adaptive to design requirement
- Rapid prototype development
- Low initial setup costs
- Low production costs

- Less thermal stresses than injection moulding and compression moulding
- Good dimensional stability

Disadvantages:

- Poor surface finish
- Parts may have non-uniform wall thickness.
- All parts need to be trimmed
- Ribs and bosses cannot be moulded easily
- Limited number of materials can be used
- Very thick plastic sheets can't be formed

Calendaring

Calendaring is the process of squeezing a plastic melt between two or more counter rotating rolls to form a continuous film and sheet. In general extrusion film blowing is the preferred method for producing films or sheets from polyolefins, but calendaring has a major advantage of causing less thermal degradation and so it is widely used for heat sensitive materials such as PVC. The PVC sheet was first successfully calendered in the 1930s in Germany. The rigid compounds contain no plasticizer where as plasticized compounds contains at least 20% plasticizer. The basic limitation of the calendaring operation is that the width of the calendered film or sheet is limited to the width of the calendar rolls

The calendaring machine consists of two or more rolls mounted on a rigid frame. The nip or roll profile decide the shape of the article. The molten material is fed to the calender rolls from a Banbury mixer - two-roll mill system, from a large extruder or from PVC dough mixer. There are different types of calendar machine based on the number of rolls and the position or orientation of rolls

I Type

The I type calender, was for many years the standard calender used. It can be built with one more roller in the stack. This design was not ideal though because at each nip there is an outward force that pushes the rollers away from the nip.

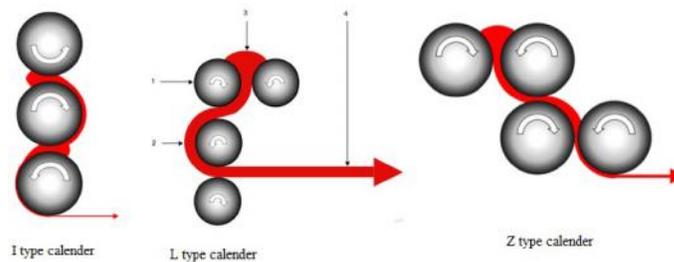


Fig: 3.5.7. Different calender machines

L Type

In L type the rolls are arranged in the L configuration. Since some rollers are at 90° to others their roll separating forces have less effect on subsequent rollers. L type calenders are often used for processing rigid vinyls and inverted L type calenders are normally used for flexible vinyls.

Z Type

The z type calender places each pair of rollers at right angles to the next pair in the chain. This means that the roll separating forces that are on each roller individually will not affect any other rollers.

Roll Bending

Owing to the large separating forces developed in the calender gap, the rolls tend to bend. The pressures are highest in the middle of the width of the roller and due to this the rollers get deflected. This deflection causes the sheet being made to be thicker in its center than it is at its sides. There are three methods that have been developed to compensate for this bending:

1. roll crowning
2. roll bending
3. roll crossing

Roll crowning uses a roller that has a bigger diameter in its center to compensate for the deflection of the roller. Roll bending involves applying moments to both ends of the rollers to counteract the forces in the melt on the roller. With roll crossing the rollers are put at a slight angle to each other and because of this the force of the rollers on the melt is higher in the middle where the rollers are on top of each other more, and less force is applied on the edges where the rollers are not directly over top of each other.

Advantages and disadvantages of calendaring

The best quality sheets of plastic today are produced by calenders; in fact, the only process that competes with the calender in sheet forming is extruding. The calender also is very good at handling polymers that are heat sensitive as it causes very little thermal degradation. Another advantage to calendaring is that it is good at mixing polymers that contain high amounts of solid additives that don't get blended or fluxed in very well. This is true because compared to extrusion the calender produces a large rate of melt for the amount of mechanical energy that is put in. Due to this

companies are able to add more filler product to their plastics and save money on raw materials. Calenders are very versatile machines meaning that it is very easy to change settings like the size of the roller gap.

Calender installations require large initial capital investment. Film and sheet extrusion are competitive processes because the capital investment for an extruder is only a fraction of the cost of a calender. However, the high quality and volume capabilities of calendaring lines make them far superior for many products. Calendaring in principle is similar to the hot rolling of steel into sheets. The process of calendaring is also used extensively in the paper industry.

DETAILING OF PRACTICALS

- 1) Collection and analysis of thermoformed products.
- 2) Field visit to a thermoforming unit.
- 3) Working practice on vacuum forming, pressure forming methods

ASSESSMENT ACTIVITIES

Seminar

Field visit report

Participation in discussion

Oral Evaluation

Theory Evaluation Questions

1. What is the advantage of plug assisted forming over vacuum forming?
2. What is matched mould forming? Write any two advantages?
3. Explain how medicine tablets are packed?

Unit VI

TESTING OF PLASTICS

Introduction

Plastic and plastic products are becoming more and more customer oriented and hence have to be tested for ensuring the quality and performance requirements. This unit deals with the mechanical, thermal and environmental testing of plastic raw materials and plastic products.

Learning outcomes

The learner :

- Identify the significance of testing, specifications and standards
- List the typical tests conducted in the plastic industry
- Determine the specific gravity, hardness, tensile, flexural, and impact properties of plastics
- Describe the testing of MFI, Vicat Softening point, Heat distortion temperature and Environment stress crack resistance of plastics

Testing of Plastics

Testing has become an integral part of any manufacturing process to ensure the reliability and performance of the products. It helps to evaluate the manufacturing process and to check the suitability & consistency of the product obtained from intermediate stages of manufacture. Testing helps to build a level of confidence in both the supplier as well as the customer. The following are some of the major reasons for testing.

1. To prove design concepts
2. To provide a basis for reliability
3. Safety
4. Protection against product liability suits
5. Quality control
6. To meet standards and specifications
7. To evaluate competitors products
8. To verify the manufacturing process
9. To establish the history for new materials

Specifications and standards

A specification is a detailed description of requirements, dimensions, materials etc. A specification for a plastic material involves defining particular requirements in terms of density, tensile strength, thermal conductivity and other related properties. The specification also relates to standard test methods to be used to determine such properties.

A standard is something established for use as a rule or a basis of comparison in measuring or judging capacity, quantity, content, value, quality etc. The purpose of the standard is to develop a common language, so that there can be no confusion among the concerned parties. Majority of the standards originate from the industry. The standards are generally established by organizations such as BIS (Bureau of Indian Standards), ASTM (American Society for Testing and Materials), SAE (Society of Automotive Engineers), ISO (International Standards Organization)

The common tests that are performed in a plastic processing industry are as follows

1) Specific Gravity (ASTMD 792)

Specific gravity is defined as the ratio of the weight of the given volume of a material to that of an equal volume of water at a stated temperature. The temperature selected for determining the specific gravity of plastic is 23 C.

Test Method -This method requires the use of a precision analytical balance equipped with a stationary support for an immersion vessel above or below the balance pan. A beaker is used as an immersion vessel. The test specimen of any convenient size is weighed in air. Next, the specimen is suspended from a fine wire attached to the balance and immersed completely in distilled water. The weight of the specimen in water is determined.

The specific gravity of the specimen is calculated as follows:

$$\text{Specific gravity} = \frac{a}{(a+w) - b}$$

Where,

a = weight of specimen in air;

b = weight of specimen and wire in water,

w = weight of totally immersed sinker (if used) and partially immersed wire

2) Tensile Properties (ASTM-D 638)

Tensile strength, elongation and tensile modulus measurements are among the most important indications of strength in a material. Tensile test, in a broad sense, is a

measurement of the ability of a material to withstand forces that tend to pull it apart and to what extent the material stretches before breaking. Tensile test data and graph provides information about the resilience and toughness of material. Dumbbell shaped specimen are used for tensile test. Specimens from thermoplastic & thermoset can be moulded by Injection, compression or transfer moulding process.

Equipment

A tensile tester / Universal Testing Machine is used for measuring the tensile properties of the plastic specimen. It is fitted with load cell and extensometer to record load and extension accurately.

Procedure

Dumbbell shaped specimens as per the specifications are prepared and the width and thickness of each test specimen in narrow parallel portion is measured. Mark Gauge length on the specimen and the specimens are placed in the grips of the tensile tester or Universal Testing Machine (UTM) at a specified grip separation and pulled until failure. Attach extensometer with specimen for measuring extension.

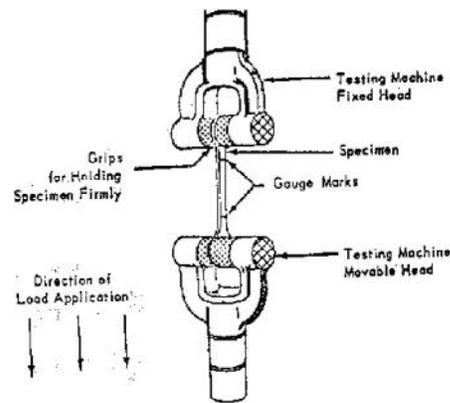


Fig: 3.6.1 Tensile testing

$$\text{Tensile strength} = \frac{\text{Force (load) (N)}}{\text{Original Cross - section area of the specimen (mm}^2\text{)}}$$

$$[\text{Elongation at yield, strain}(\%) =] \frac{\text{Change in length (elongation)}}{\text{Original length (gauge length)}}$$

$$\text{Percent Elongation} = \text{ } \times 100$$

3) Flexural testing ASTM D 790

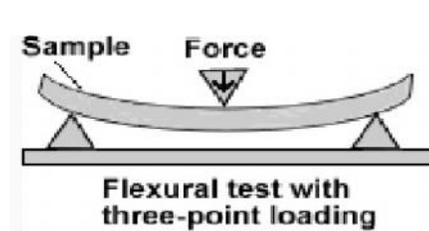


Fig: 3.6.2 Flexural testing

Flexural strength is the ability of a material to withstand bending forces applied perpendicular to its longitudinal axis. The stress induced due to flexural load is the combination of compressive and tensile stresses. If a material is used in the form of a beam, flexural test is more relevant for design than a tensile test

Equipment

Universal testing machine consisting of flexural test fixture such as specimen support and loading nose is used. Machine consists of load cell and internal extensometer for recording the load and deflection of specimen. Rectangular shaped specimen of recommended size 127mm x 12.7mm x 6.4mm is prepared by moulding or machined from sheets

Procedure

Measure length, width and thickness of specimen accurately using a micrometer. Adjust span length between two supports equal to 16 times of specimen thickness. Place specimen on the support centrally with load axis perpendicular to loading nose. The test is initiated by applying a load to the specimen at a specified cross head rate.

Calculate Flexural strength by using following formula:

$$\text{Flexural Strength} = 3 PL / 2bd^2$$

Where

- P = Load in N
- L = Distance of supports in mm.
- b = Width of specimen in mm.
- d = Thickness of test specimen in mm.

4) Impact tests

Impact tests measures the ability of the plastics material to resist a rapidly applied stress. The test is commonly performed by striking a plastic bar with pendulum or hammer at a specified speed and then measuring the load to break. . It is expressed in J/m or Kg. Impact test is directly related to the toughness of material.

There are two major types of pendulum impact tests

1. Izod Impact
2. Charpy Impact.

Izod impact tests

Izod impact test indicates the energy required to break notched specimens under standard conditions. The pendulum of the machine is cantilevered upward and the notch of the specimen should face the direction of impact. The pendulum is released and the force consumed in breaking the sample is calculated from the height of the

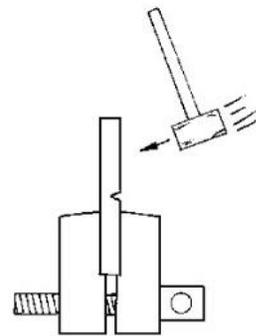


Fig: 3.6.3 Izod Impact Testing

pendulum that reaches on the follow through. Izod value is useful in comparing various types or grades of plastics.

Charpy impact testing

The Charpy impact test uses a rectangular bar which is struck by a pendulum or hammer. The impact strength may be expressed as the amount of energy needed to break a specified bar. The sample unlike Izod test is supported at both ends and has a notch at the other side of the specimen, which is struck centrally.

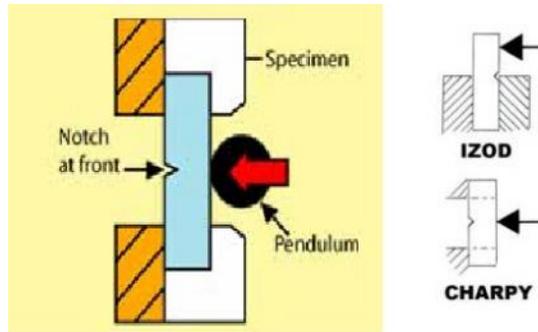


Fig: 3.6.4 Charpy impact testing

5) Hardness Tests

Hardness is defined as the resistance of a material to deformation, indentation, or scratch. Different test methods are used for measuring the hardness of plastics. Principle of any hardness test method is forcing an indenter into the sample surface followed by measuring dimensions of the indentation (depth or actual surface area of the indentation).

The Durometer hardness test (ASTM D 2240)

The Durometer hardness tester consists of a pressure foot, an indenter, and an indicating device. The indenter is spring loaded and the point of the indenter protrudes through the hole in the base. The test specimens are at least 3 mm thick and can either be moulded or cut from a sheet. The test is carried out by first placing a specimen on a hard, flat surface. The pressure foot of the instrument is pressed onto the specimen, making sure that it is parallel to the surface of the specimen. The durometer hardness is read within 1 sec after the pressure foot is in firm contact with the specimen. The hardness numbers derived from either scale are just numbers without any units. Two types of durometers are most commonly used - Type A & Type D. Type A durometer is used for soft material. Type D durometer is used for hard material.

Rockwell Hardness ASTM D 785

Rockwell hardness number is derived from the net increase in depth impression as the load on an indenter is increased from a fixed minor load a major load and then returned to minor load.

The test specimen of 25mm x 25mm x 6mm is placed on the anvil of the apparatus

and minor load is applied by lowering the steel ball onto the surface of the specimen. The minor load indents the specimen slightly and assures good contact. The dial is adjusted to zero under minor load and the major load is immediately applied by releasing the trip lever. After 15 sec the major load is removed and the specimen is allowed to recover for an additional 15 sec. Rockwell hardness is read directly off the dial with the minor load still applied.

6) Thermal tests

Thermal properties play a vital role in evaluating the product performance as well as predicting the processability characteristics in plastics for specific applications. These properties are of great importance to the process engineers and designers in designing the machines and tool for shaping of plastics. The following are the important thermal tests conducted on plastics

6.1 Heat Deflection Temperature (HDT)

Heat Deflection Temperature (HDT) is a relative measure of a material's ability to perform for a short time at elevated temperatures while supporting a load. The test measures the effect of temperature on stiffness. It is defined as the temperature at which a standard test bar ($5 \times \frac{1}{2} \times \frac{1}{4}$ inch) deflects 0.010 inch under a stated load of either 66 or 264 psi when heated at the rate of $2^{\circ}\text{C}/\text{minutes}$. Specimens of dimensions 127 mm in length, 13 mm in depth cut should be conditioned at 23°C and 50% relative humidity for not less than 40 hrs prior to test.

The test specimens are positioned edgewise in the apparatus to ensure that they are properly aligned on the supports. Carefully apply the load 66 psi or 264 psi is obtained on to the specimen. Five minutes after applying the load, adjust the deflection measurement device to zero position. Heat the liquid heat-transfer medium at a rate of 2.0 $0.2^{\circ}\text{C}/\text{min}$. Record the temperature of the liquid heat-transfer medium at which the specimen has deflected the specified amount at the specified stress.

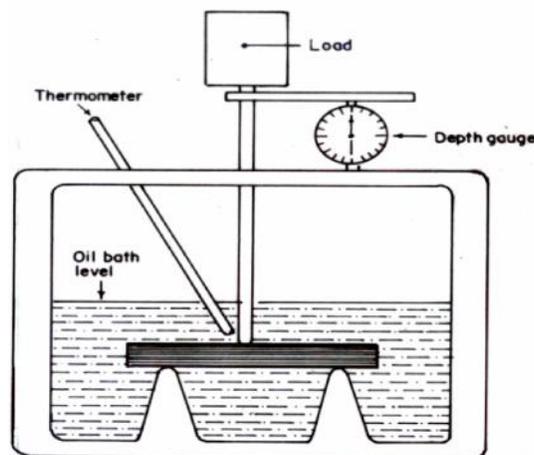


Fig: 3.6.5 : 3.6.5 Apparatus for the determination of HDT

6.2 Vicat Softening Point (VSP) ASTM D 1525

The test determines the temperature at which a standard indenter penetrates 1mm under the surface of a test specimen under load. Data obtained by this test method may be used to compare the heat-softening qualities of thermoplastic materials. This test method is also useful in the areas of quality control, development and characterization of plastic material.

Test method

The specimen shall be flat, between 3 and 6.5 mm thick and at least 10×10 mm in area or 10 mm in diameter. The test specimens shall be conditioned at $23 \pm 2^\circ\text{C}$ and at 50–5% relative humidity of not less than 40 hrs. The sample is immersed in the heating bath of the vicat apparatus. A flat-ended needle placed in direct contact with the test specimens. The specified weight of about 50N is applied to the load carrying plate. Temperature of the bath is raised at the uniform rate of 500°C/hr . The liquid is stirred well during the test. Temperature of the bath at which the indenting tip penetrates into the specimen by 1.00 mm is recorded as the Vicat softening temperature of the test specimen.

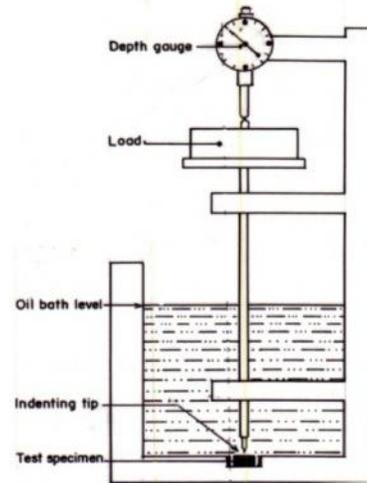


Fig: 3.6.6 Vicat Softening point Apparatus

6.3 Melt flow index (MFI) ASTM D (1238-70)

It is defined as the amount of material flow in ten minutes from a standard die under prescribed conditions of temperature and pressure. The unit of MFI is $\text{g}/10\text{min}$. The melt index values help to distinguish between the different grades of a polymer and is indicative of the molecular weight of a polymer. A high molecular weight material is more resistant to flow than a low molecular-weight material.

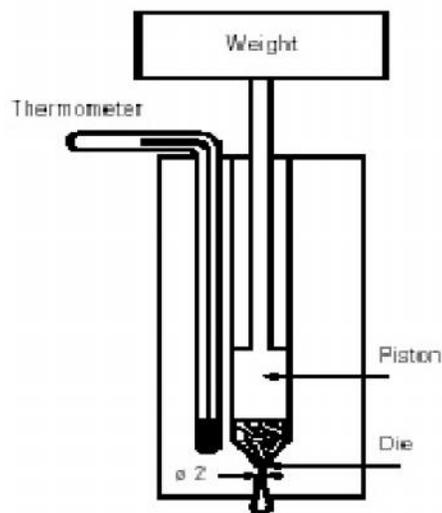


Fig: 3.6.7 MFI apparatus

The extrusion plastometer consists of a vertical cylinder with a small die of 2 mm at the bottom and a removable piston at the top. The material is loaded in to the preheated cylinder. The piston placed on top of the molten polymer and its weight forces the polymer through the die and on to a collecting plate. Loads used

are 1.2, 5 and 10 kg. The amount of polymer extruded after a specific interval is weighed and normalized to the number of grams that would have been extruded in 10 minutes.

7. Environmental stress crack resistance (ESCR)

Environmental Stress Crack Resistance (ESCR) describes the tendency of poly ethylene products to prematurely fail in the presence of detergents, water, sunlight, oil etc under conditions of strain. It is a physical phenomenon that involves no swelling or similar mechanical weakening of the metal. The test is carried out using 1.5*1/2 inch specimens cut from the sample. It is bend through 180° fixed to a holder. Holder is inserted in to a test tube. Fill the test tube with soap or any organic liquid. The tube is placed in a constant temperature bath. Test specimens are removed after specified time and observed for cracks.

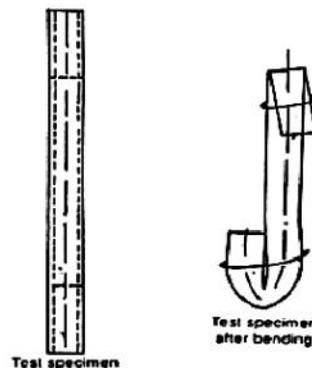


Fig: 3.6.7 Environmental stress crack resistance (ESCR)

DETAILING OF PRACTICALS

1. Demonstration about personal, machine & electrical safety while working on plastics testing machines
 2. Determination of Tensile properties of plastics
 3. Determination of Density/Specific Gravity
 4. Determination of Impact strength
- Procedure

The procedure for the practical in this unit is detailed in the section 1 - 7 of this unit.

ASSESSMENT ACTIVITIES

Practical evaluation

Oral Evaluation

Class test

Theory Evaluation Questions

- 1) What are the common thermal tests done on plastics?
- 2) Explain the Izod and Charpy impact tests on plastics
- 3) Describe the tensile and flexural property measurement of plastics
- 4) Identify the equipment used for measuring the hardness of plastics
- 5) Explain how to determine the specific gravity of a plastic sample in the laboratory

Module IV

FIBRE REINFORCED COMPOSITES

Overview

Fibre-reinforced plastic (FRP), is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, or aramid. Other fibres such as paper, wood or asbestos etc were rarely used. The polymer used is usually an epoxy, vinyl ester or polyester thermosetting plastic. Combining fibres with resin matrix results in composites that are strong, lightweight, corrosion-resistant and dimensionally stable. They also provide good design flexibility and require lower tooling costs. Because of these advantages, composites are being used in a growing number of industries, such as aerospace, automobile, civil infrastructure, wind energy, marine and sports. Their high strength-to-weight ratio and design flexibility make them ideal in structural components. High-strength lightweight premium composite materials such as carbon fibre - epoxies are being used for aerospace applications and in high performance sporting goods. Composite's superior electrical insulating properties also make them ideal for appliances, tools and machinery. Tanks and pipes constructed with corrosion-resistant composites offer extended service life over those made with metals.

One of the advantages of composites is that, their components - fibre and resin matrix, complement each other. While thin fibres are quite strong, they are also susceptible to damage. Plastics are relatively weak, but are versatile and tough. Combining these two components together, however, results in a material that is more useful than either is separately. With the right fibre, resin and manufacturing process, designers today can tailor composites to meet final product requirements that could not be met by using other materials.

This module is divided into five units. The first unit covers the fundamentals of Fibre reinforced composites, basic features and applications. Then different reinforcements, matrix materials and other additives used in fibre reinforced composites dealt in detail in second and third units respectively. Fourth unit is dedicated to the various manufacturing processes used for making FRP products. The fifth unit deals with the design of FRP products, materials selection, mould or pattern making and repair of composites.

Unit I

Introduction to Composites

Over view of the unit

This unit is an introduction to composite materials. It deals with the basic features, components, properties and applications of fibre reinforced composites. Classification of different composites, advantages, disadvantages and comparison of composite materials with conventional materials are also covered.

Learning outcomes

The learner :

- 4.1.1 Explains composites, its basic features and constituents of composites, role of matrix, reinforcement and interphase
- 4.1.2 Classifies different composites based on matrix, structure, and type of reinforcements, orientation and applications

Introduction

Composites are materials made by combining two or more dissimilar materials. One phase is the reinforcing phase and the other phase is the matrix phase in which the reinforcing materials is embedded. The reinforcing material may be in the form of fibres, particles, or flakes. The matrix phase materials are generally continuous. The matrix phase is light but weak. The reinforcing phase is strong and hard and may not be light in weight. But the combination of the two exhibits the best of individual properties as well as enhanced properties that none of the individual components possesses.

Example: helmet

Helmet is made of glass fibre and polyester resin. Both glass fibre and polyester are brittle and cannot individually withstand the impact energy in an accident. However the two together as group can have its impact resistance increased several folds absorbing the energy by developing numerous micro cracks and preventing the shock from transmitting to the head and brain. It is light in weight and can be moulded easily.

Constituents of composite material

Reinforcements:

Reinforcements give high strength, stiffness and other improved mechanical properties to the composites. Also their contribution to other properties such as the co-efficient of thermal expansion, conductivity etc is remarkable.

Matrices:

Matrices gives shape to the composites and the reinforcement fibres are embedded in it. It keeps the fibres in place and transfer stresses to the fibres, protects the reinforcement from the environment, such as chemicals & moisture, protect the surface of the fibres from mechanical degradation, and act as shielding from damage due to handling.

Fibre-matrix interface:

When the load is applied on a composite material, the load is directly carried by the matrix and it is transferred to the fibres from the matrix through fibre-matrix interface. So, it is clear that the load-transfer from the matrix to the fibre depends on the fibre-matrix interface. This interface may be formed by chemical, mechanical, and reaction bonding. In most cases, more than one type of bonding occurs.

Advantages of composites

- a) High resistance to fatigue and corrosion degradation
- b) High strength to weight ratio
- c) Can be tailor made to meet the design requirements
- d) High resistance to impact damage
- e) Simplified manufacturing processes
- f) Close tolerances can be achieved without machining

Disadvantages of composites

- a) Composites are more brittle than metals
- b) Reuse and disposal may be difficult
- c) Directional dependence of properties
- d) Matrix is weak, therefore low toughness
- e) Matrix is subjected to environmental degradation

Applications of composites

1. Aerospace
2. Land transport including road and rail transport
3. Marine vessels and ocean structures
4. Building and civil engineering construction including agriculture, aqua culture, irrigation, water treatment, sewerage disposal and railway track construction
5. Chemical plants and corrosion resistant products and structures
6. Electrical electronics and communication applications

7. Mechanical systems, machine elements and energy appliances
8. Biomedical appliances including prosthetic and orthotic devices and hospital appliances
9. Sports goods and consumer durable goods

Indian composites scene

- Indian composites industry started in 1962 at Coimbatore
- Helmet production started in 1964 and chemical Plants were made in 1965 and marine application Started in 1967
- R & D in composites started in 1969 at VSSC and 1971 at NAL
- FRP research centre (the present composite Technology centre), IIT madras started in 1974 for teaching, research and design
- Industrial production of FRP in 2001 was 55,000 Tonnes
- There are 1200 FRP fabricators 4 glass fibre Manufacturers and 91 resin manufacturers

Classification of composites

Composites have been in the nature before man made composites came into existence. Wood, bamboo, bone, muscle, shell of beetle, horn of rhino, coconut husk etc are examples of natural composites. Polymer matrix composites are made using resins such as polyester, epoxy, vinyl ester etc and fibres such as glass fibre, carbon fibre and aramids

Composite materials can be classified based on the type of matrices, type of reinforcement and their orientation.

Classification of composites based on matrix

The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

Classification of Composites based on reinforcements

Based on the form of reinforcement the composites are classified as fibre reinforced composites, laminar composites and particulate composites. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.

Fibre Reinforced Composites are composed of fibres embedded in matrix material. These are further divided into short fibre and continuous fibre composites based on the length of the fibres used. Depending on the fibre direction and orientation uniaxial, biaxial, woven fabrics, knitted fabrics, braided fabrics, chopped strand mats etc are used in composites.

Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.

Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

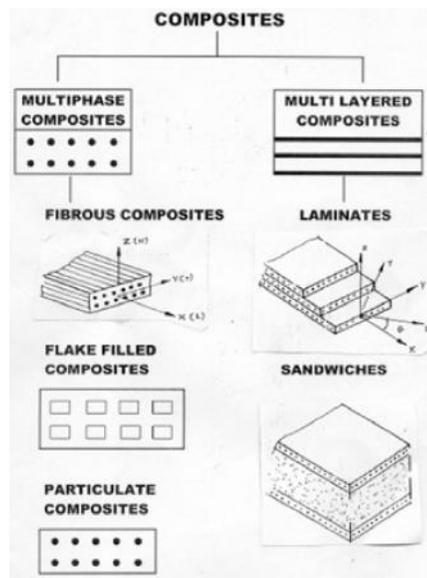


Fig: 4.1.1 Different types of composites

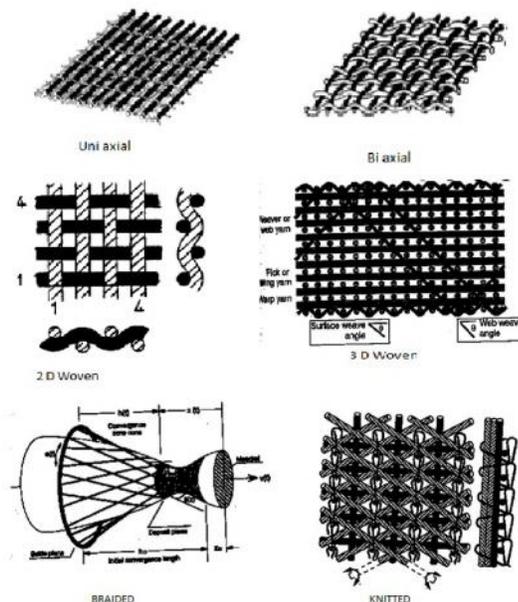


Fig: 4.1.2 Different forms of reinforcement

DETAILING OF PRACTICALS

Prepare a sample FRP sheet using the given compounded polyester resin and glass fibre.

Procedure

Take two clean OHP films. Apply one coat of release agent (wax or PVA) on to the surface of the OHP films. Now apply a thin gel coat of compounded resin on one film using a paint brush or roller. Place one layer of glass fibre and wet thoroughly

with the compounded resin. Build successive layers to get the desired thickness. Then apply a second gel coat. Place the other film above this and consolidate using rollers. Keep it undisturbed for about half an hour to allow the resin to harden. After 30 remove the OHP films and finish the FRP sheet by trimming the edges.

ASSESSMENT ACTIVITIES

- 1) Assignment of the application of composites.
- 2) Chart - Classification of composites

Theory Evaluation Questions

- 1) Helmets are made of Fibre reinforced plastics
 - a. Explain how the combination of resin matrix and reinforcement fibre effectively protects us from head injuries during an accident.
 - b. Identify the materials used in the construction of helmets
- 2) Many automobile components are nowadays made of FRP materials. Discuss the advantages and disadvantages of FRP materials.
- 3) FRP materials consist of matrix and reinforcements. Explain the role of each in a successful FRP product.
- 4) Classify the FRP products on the basis of matrices used for construction?
- 5) Classify the FRP products on the basis of the form of reinforcements used?
- 6) Discuss the advantages of FRP materials in aerospace, agriculture, and marine applications
- 7) Which of the following combination is an essential part of a composite?
 - a) Filler and pigments
 - b) Catalyst and lubricants
 - c) Plastic resin and reinforcements
 - d) Resin and stabilizer
- 8) Which of the following are major advantages of composites
 - a) Unlimited moulding size
 - b) Low capital investment
 - c) High strength to weight ratio
 - d) All of the above

Unit II

REINFORCEMENT FIBRES

Over view of the unit

Reinforcing fibres are a key component of polymer matrix composites. They impart high strength and stiffness to the matrix materials. This unit deals with different kinds of reinforcement fibres used for making Fibre Reinforced Composites. Different fibres such as Glass fibre, Carbon fibre, Aramid fibres etc and the different forms in which they are used in composites are also discussed. The terminologies used in fibre science are also provided understand the fibre characteristics.

Learning outcomes

The learner :

- 4.2.1 Explains the functions and properties of reinforcing fibres used in composites
- 4.2.2 Identifies the different types of fibres like roving, continuous filaments, chopped strand mats, woven fabric etc
- 4.2.3 Describes the properties and applications of different types of glass fibres, carbon fibre, Aramid fibre, Boron fibre, UHMWHDPE fibres, and different natural fibres used in composites and their applications

Reinforcing fibres

Reinforcing fibres are a key component of fibre reinforced composites. They impart high strength and stiffness to the matrix material and share a major portion of the load acting on the composite structure. Proper selection of the fibre type, volume fraction, length, and fibre orientation is very important, since it influences the density, strength, stiffness, electrical and thermal properties and cost characteristics of the composites. The fibre generally occupies 30% - 70% of the matrix volume in the composites. The fibres can be chopped, woven, stitched, and braided. They are usually treated with sizing such as starch, gelatin, oil or wax to improve the bond as well as to improve the handling. The most common types of fibres used in advanced composites are fibreglass, aramid, and carbon. The fibreglass is the least expensive and carbon being the most expensive. The cost of aramid fibres is about the same as the lower grades of the carbon fibre. Other fibres used in composites include polyethylene, aromatic polyester, boron fibres etc. In addition to this certain low cost fibres such as cotton, jute, flax, sisal, asbestos etc are used in low cost composite applications.

Functions of a reinforcing agent

The functions of a reinforcing agent are:

1. These are the main load carrying constituents.
2. They contribute the desired properties to the composite.
3. It transfers the strength and stiffness to the matrix material.

Requirements of reinforcement fibres

- High Modulus
- Fine diameter (flexible, smaller size defects)
- High aspect ratio (length to diameter ratio)
- Stable during processing conditions
 - thermally
 - chemically
 - physically (mixing, pressing, injection operations)

Terminologies used in fibre reinforced composites

The following terms are frequently used to describe fibre characteristics and hence it is necessary to know these terms.

Staple fibre	: Represents discontinuous fibre
Filament	: Represents a single continuous fibre
Strand	: Represents a bundle of 204 untwisted fibres (filament)
Roving	: Combination of strands to form thicker parallel bundles
Tow	: Represents bundle of untwisted filaments in large numbers, say 2000 to 12000 filaments.
Yarn	: Represents bundle of twisted fibres (strands).
Sizes	: Represents a thin coating of chemical applied on filament surface to protect the fibres from damage and environmental effects (e.g., polyvinyl acetate)
Coupling agents	: Used to get good bonding between fibre and matrix (e.g. chrome complexes, silanes)
Braiding	: Two or more yarns are intertwined to form an elongated structure. The long direction is called the bias direction or machine direction.

- Chopped strands : Fibres are chopped to various lengths, 3 to 50 mm, for mixing with resins.
- Chopped strand Mat : Randomly dispersed chopped fibres or continuous fibre strands, held together with a binder.
- Cord : A relatively thick fibrous product made by twisting together two or more plies of yarn.
- Denier : A unit of linear density. It is the weight in grams of 9000m long yarn.
- Knitted fabric : One set of yarn is looped and interlocking to form a planar structure.
- Warp : Lengthwise yarn in a woven fabric.
- Weft : Transverse yarn in a woven fabric. Also called fill.
- Woven Fabric : Flat, drapable sheet made by interlacing yarns or tows
- Woven roving : Heavy, drapable fabric woven from continuous roving.

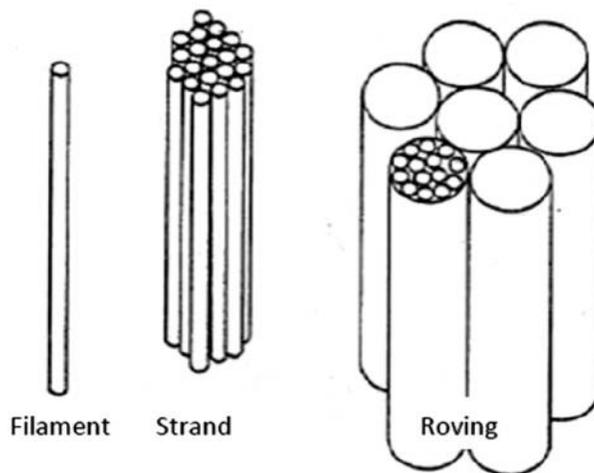


Fig: 4.2.1 Fibre forms

Glass fibres

Glass fibres are the most common of all reinforcing fibres for polymeric matrix composites (PMC). The principal advantages of glass fibres are low cost, high tensile strength, high chemical resistance, and excellent insulating properties. The disadvantages are relatively low tensile modulus and high density, sensitivity to abrasion during handling, relatively low fatigue resistance, and high hardness

The three types of glass fibres commonly used in the fibre-reinforced plastics (FRP) industry are E-glass S-glass and C-glass. E-glass has the lowest cost of all commercially available reinforcing fibres, S-glass, has the highest tensile strength

among all fibres in use and is more expensive than E-glass. C-glass is used in chemical applications requiring greater corrosion resistance to acids.

Table 4.2.1 Chemical compositions of E- and S-glass fibres

Composition of Glass fibres (wt %)						
Type	SiO ₂	Al ₂ O ₃	CaO	MgO	B ₂ O ₃	Na ₂ O
E glass	54.5	14.5	17	4.5	8.5	0.5
S glass	64	26		10		

The principal ingredient in all glass fibres is silica (SiO₂). Other oxides, such as B₂O₃ and Al₂O₃, are added to modify the network structure of SiO₂ as well as to improve its workability. Various ingredients in the glass formulation are first dry-mixed and melted in a refractory furnace at about 1370°C. The molten glass is extruded through a number of orifices contained in a platinum bushing and rapidly drawn into filaments of ~10 µm in diameter. A protective coating (size) is then applied on individual filaments before they are gathered together into a strand and wound on a drum. The coating or size is a mixture of lubricants (which prevent abrasion between the filaments), antistatic agents (which reduce static friction between the filaments), and a binder (which packs the filaments together into a strand). It may also contain small percentages of a coupling agent that promotes adhesion between fibres and the specific polymer matrix for which it is formulated.

Table 4.2.2 Mechanical properties of glass fibres:

Properties		E-glass	S-glass
Specific gravity		2.60	2.50
Modulus	GPa	72	87
Strength	MPa	3450	4310
Percentage tensile elongation		4.8	5.0
Co-efficient of thermal expansion	µm/m/°C	5.0	5.6

The basic commercial form of glass fibre is a strand, which is a collection of 204 parallel filaments. A roving is a group of untwisted parallel strands (also called ends) wound on a cylindrical forming package. Rovings are used in continuous moulding operations, such as filament winding and pultrusion. They can also be pre impregnated with a thin layer of polymeric resin matrix to form prepregs. Prepregs are subsequently

cut into required dimensions, stacked, and cured into the final shape in batch moulding operations, such as compression moulding and hand layup moulding.

Chopped strands are produced by cutting continuous strands into short lengths. The ability of the individual filaments to hold together during or after the chopping process depends largely on the type and amount of the size applied during fibre manufacturing operation. Strands of high integrity are called "hard" and those that separate more readily are called "soft." Chopped strands ranging in length from 3.2 to 12.7 mm are used in injection-moulding operations. Longer strands, up to 50.8 mm in length, are mixed with a resinous binder and spread in a two-dimensional random fashion to form chopped strand mats (CSMs). These mats are used mostly for hand layup mouldings and provide nearly equal properties in all directions in the plane of the structure.

Glass fibres are also available in woven form, such as woven roving or woven cloth. Woven roving is a coarse drapable fabric in which continuous roving are woven in two mutually perpendicular directions. Woven cloth is weaved using twisted continuous strands, called yarns. Both woven roving and cloth provide bidirectional properties that depend on the style of weaving as well as relative fibre counts in the length (warp) and crosswise (fill) directions. A layer of woven roving is sometime s bonded with a layer of CSM to produce a woven roving mat. All of these forms of glass fibres are suitable for hand layup moulding and liquid composite moulding.

Carbon fibre

A carbon fibre is a thin, long fibre composed mostly of carbon atoms. Carbon fibre-reinforced composite materials are used to make aircraft and spacecraft parts, racing car bodies, golf club shafts, bicycle frames, fishing rods, automobile springs, and many other components where light weight and high strength are needed.

Carbon fibres are classified by the tensile modulus of the fibre. Low modulus carbon fibres have a tensile modulus below 250 GPa. Other classifications, in ascending order of tensile modulus, include "standard modulus," "intermediate modulus," "high modulus," and "ultrahigh modulus." Ultrahigh modulus carbon fibres have a tensile modulus of 500 - 1000GPa. As a comparison, steel has a tensile modulus of 200 GPa). Thus, the strongest carbon fibres are five times stronger than steel.

In general, the low-modulus fibres have lower density, lower cost, than the high-modulus fibres. Among the advantages of carbon fibres are their exceptionally high tensile strength-weight ratios as well as tensile modulus-weight ratios, very low coefficient of linear thermal expansion (which provides dimensional stability in such applications as space antennas), high fatigue strengths, and high thermal conductivity (which is even higher than that of copper). The disadvantages are their low strain-

to-failure, low impact resistance, and high electrical conductivity, which may cause "shorting" in unprotected electrical machinery. Their high cost has so far excluded them from widespread commercial applications. They are used mostly in the aerospace industry, where weight saving is considered more critical than cost.

Table 4.2.3 Mechanical properties of carbon fibres:

Properties	Low	Intermediate	Ultra-high
Specific gravity	1.8	1.9	2.2
Modulus GPa	230	370	900
Strength MPa	3450	2480	3800
Percentage tensile elongation	1.1	0.5	0.4
Co-efficient of thermal expansion $\mu\text{m/m}^\circ\text{C}$	-0.4	-0.5	-0.5

The raw material used to make carbon fibre is called the precursor. About 90% of the carbon fibres produced are made from polyacrylonitrile (PAN). The remaining 10% are made from rayon or petroleum pitch. All of these materials are organic polymers, characterized by long strings of molecules bound together by carbon atoms.

The process for making carbon fibres is part chemical and part mechanical. The precursor is drawn into long strands or fibres and then heated to a very high temperature without allowing it to come in contact with oxygen. Without oxygen, the fibre cannot burn. Instead, the high temperature causes the atoms in the fibre to vibrate violently until most of the non-carbon atoms are expelled. This process is called carbonization and leaves a fibre composed of long, tightly inter-locked chains of carbon atoms with only a few non-carbon atoms remaining.

After carbonizing, the fibres have a surface that does not bond well with the epoxies and other materials used in composite materials. To give the fibres better bonding properties, their surface is slightly oxidized. The addition of oxygen atoms to the surface provides better chemical bonding properties and also etches and roughens the surface for better mechanical bonding properties.

After the surface treatment, the fibres are coated to protect them from damage during winding or weaving. This process is called sizing. Coating materials are chosen to be compatible with the adhesive used to form composite materials. Typical coating materials include epoxy, polyester, nylon, urethane, and others. The coated fibres are wound onto cylinders called bobbins. The bobbins are loaded into a spinning machine and the fibres are twisted into yarns of various sizes.

Aramid fibres

Aramid (aromatic polyamide) fibres have the lowest density and the highest tensile strength-to-weight ratio. They are commonly known by the trade name Kevlar. Aramid fibres are used in many marine and aerospace applications where lightweight, high tensile strength, and resistance to impact damage are important. Like carbon fibres, they also have a negative coefficient of thermal expansion in the longitudinal direction, which is used in designing low thermal expansion composite panels. The major disadvantages of aramid fibre reinforced composites are their low compressive strengths and difficulty in cutting or machining.

Kevlar filaments are manufactured by extruding an acidic solution of a proprietary precursor (a polycondensation product of terephthaloyl chloride and p-phenylene diamine) from a spinneret. During the filament drawing process, Kevlar molecules become highly oriented in the direction of the filament axis. Weak hydrogen bonds between hydrogen and oxygen atoms in adjacent molecules hold them together in the transverse direction. The resulting filament is highly anisotropic, with much better physical and mechanical properties in the longitudinal direction than in the radial direction. One interesting application of Kevlar fibres is in soft lightweight body armors and helmets used for protecting police officers and military personnel. Kevlar fibres do not melt or support combustion but will start to carbonize at about 427°C. The maximum long-term use temperature recommended for Kevlar is 160°C. They have very low thermal conductivity, but a very high vibration damping coefficient. Except for a few strong acids and alkalis, their chemical resistance is good. However, they are quite sensitive to ultraviolet light. Prolonged direct exposure to sunlight causes discoloration and significant loss in tensile strength. The problem is less pronounced in composite laminates in which the fibres are covered with a matrix. Ultraviolet light-absorbing fillers can be added to the matrix to further reduce the problem. Kevlar fibres are hygroscopic and can absorb up to 6% moisture. Absorbed moisture seems to have very little effect on the tensile properties of Kevlar fibres. Kevlar 49 and Kevlar 149 are two grades of commercial aramid fibres.

Table 4.2.4 Mechanical properties of Kevlar fibres:

Properties		Kevlar 149	Kevlar 49	Kevlar 129	Kevlar 29
Specific gravity		1.44	1.44	1.44	1.44
Modulus	GPa	186	124	96	68
Strength	MPa	3440	3700	3380	2930
Percentage tensile elongation		2.5	2.8	3.3	3.6
Co-efficient of thermal expansion	$\mu\text{m/m/}^\circ\text{C}$	-2.0	-2.0	-2.0	-2.0

Extended chain polyethylene fibres

Extended chain polyethylene fibres, commercially available under the trade name Spectra, are produced by gel spinning a high-molecular-weight polyethylene. Gel spinning yields a highly oriented fibrous structure with exceptionally high crystallinity (95%-99%) relative to melt spinning used for conventional polyethylene fibres. Spectra polyethylene fibres have the highest strength-to-weight ratio of all commercial fibres available to date. Two other outstanding features of Spectra fibres are their low moisture absorption (1% compared with 5%-6% for Kevlar) and high abrasion resistance, which make them very useful in marine composites, such as boat hulls and water skis.

The melting point of Spectra fibres is 147°C; however, since they exhibit a high level of creep above 100°C, their application temperature is limited to 80°C-90°C. The safe manufacturing temperature for composites containing Spectra fibres is below 125°C, since they exhibit a significant and rapid reduction in strength as well as increase in thermal shrinkage above this temperature. Another problem with Spectra fibres is their poor adhesion with resin matrices, which can be partially improved by their surface modification with gas plasma treatment. Spectra fibres provide high impact resistance for composite laminates even at low temperatures and are finding growing applications in ballistic composites, such as armors, helmets, and so on. However, their use in high-performance aerospace composites is limited, unless they are used in conjunction with stiffer carbon fibres to produce hybrid laminates with improved impact damage tolerance than all-carbon fibre laminates.

Table 4.2.5 Mechanical properties of UHMWPE fibres:

Properties	Spectra 900	Spectra 1000	Spectra 2000
Specific gravity	0.97	0.97	0.97
Modulus GPa	70	105	115
Strength MPa	2600	3200	3400
Percentage tensile elongation	3.8	3.0	3.0
Co-efficient of thermal expansion $\times 10^6 \mu\text{m/m}^\circ\text{C}$	>70	>70	-

Natural fibres

Examples of natural fibres are jute, flax, hemp, sisal, coconut fibre (coir), and banana fibre. The components of natural fibres are cellulose micro fibrils dispersed in an amorphous matrix of lignin and hemicellulose. Depending on the type of the natural fibre, the cellulose content is in the range of 60-80 wt% and the lignin content is in

the range of 5-20 wt%. In addition, the moisture content in natural fibres can be up to 20 wt%. The use of natural fibre-reinforced composites are increasing because

- They are biodegradable, and unlike glass and carbon fibres, the energy consumption to produce them is very small.
- The density of natural fibres is in the range of 1.25-1.5 g/cm³ compared with 2.54 g/cm³ for E-glass fibres and 1.8-2.1 g/cm³ for carbon fibres.
- The modulus-weight ratio of some natural fibres is greater than that of E-glass fibres,
- Natural fibre composites provide higher acoustic damping than glass or carbon fibre composites, and therefore are more suitable for noise attenuation.
- Natural fibres are much less expensive than glass and carbon fibres.

However, there are several limitations of natural fibres.

- The tensile strength of natural fibres is relatively low.
- Low melting point and high moisture absorption.
- At temperatures higher than 200°C, natural fibres start to degrade.

Natural fibre composites are now used in automobile door inner panel, seat back, roof inner panel, and so on.

Boron fibres

Boron fibres have extremely high tensile modulus, in the range of 400 GPa. Coupled with their relatively large diameter, boron fibres offer excellent resistance to buckling, which in turn contributes to high compressive strength for boron fibre-reinforced composites. The high cost of boron fibres sometimes even higher than that of many forms of carbon fibres, restricts its use a few aerospace applications.

Boron fibres are manufactured by chemical vapor deposition (CVD) of boron onto a heated substrate (either a tungsten wire or a carbon monofilament). It is continuously pulled through a reaction chamber in which boron is deposited on its surface at 1100°C-1300°C. Commercial boron fibres are produced in diameters of 0.1, 0.142, and 0.203 mm, which are much larger than those of other reinforcing fibres.

Surfacing tissues

It is an overlay mat used as a top layer in laminates. Surfacing Tissue or surface mat or veil consists of a thin randomly distributed fibrous mat. They are available in different thicknesses ranging from 0.08 to 0.34 mm manufactured from C glass fibre or synthetic fibres such as PAN or PET. Pattern, trade name and design can be

printed on to the surface tissues. Surfacing tissues may be used to reinforce the gel coat and is applied immediately after the gel coat while the resin is still wet and lightly rolled to displace the air bubbles outwards. The advantages of surfacing tissues are

- They provide a resin rich finish with improved chemical and weathering resistance.
- Ensure adequate bond between the resin rich surface layer and the bulk laminate
- Help to mask the pattern of the underlying glass reinforcement
- Provide a degree of elasticity to the surface layer to improve impact and abrasion resistance
- It prevents fibre from protruding from the resin and giving a hairy finish

DETAILING OF PRACTICALS

- 1) Determine the denier of the given fibre sample.

Procedure

From the given fibre sample cut a length of 90 cms and place in an oven at 70° C for 1 hour. Cool in a desiccator and weigh. From this weight find out the weight of 9000 meters of the fibre and report as denier.

- 2) Prepare FRP sheets using Continuous Glass fibre and Chopped strand mats. Take two clean OHP films. Apply one coat of release agent (wax or PVA) on to the surface of the OHP films. Now apply a thin gel coat of compounded resin on one film using a paint brush or roller. Place one layer of continuous glass fibre on one and chopped strand mat on the other. Wet the fibres thoroughly with the compounded resin. Build successive layers to get the desired thickness. Then apply a second gel coat. Place one more OHP film above this and consolidate using rollers. Keep it undisturbed for about half an hour to allow the resin to harden. After 30 remove the OHP films and finish the FRP sheet by trimming the edges. Compare the directional properties of both the sheets.

ASSESSMENT ACTIVITIES

- 1) Assignment - Comparison of different fibres
- 2) Group discussion - Different forms of reinforcement.

Theory Evaluation Questions

- 1) Glass fibres are the most used fibres in FRP Industry.
 - a. Compare the different types glass fibres used in the FRP industry.
 - b. List the various forms of glass fibre reinforcement.
- 2) Which of the following fibres are most suited for Aerospace applications
 - a) Glass fibre
 - b) Kevlar fibre
 - c) Carbon fibre
 - d) Polyester
- 3) Prepregs is a
 - a) Reinforcement
 - b) Pre coated reinforcement
 - c) Curing agent
 - d) Release agent
- 4) Carbon fibres are the highest strength fibres used in aerospace application. Discuss the advantages and disadvantages of carbon fibre
- 5) List four natural fibres used for making FRP products and suggest one application for each
- 6) Carbon fibre and aramid fibres are high strength fibres. Compare the properties of carbon fibres and aramid fibres
- 7) Discuss the advantages of using surface mats or veil
- 8) Define the following
 - a) Filament
 - b) Strand
 - c) Roving

Unit III

MATRIX MATERIALS AND ADDITIVES

Over view of the unit

In composites, the resin matrix acts as a binding agent which holds the fibres together and assists the fibres in carrying the loads. Polyester and epoxy resins are the most widely used resins in the FRP industry. Apart from this other thermoset resins such as phenolic resins, polyurethanes and certain thermoplastics like poly ether ether ketone, nylon, poly ether imide etc are also used as matrix materials. Thermoplastic composites are used in small quantities and hence are not included in this unit. Thermoset resins require curing agents, catalysts, filler, pigments etc, to develop full functional properties. In addition to this core materials, which are widely used to enhance the stiffness and reduce weight and saves materials are also covered in this unit.

Learning outcomes

The learner :

- Describes the properties and applications of epoxy resins, polyester resins, phenolic resins and vinyl ester resins used in composites
- Describes the curing reaction, gelation, gel time, cure time and cure rate of different thermoset resins
- Describes the functions of various additives used in composites
- Explains the use of different core materials in composites

Introduction

The resin materials used in FRP industry are available in a variety of forms, as powders, liquid resins, solutions in organic solvents etc covering a wide range of viscosity. Resins that can be used at low pressures are preferred for FRP as the manufacturing equipments mostly involve low pressure, less costly and simple machines. The important resins are epoxies, polyesters, vinyl esters, and phenolics.

Functions of matrix

In a composite material the matrix material serves the following functions.

- Holds the fibres together
- Protects the fibre from environment

- Distributes the loads evenly between fibres so that all fibres are subjected to the same strain
- Enhances transverse properties of a laminate
- Improves the impact and fracture resistance of a component
- Help to avoid propagation of crack growth
- Carry inter laminar shear

Thermosets and thermoplastics

Both thermosets and thermoplastics are used as matrix materials for composites. A thermosetting material is one which when cured by heat or chemical reaction is changed into an infusible and insoluble material. Thermosetting resins undergo irreversible chemical crosslinking reaction upon application of heat. On the other hand thermoplastics do not undergo crosslinking upon application of heat. They simply melt on application heat and can be shaped by application of pressure. They can be repeatedly softened by heating and hardened by cooling. Different types of thermoset and thermoplastic resins commonly use are as follows.

Table 4.3.2 Polymer matrix materials for Composites

Thermosets	Thermoplastics
Epoxy resin	Polypropylene
Polyesters	Nylon
Vinyl ester	Poly ether ether ketone (PEEK)
Phenolics	Poly ether imide (PEI)

Epoxy Resins

Epoxy resins generally out-perform most other resin types in terms of mechanical properties and resistance to environmental degradation, which leads to their almost exclusive use in aircraft components. As a laminating resin their increased adhesive properties and resistance to water degradation make these resins ideal for use in applications such as boat building. The term 'epoxy' refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded in some way.

Usually identifiable by their characteristic amber or brown colouring, epoxy resins have a number of useful properties. Both the liquid resin and the curing agents form low viscosity easily processed systems. Epoxy resins are easily and quickly cured at

any temperature from 5°C to 150°C, depending on the choice of curing agent. One of the most advantageous properties of epoxies is their low shrinkage during cure which minimises fabric 'print-through' and internal stresses. High adhesive strength and high mechanical properties are also enhanced by high electrical insulation and good chemical resistance. Epoxies find uses as adhesives, caulking compounds, casting compounds, sealants, varnishes and paints, as well as laminating resins for a variety of industrial applications. Epoxy resins are formed from a long chain molecular structure similar to vinyl ester with reactive sites at either end. In the epoxy resin, however, these reactive sites are formed by epoxy groups instead of ester groups. The absence of ester groups mean that the epoxy resin has particularly good water resistance. The epoxy molecule also contains two ring groups at its centre which are able to absorb both mechanical and thermal stresses better than linear groups and therefore give the epoxy resin very good stiffness, toughness and heat resistant properties.

Chemistry

Epoxies are characterized by the presence of one or more epoxide functional groups in the polymer chain. Figure 4.3.1 shows the epoxide functional group, where R1 represents the functionalized molecule.

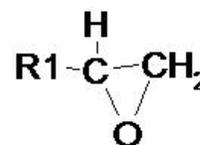


Fig: 4.3.1 Epoxide group

Epoxy resin formed by the reaction between bisphenol A and epichlorohydrin, known as Diglycidyl ether of bisphenol-A (DGEBA), currently commands a 75% share of the epoxy-resin market.

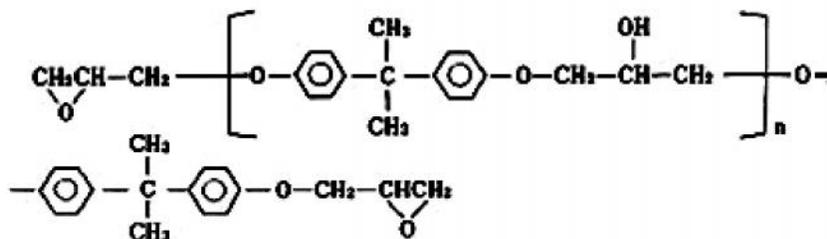


Fig: 4.32 Structure of Diglycidyl ether of bisphenol-A (DGEBA)

Hardener (Curing agent)

The epoxy resins can be cured by amine type or anhydride type curing agents.

Amine type

Aliphatic amine is curing agent for epoxy resin and able to cure at room temperature. The cured resin has excellent properties, and its heat resistance is 100°C. Aromatic

amine has been developed to achieve greater heat resistance and chemical resistance than those of aliphatic amine.

Aromatic amine has weaker basicity than aliphatic amine and slowly cures at room temperature due to steric hindrance by the aromatic ring. The curing virtually stops in the B-stage of a linear polymer solid due to the large difference in the reaction of primary and secondary amines. Normally, the curing of aromatic amine requires heating in two steps. The first heating is carried out at a rather low temperature of approximately 80°C so as to lessen heat generation, and the second heating is carried out at a high temperature of 150°C to 170°C.

Anhydrides

Anhydrides used as epoxy-resin curing agents have been used as curing agents for electrical insulating materials. Anhydrides require severer curing conditions than amine-based curing agents, but are suitable for making large mouldings, as they have a long pot life and form cured resins having relatively well-balanced electrical, chemical, and mechanical properties while generating a small quantity of heat.

Polyester resins

Polyester resins are the most widely used resin systems, particularly in the marine industry. Unsaturated polyester resin is a thermoset, capable of being cured from a liquid or solid state when subject to the right conditions. Polyesters are produced by the condensation reaction of di alcohols, such as a glycol, with di-basic acids such as terephthalic acids. This reaction, together with the addition of compounds such as saturated di-basic acids and cross-linking monomers, forms the basic process of polyester manufacture. There is a wide range of polyesters made from different acids, glycols and monomers, all having varying properties. There are two principle types of polyester resin used as standard laminating systems in the composites industry. Orthophthalic polyester resin is the standard economic resin used by many people. Isophthalic polyester resin is now becoming the preferred material in industries such as marine where its superior water resistance is desirable. Idealized chemical structure of a typical polyester is given below.

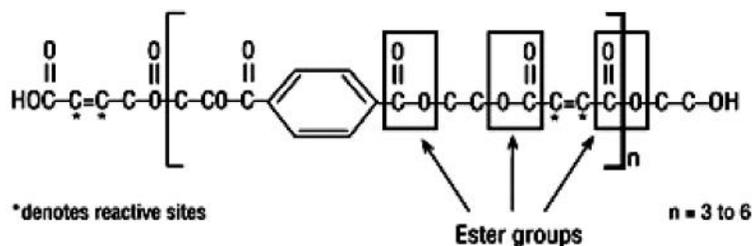


Fig: 4.3.3 Chemical structure of typical Isophthalic polyester

important to add the accelerator and catalyst in carefully measured amounts to control the polymerization reaction to give the best material properties. Too much catalyst will cause too rapid a gelation time, whereas too little catalyst will result in under-cure. Colouring of the resin mix can be carried out with pigments. Filler materials are used extensively with polyester resins to reduce the cost of the moulding and to impart specific properties to the moulding

Fillers are often added in quantities up to 50% of the resin weight although such addition levels will affect the flexural and tensile strength of the laminate. The use of fillers can be beneficial in the laminating or casting of thick components where otherwise considerable exothermic heating can occur. Addition of certain fillers can also contribute to increasing the fire-resistance of the laminate.

Phenolic resin

Phenolic or PF resins were the first polymeric resins produced commercially from simple low molecular weight compounds. These are prepared by the polycondensation between phenol and formaldehyde in the presence of either an acid or a base catalyst. The nature of the product is dependent on the type of catalyst and the mole ratio of reactants. The initial phenol-formaldehyde reaction products may be of two types, novolacs and resols.

Novolacs are prepared by reacting formaldehyde and a molar excess of phenol under acidic conditions. Novolacs do not contain any reactive groups and hence require the addition of a crosslinking agent and heat to achieve cure. The novolacs are also referred to as two-stage resins. A resol is prepared by reacting phenol with an excess of formaldehyde under basic conditions. Although initial methylol formation is rapid, subsequent condensation is slow. This results in low molecular weight liquid resols containing 23 benzene rings. When the resol is heated cross-linking via the uncondensed methylol groups occurs. Resols are also known as one-stage resins.

Phenolic resins have high temperature resistance of up to 250°C and have good mechanical strength, dimensional and thermal stability, high chemical resistance, and good dielectric properties. Some of the disadvantages of phenolic resins include by-product generation during curing, high shrinkage on cure, and porosity in the laminates.

Vinyl ester resins

Vinyl ester resins are the most recent addition to the family of thermoset resins. There are two basic types of vinyl esters having commercial significance, viz. general purpose lower molecular weight vinyl esters and the high heat resistant vinyl esters. General purpose vinyl esters have excellent mechanical properties and outstanding

chemical resistance to acids, bases and many solvents. Heat resistant vinyl esters have 10 -30°C higher heat resistance than the general purpose ones. The disadvantages of vinyl esters are: vinyl esters are not as good as epoxy resins with regard to bondability to other surfaces and high cost.

Gelation, curing & post curing

On addition of the catalyst or hardener a resin will begin to become more viscous until it reaches a state when it is no longer a liquid and has lost its ability to flow. This is the 'gel point'. The resin will continue to harden after it has gelled, until, at some time later, it has obtained its full hardness and properties. This reaction itself is accompanied by the generation of exothermic heat, which, in turn, speeds the reaction. The whole process is known as the 'curing' of the resin. The speed of cure is controlled by the amount of accelerator in a polyester or vinyl ester resin and by varying the type, not the quantity, of hardener in an epoxy resin. Generally polyester resins produce a more severe exotherm and a faster development of initial mechanical properties than epoxies of a similar working time.

With both resin types, however, it is possible to accelerate the cure by the application of heat, so that the higher the temperature the faster the final hardening will occur. This can be most useful when the cure would otherwise take several hours or even days at room temperature. A quick rule of thumb for the accelerating effect of heat on a resin is that a 10°C increase in temperature will roughly double the reaction rate. Therefore if a resin gels in a laminate in 25 minutes at 20°C it will gel in about 12 minutes at 30°C, providing no extra exotherm occurs. Curing at elevated temperatures has the added advantage that it actually increases the end mechanical properties of the material, and many resin systems will not reach their ultimate mechanical properties unless the resin is given this 'postcure'. The postcure involves increasing the laminate temperature after the initial room temperature cure, which increases the amount of cross-linking of the molecules that can take place. To some degree this postcure will occur naturally at warm room temperatures, but higher properties and shorter postcure times will be obtained if elevated temperatures are used. This is particularly true of the material's softening point or Glass Transition Temperature (T_g), which, up to a point, increases with increasing postcure temperature.

Additives and Modifiers

A wide variety of additives are used in composites to modify materials properties and tailor the laminate's performance. Although these materials are generally used in

relatively low quantity by weight compared to resins, reinforcements and fillers, they perform critical functions.

Catalysts, Promoters, Inhibitors

In polyesters, the most important additive is catalyst or initiator. Typically, organic peroxide such as methyl ethyl ketone peroxide (MEKP) is used for room temperature cured processes, or Benzoyl peroxide is added to the resin for heat-cured moulding. When triggered by heat, or used in conjunction with a promoter (such as cobalt naphthenate), peroxides convert to a reactive state (exhibiting free radicals), causing the unsaturated resin to react (cross-link) and become solid. Some additives such as TBC (tertiary butyl catechol) are used to slow the rate of reaction and are called inhibitors. Accelerators such as DMA (dimethyl aniline) speed curing.

Additives used in thermoset and thermoplastic composites include the following:

- **Fire retardants:** Combustion resistance is improved by proper choice of resin, use of fillers or flame retardant additives like ATH (alumina trihydrate), bromine, chlorine, borate and phosphorus.
- **Air release agents:** most laminating resins, gel coats and other polyester resins might entrap air during processing and application. This can cause air voids and improper fibre wet-out. Air release additives are used to reduce such air entrapment and to enhance fibre wet-out.
- **Viscosity control:** in many composite types, it is critical to have a low, workable viscosity during production. Lower viscosity in such filled systems is usually achieved by use of wetting and dispersing additives. These additives facilitate the wet-out and dispersion of fillers resulting in lower viscosity.
- **Electrical conductivity:** most composites do not conduct electricity. It is possible to obtain a degree of electrical conductivity by the addition of metal, carbon particles or conductive fibres. Electromagnetic interference shielding can be achieved by incorporating conductive materials.
- **Toughness:** can be enhanced by the addition of reinforcements. It can also be improved by special additives such as certain rubber or other elastomeric materials.
- **Antioxidants:** plastics are sometimes modified with antioxidants, which retard or inhibit polymer oxidation and the resulting degradation of the polymer.
- **Antistatic agents:** are added to polymers to reduce their tendency to attract electrical charge. Control of static electricity is essential in certain plastics

processing and handling operations, as well as in finished products. Static charges on plastics can produce shocks, present fire hazard and attract dust.

- **Foaming agents:** are chemicals that are added to polymers during processing to form minute cells throughout the resin. Foamed plastics exhibit lower density, decrease material costs, improve electrical and thermal insulation, increase strength-to-weight ratio and reduce shrinkage and part warping.
- **Plasticizers:** are added to compounds to improve processing characteristics and offer a wider range of physical and mechanical properties.
- **Slip and blocking agents** provide surface lubrication. This results in reduced coefficient of friction on part surfaces and enhances release of parts from the mould.
- **Heat stabilizers:** are used in thermoplastic systems to inhibit polymer degradation that results from exposure to heat.
- **Ultraviolet stabilizers:** both thermoset and thermoplastic composites may use special materials which are added to prevent loss of gloss, crazing, chalking, discoloration, changes in electrical characteristics, embrittlement and disintegration due to ultraviolet (UV) radiation. Additives, which protect composites by absorbing the UV, are called ultraviolet absorbers. Materials, which protect the polymer in some other manner, are known as ultraviolet stabilizers.

Colorants

Colorants are often used in composites to provide color throughout the part. Additives can be mixed in as part of the resin or applied as part of the moulding process (as a gel coat). Also, a wide range of coatings can be applied after moulding.

Release Agents

Release agents facilitate removal of parts from moulds. These products can be added to the resin, applied to moulds, or both. Zinc stearate is a popular mould release agent that is mixed into resin for compression moulding. Waxes, silicones and other release agents may be applied directly to the surface of moulds.

Thixotropic agents

In some processes such as hand lay-up or spray-up, thixotropic agents may be used. When "at rest", resins containing thixotropic agents remain at elevated viscosities. This reduces the tendency of the liquid resin to flow or drain from vertical surfaces. When the resin is subjected to shear, the viscosity is reduced and the resin can be easily sprayed or brushed on the mould. Fumed silica and certain clays are common thixotropic agents.

Fillers

Use of inorganic fillers in composites is increasing. Fillers not only reduce the cost of composites, but also frequently impart performance improvements that might not otherwise be achieved by the reinforcement and resin ingredients alone. Fillers can improve mechanical properties including fire and smoke performance by reducing organic content in composite laminates. Also, filled resins shrink less than unfilled resins, thereby improving the dimensional control of moulded parts. Important properties, including water resistance, weathering, surface smoothness, stiffness, dimensional stability and temperature resistance, can all be improved through the proper use of fillers.

There are a number of inorganic filler materials that can be used with composites including:

- Calcium carbonate is the most widely used inorganic filler. It is available at low cost in a variety of particle sizes and treatments from well-established regional suppliers, especially for composite applications. Most common grades of calcium carbonate filler are derived from limestone or marble and very common in automobile parts.
- Kaolin (hydrous aluminum silicate) is the second most commonly used filler. It is known throughout the industry by its more common material name, clay. Mined clays are processed either by air flotation or by water washing to remove impurities and to classify the product for use in composites. A wide range of particle sizes is available.
- Alumina trihydrate is frequently used when improved fire/smoke performance is required. When exposed to high temperature, this filler gives off water (hydration), thereby reducing the flame spread and development of smoke. Composite plumbing fixture applications such as bathtubs, shower stalls and related building products often contain alumina trihydrate for this purpose.
- Calcium sulfate is a major flame/smoke retarding filler used by the tub/shower industry. It has fewer waters of hydration, and water is released at a lower temperature. This mineral filler offers a low cost flame/smoke retarding filler.

Other commonly used fillers include Mica, Feldspar, Wollastonite, Silica, Talc, Glass microspheres, Flake glass, Milled glass fibres etc.

Advantages of using Fillers in Composites

- Fillers reduce the shrinkage of the composites part.

- Fillers influence the fire resistance of laminates.
- Fillers lower compound cost by diluting more expensive resin and may reduce the amount of reinforcement required.
- Fillers can influence the mechanical strengths of composites.
- Fillers serve to transfer stresses between the primary structural components of the laminate
- Uniformity of the laminate can be enhanced by the effective use of fillers.
- Crack resistance and crack prevention properties are improved with filled resin systems.
- Low-density fillers are used extensively in marine putty and the transportation industry. They offer the lowest cost of filled systems, without the increases of weight that affect the performance of the final product.

Core Materials for Sandwich Structures

Sandwich composites are becoming more and more popular in structural design, mainly for their ability to substantially decrease weight while maintaining mechanical performance. This weight reduction results in a number of benefits, including increased range, higher payloads and decreased fuel consumption. All have a positive impact on cost as well as a decreased impact on the environment. These benefits are possible because, as has long been known, separating two materials with a lightweight material in between increases the structure's stiffness and strength. This distinction, along with many other material characteristics available through strategic choice of core material - such as thermal insulation, low water absorption, sound and dielectric properties, among others - benefit a wide range of industries and applications, including wind, marine, aerospace, transportation and industry.

Core materials are used to provide stiffness, thermal insulation and light weight to composite structures especially in boat and wind blade construction. These materials include balsa wood, plastic forms of PU and PVC, PET, PES and honey comb structures.

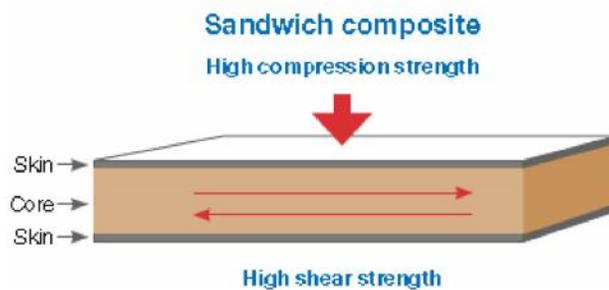


Fig: 4.3.6 Sandwich composite structure

Gel Coats

Gel coats are considered resins but have a very special purpose. A gel coat is a specially formulated polyester resin incorporating thixotropic agents to increase the gel coat's viscosity and non-sag properties, fillers for flow properties, pigments to give the desired color, and additives for specific application properties, such as gel time and cure. Gel coats are primarily used for contact moulding (hand or spray lay-up). The gel coat, usually pigmented, provides a moulded-in finished surface that is weather and wear resistant. The gel coat helps in hiding the glass reinforcement pattern that may show through from the inherent resin shrinkage around the glass fibres. Considerations used for the proper selection of a gel coat are compatibility of the underlying FRP materials to ensure good adhesion of the gel coat, as well as the operating environment. The most common current usage of gel coats in "in-mould applications." That is, the gel coat is sprayed into the mould and the laminate is applied behind it. Adhesion of the laminating resin to the gel coat is a critical issue. Thickness of the gel coat can vary depending on the intended performance of the composite product. Gel coats are typically applied by spray application to approximately 16-20 mils wet film thickness. While gel coats do not add any structural strength to the FRP part, gel coats should be resilient. Gel coats should be able to bend without cracking. They should be resistant to thermal cracking (cracking that may occur with dramatic changes in temperature). The primary measurements of resilience are flexural modulus and elongation. Gel coats should be UV stable and pigmented sufficiently to provide good opacity.

Gel coats are used to improve weathering, filter out ultraviolet radiation, add flame retardancy, provide a thermal barrier, improve chemical resistance, improve abrasion resistance, and provide a moisture barrier. Gel coats are used to improve the product appearance such as the surface of a boat hull or golf cart. A unique benefit of gel coats is that they are supplied in many colors by the incorporation of pigments per the specification of the engineer.

DETAILING OF PRACTICALS

- 1) Study of resin curing reaction

Procedure

Polyester resin: Take 100 gms of unsaturated polyester resin and add sufficient quantity of catalyst (MEKP) and accelerator (Cobalt naphthenate). Mix it thoroughly and kept undisturbed for curing. Observe the curing exotherm, gel time and cure time.

Epoxy resin: Take 100 gm of Epoxy resin and mix it with amine type hardener and heated to establish the curing. Difference the curing pattern of both epoxy and polyester resin are reported.

- 2) Study of sandwich composites

Procedure

A sandwich composite structure is made by using polyester and glass fibre and with PVC form as core material. First the gel coat is applied then the glass fibre reinforcement is placed and consolidated. It is then wet with resin and then a PVC form core is placed on one half of the laminate and the other half is left alone. The other surface of the core is wet with the resin and then glass fibre reinforcement is used as the same as bottom layer and the gel coat is applied. After curing observe the stiffness in the sandwich portion and non sandwich portion.

ASSESSMENT ACTIVITIES

- 1) Seminar on core materials
- 2) Group discussion - Different thermoset resins and applications

Theory Evaluation Questions

- 1) Epoxy and polyester resins are the most used resin matrix materials in FRP Industry.
 - a. Compare the different properties and applications of Epoxy and polyester resins
 - b. Compare the curing / hardening of Epoxy and polyester resins.
- 2) Which of the following Resin is the most used in FRP industry
 - a) Epoxy resin
 - b) Vinyl ester resin
 - c) Unsaturated polyester resin
 - d) Phenolic resin
- 3) Which of the following is a curing agent used in polyester.
 - a) Aliphatic amine
 - b) MEKP
 - c) Anhydride
 - d) Tertiary butyl catechol
- 4) In addition to fibre reinforcement, fillers are also used in FRP composites. List the advantages of using fillers FRP products
- 5) Which of the following thermoset resin give very low shrinkage on cure
 - a) Poly ester
 - b) Epoxy resin
 - c) Furan resin
 - d) Poly urethane
- 6) Gel coats give good surface finish and protection to FRP laminates. Explain the preparation of gel coats.

Unit IV

MANUFACTURING METHODS

Over view of the unit

Reinforced plastics composites are a combination of resin matrix, fibres and fillers, which when cured produces a solid structure. There are plenty of methods to produce a composite structure. Each method has its own merits and limitations. Selection of particular manufacturing process is based on the type of matrix and fibres, temperature to form and cure the matrix, the geometry of the end product and cost effectiveness. This unit covers the various manufacturing methods used in the FRP industry.

Learning outcomes

The learner :

- Describes different open mould FRP manufacturing processes such as Hand lay-up, spray-up, and filament winding.
- Explains the preparation FRP products using closed mould processes such as compression moulding, vacuum bag moulding, pressure bag moulding, autoclave moulding and injection moulding.
- Describes the preparation of prepregs, SMC and DMC compounds for FRP processing.
- Explains the Resin transfer moulding and Vacuum assisted resin transfer moulding methods
- Explains the continuous processes such as pultrusion and braiding.
- Prepares FRP products using different manufacturing processes.

Introduction

The fabrication of composites is a complex process and it requires simultaneous consideration of various parameters such as component geometry, production volume, reinforcement & matrix types, tooling requirements, and process and market economics. The most widely used manufacturing methods for polymer fibre composites are as follows.

Open mould processes

- Hand lay-up
- Spray lay-up
- Filament winding

Closed mould processes

- Compression moulding

- Vacuum bag moulding
- Pressure bag moulding
- Autoclave moulding
- Injection moulding
- Resin transfer moulding
- Vacuum assisted resin transfer moulding

Continuous processes

- Pultrusion
- Braiding

Open mould processes

Hand lay-up method

The Hand Lay-up involves the following operations:

- The mould is coated with a release agent, to prevent sticking of the moulded part to the mould surface.
- The prime surface layer of the part is formed by applying gel coat.
- A layer of fine fibre reinforcing tissue is applied.
- Layers of the liquid matrix resin and reinforcing fibres in form of woven fabric, roving or chopped strands are applied. The resin mixture may be applied by either brush or roll.
- The part is cured (usually at room temperature).
- The part is removed from the mould surface.

There are two methods of Hand Lay-up:

Wet Lay-up: Dry reinforcement (fibre mat or woven cloths) is first applied to the mould, and then is saturated with liquid resin

Dry Lay-up: Reinforcement and resin (thermoset) are applied simultaneously as a pre-impregnated fibre tape (prepreg) The resin in the prepreg sheets is 'B' staged (i.e. solidified and tacky but only partially cured)

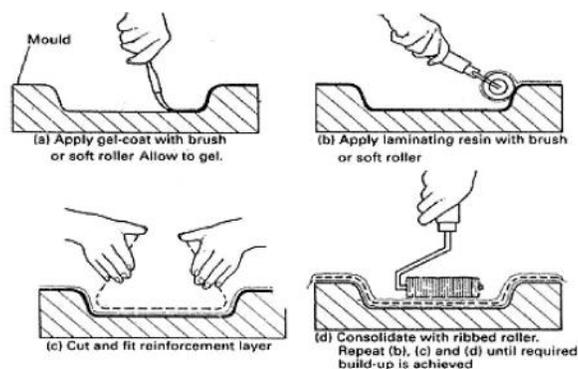


Fig: 4.4.1 Hand Lay-up process

Advantages

- Simplest method, low-cost tooling, and wide range of part sizes.
- Design changes can be readily made.
- Minimum investment in equipment.
- With skilled operators, good production rates and consistent quality are obtainable.

Disadvantages

- Low concentration of reinforcing phase (up to 30%)
- Low densification of the composites (entrapped air bubbles)
- Labour intensive
- Difficult to control the hand laminating process

Application

Boats, tanks, bath ware, housings, Bus, truck, auto components, architectural products, and many other products ranging from very small to very large parts.

Spray lay-up

In spray lay-up method, the fibre is chopped in a hand held gun and fed into a spray of catalysed liquid resin directed at the mould. The resin will wet the reinforcement fibres which are simultaneously chopped in the same spray gun. The deposited materials are cured under standard conditions.

Advantages

- Low cost way of quickly depositing fibre and resin
- low-cost tooling

Disadvantages

- Laminates tend to be resin rich and therefore excessively heavy.
- Only short fibres can be incorporated which limits the mechanical properties of the laminate.
- Resins needs to be in low viscosity to be sprayable.

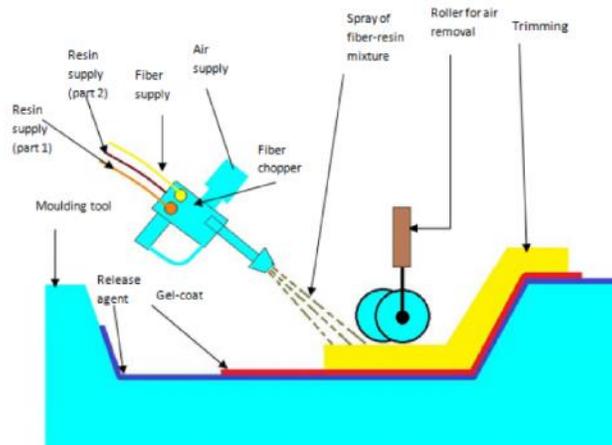


Fig: 4.4.2 Spray Lay-up process

Filament winding

Filament winding consists of winding resin impregnated fibres or roving of glass, aramid, or carbon on a rotating mandrel in predetermined patterns. The method makes void free product possible and gives high fibre volume ratio up to 80%. In the wet method, the fibre picks up the low viscosity resin either by passing through a trough or from a metered application system. In the dry method, the reinforcement is in the pre impregnated form.

After the layers are wound, the component is cured and removed from the mandrel. This method is used to produce pressure vessels, rocket motor cases, tanks, ducting, golf club shafts, and fishing rods. Thermoset resins used in

filament wound parts include polyesters, vinyl esters, epoxies, and phenolics. This method can be automated and provides high production rates. Highest-strength products are obtained because of fibre placement control. Control of strength in different direction is also possible.

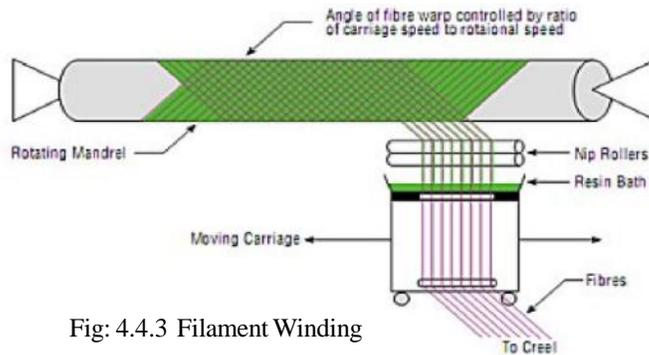


Fig: 4.4.3 Filament Winding

Closed mould processes

Compression moulding

Compression moulding is considered as the primary method of manufacturing for many structural automotive components. It is done by transforming sheet-moulding compounds (SMC) into finished products in matched moulds. It has the ability to produce parts of complex geometry in short periods of time. It allows the possibility of eliminating a number of secondary finishing operations, such as drilling, forming, and welding.

The moulding compound is first placed in an open, heated mould cavity. The mould is then closed and pressure is applied to force the material to fill up the cavity. A hydraulic ram is often used to produce sufficient force during the moulding process. Excess material is channelled away by the overflow grooves. The heat and pressure are maintained until the material is cured. The final part is removed from the mould after curing. The moulding pressure may vary from 1.4 to 34.5 MPa and the mould

temperature is usually in the range of 130°C to 160°C.

There are two different types of compounds most frequently used in compression moulding: Bulk Moulding Compound (BMC) and Sheet Moulding Compound (SMC). SMC costs higher but can be pre-cut to conform to the surface area of the mould.

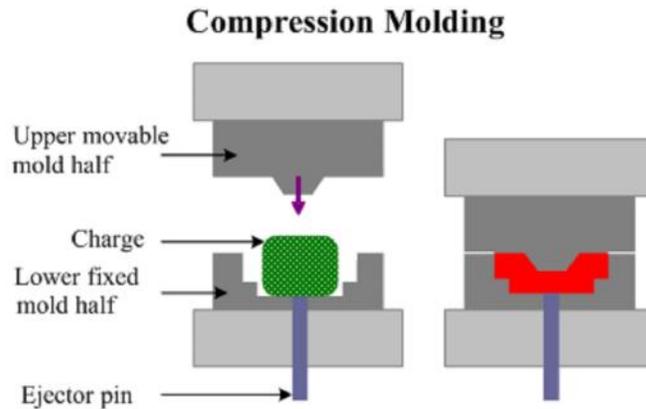


Fig: 4.4.4 Compression moulding

Sheet Moulding Compound (SMC)

Sheet moulding compound is a composition of resins, fibers, pigments, fillers and other additives that have been compounded and processed into sheet form to facilitate handling in the moulding operation. The sheet moulding compound is cut to a shape which is slightly larger than the mould area and is placed into the bottom mould cavity. Both top and bottom cavities are kept at an elevated temperature. The press is then activated and the material is pressed into the cavities under high compression. The heated cavities activate the curing of the material. The part is then removed and sometimes post cured in a post cure oven.

Bulk Moulding Compound (BMC)

Bulk Moulding Compound (BMC) is a thermosetting resin mixed with reinforcement, fillers etc into a viscous compound for compression or injection moulding. The Bulk moulding compound is preformed into the shape of the mould cavity. This preform is placed in the lower mould cavity and moulded under heat and pressure to get the product.

Prepregs

Prepregs are high quality reinforcement fibers which are pre-impregnated with a resin system and partially cured to B stage. Prepregs are prepared by passing the fibre through a resin rich solution which is then dried to remove the solvent. The excess resin is removed using a doctor blade and then the cured to B stage. Prepregs

reduce the handling damage to dry fibers, reduces the voids and improves fiber wetting. The disadvantages of prepregs are higher cost and limited shelf life.

Types of Compression Moulding

1. Hot pressing in which the moulding charge is heated while shaping.
2. Cold pressing which uses a wet lay-up process and the product is pressed to the required shape, but cured without the application of heat.

Advantages

1. Good finish on both sides.
2. Faster production.
3. Uniform product quality.
4. Less labor.
5. Very little finishing operations required.

Disadvantages

1. This process is not suited for low volume of production because of high cost of moulds and press.
2. The process is also not suitable for very large sized products.

Application

Automotive exterior panels especially for commercial vehicles, Radio & appliance knobs, ash trays & electrical parts.

Vacuum bag moulding

The mechanical properties of open-mould laminates can be improved with vacuum bagging. By reducing the pressure inside the vacuum bag, external atmospheric pressure exerts force on the bag. The pressure on the laminate removes entrapped air, excess resin and compacts the laminate. A higher percentage of fibre reinforcement is the result. Additionally, vacuum bagging reduces styrene emissions. Vacuum bagging can be used with wet lay-up laminates and prepreg advanced composites. In wet lay-up bagging the reinforcement is saturated using hand lay-up, then the vacuum bag is mounted on the mould and used to compact the laminate and remove air voids.

Process

- In the simplest form of vacuum bagging, a flexible film (PVA, nylon, polyethylene)

is placed over the wet lay-up, the edges sealed, and a vacuum drawn.

- Pulling a vacuum from within the bag uses atmospheric pressure to eliminate voids and force excess resin from the laminate.
- The addition of pressure further results in high fibre concentration and provides be

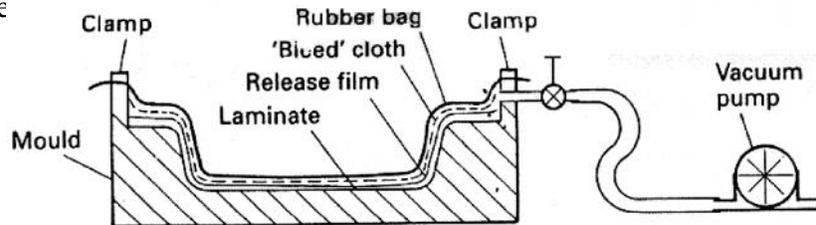


Fig: 4.4.5 Vacuum bag moulding

Advantages

- Vacuum bag moulding can produce laminates with a uniform degree of consolidation
- Remove entrapped air, thus reducing the finished void content
- Complete fibre wet-out can be accomplished if the process is done correctly.
- Improved core-bonding.
- Higher percentage of fibre reinforcement
- Reduces styrene emissions.

Disadvantages

- Wall thickness is depend on operator skill

Pressure bag moulding

Pressure bag moulding is similar to the vacuum bag moulding method except that air pressure, usually 200 to 350 kPa, is applied to a rubber bag, or sheet that covers the laid up composite to force out entrapped air and excess resin. Pressurized steam may be used instead, to accelerate the cure. Cores and inserts can be used with the process, and undercuts are

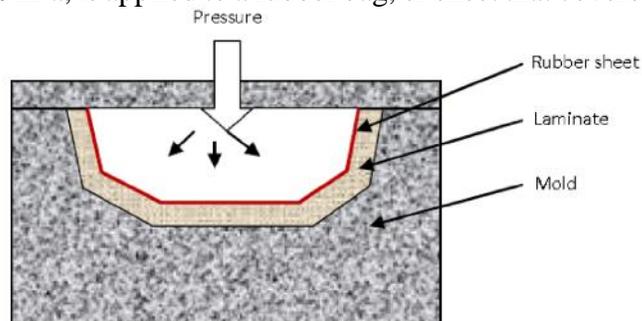


Fig: 4.4.6 Pressure bag moulding

practical, but only female and split moulds can be used to make items such as tanks, containers, and wind turbine blades.

Autoclave moulding

Autoclave moulding is a modification of pressure-bag and vacuum-bag moulding. This advanced composite process produces denser, void free mouldings because higher heat and pressure are used for curing the resin. A non adhering film of polyvinyl alcohol or nylon is placed over the lay-up and sealed at the mould flange. Autoclaves are essentially heated pressure vessels into which the bagged lay-up on the mould is placed for curing. Curing pressures are generally in the range of 350 to 700 kPa and cure cycles normally involve many hours. The method accommodates higher temperature matrix resins such as epoxies, having higher properties than conventional resins.

Autoclave size limits part size. It is widely used in the aerospace industry to fabricate high strength/weight ratio parts from pre impregnated high strength fibres for aircraft, spacecraft and missiles. Many large primary structural components for aircraft, such as fins, wing spars and skins, fuselages and flying control surfaces, are manufactured by this method.

The starting material for autoclave moulding process is prepreg. After layup, a porous release cloth and a few layers of bleeder papers are placed on top of the prepreg stack. The bleeder paper is used to absorb the excess resin in the moulding process. The complete layup is

covered with another Teflon sheet and then a thin heat resistant vacuum bag. The entire assembly is kept inside an autoclave where a combination of pressure and temperature is applied and the plies are converted into a solid laminate.

Injection moulding

Injection moulding is a closed mould process in which molten polymer (commonly thermoplastic) mixed with very short reinforcing fibres (10-40%) is injected under high pressure into a mould cavity through an opening (sprue).

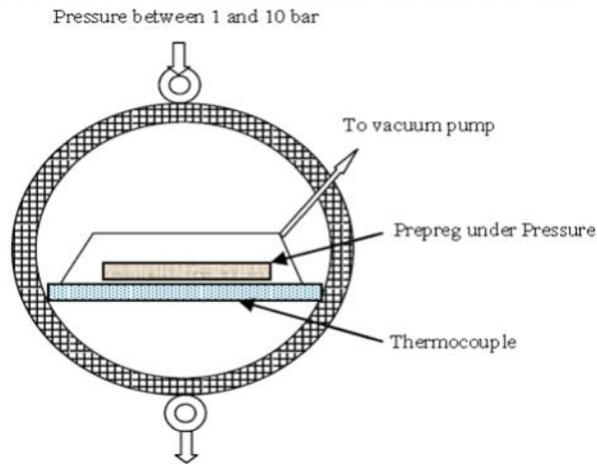


Fig: 4.4.7 Autoclave moulding

Process

- Polymer-fibre mixture in form of pellets is fed into an Injection Moulding machine through a hopper.
- The material is then conveyed forward by a feeding screw and forced into a split mould, filling its cavity through a feeding system with sprue gate and runners.
- Screw acts as a ram in the filling step when the molten polymer-fibre mixture is injected into the mould and then it retracts backward in the moulding step. Heating elements, placed over the barrel, soften and melt the polymer.
- The mould is equipped with a cooling system providing controlled cooling and solidification of the material.
- The polymer is held in the mould until solidification and then the mould opens and the part is removed from the mould by ejector pins.

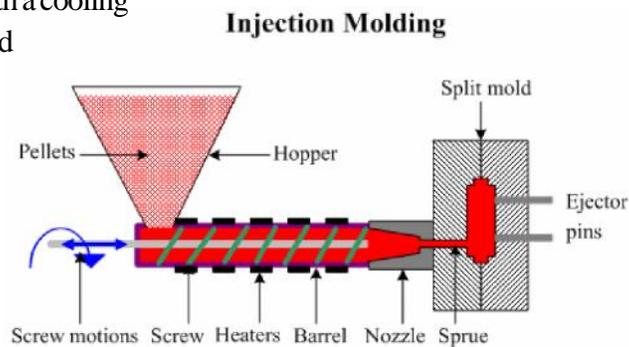


Fig: 4.4.8 Injection moulding

Advantages

- Highly productive method
- High accuracy and control of shape of the manufactured parts.
- Profitable in mass production of large number of identical parts.

Disadvantages

- Limited length of fibres decreasing their reinforcing effect.

Applications

Containers, household goods, auto components, electronic parts, flower pots.

Resin Transfer Moulding (RTM):

Resin transfer moulding is a low pressure closed moulding process for moderate volume productions. Dry continuous strand mats and woven reinforcements are laid up in the bottom half of the mould. Preformed glass reinforcements are often used for complex mould shapes. The mould is closed and clamped, and a low viscosity, catalyzed resin is pumped in, displacing the air through strategically located vents. The injection pressure of resin is in the range of 70-700 kPa.

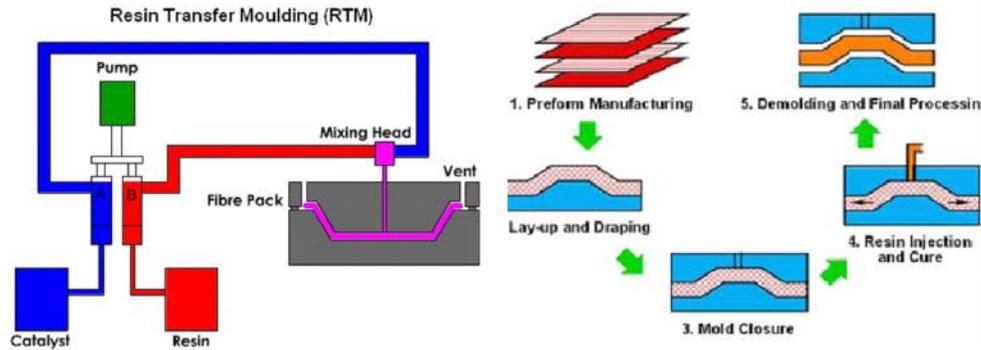


Fig: 4.4.9 Resin transfer moulding

Advantages and limitations

RTM process gives better control on product thickness and good finish on both sides. Metallic moulds are not necessary because the product curing is generally done under ambient temperature. By applying gel coats on both sides, the product will have a smoother finish on both sides. When the injection pressure is increased, there is a tendency for fibre wash. This tendency can be countered by using continuous strand mats or special woven preforms. Other advantages can be listed as follows.

1. Controlled usage of fibre and resin reduces the material wastage and unit cost
2. A variety of mould shapes and sizes can be moulded sequentially.
3. A wide range of resin systems can be used including polyester, vinyl ester, epoxy, phenolics etc.
4. Styrene emission is practically eliminated during resin transfer into the mould.
5. Low labor cost and lower capital cost
6. Close tolerances in the product
7. As RTM is a closed mould technique, the moulded parts are reproducible.
8. RTM produces parts at a rate that is 5-20 times faster than open moulding technique.
9. Low Void Content - Void content less than 1% can be consistently achieved with RTM.
10. Low Operator Skills

Some of the limitations are given below:

1. Since, this process can develop pressures up to 5 to 10 bars, tool rigidity and clamping techniques have to be designed for such pressures.

2. Handling of large and heavy moulds requires adequate lifting equipments.
3. Unlike in compression moulding, post trimming is required for this process.
4. The process is more costly than hand lay-up for small production runs.
5. The tooling can get complicated for cavities with projections or undercuts.
6. Parts having open cell cores (inside) such as honeycomb cores porous foams, tubular structures are difficult to make by RTM.
7. The process may become uneconomical for thin and smaller parts.

Types of RTM machines

There are two types of RTM injection equipments based on position of mixing of catalyst with resin.

Two pot system

This system has two equal volume containers or pots. In one of these pots the resin is mixed with accelerator. In the other pot the resin is mixed with the catalyst. Two pumps are used to pump these mixtures to the injection points where they are mixed well in the mixing head.

Catalyst injection system

In this system the catalyst is not mixed with the resin until it reaches the entry pot attached to the mould. The resin mixed with accelerator is pumped into the injection chamber. The catalyst is taken separately into the chamber by means of controlling valve. In this system the gel and cure time can be controlled by varying the amount of catalyst used.

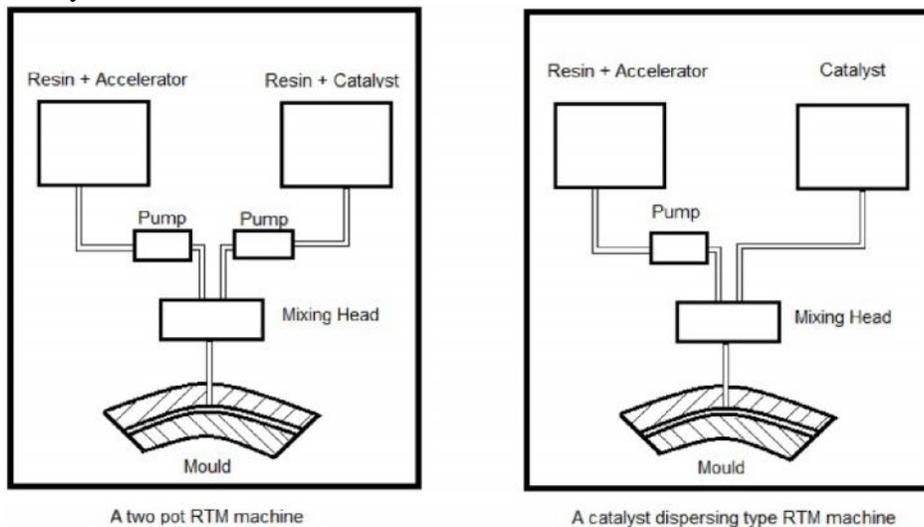


Fig: 4.4.10 RTM Machines

Application

RTM is a variation of compression moulding and is particularly used for moulding intricate shapes. It is also useful when metal inserts have to be incorporated as in electrical components. It is used frequently when the mould sections are very delicate, when the moulded parts has thick sections 3.2 mm or more, or when an insert is retained in the cavity for moulding in place. In the semiconductor industry, package encapsulation is usually done with transfer moulding due to the high accuracy tooling and low cycle time of the process.

Vacuum Assisted Resin Transfer Moulding (VARTM)

This method is also referred to as vacuum infusion process (VIP) moulding. VARTM is accomplished on a single open mould. This process has been used to make both thin and very thick laminates. Fabrics or core materials are laid up as a dry stack of materials as in RTM and covered with peel ply and a knitted type of non-structural fabric. The whole dry stack is then vacuum bagged, and once bag leaks have been eliminated, resin is allowed to flow into the laminate using vacuum. The resin distribution over the whole laminate is aided by resin flowing easily through the non structural fabric, and wetting the fabric.

Process

The mould is cleaned with acetone and release agent is applied. Dry fabric preforms or core materials are laid on the mould. Spiral tubes are then laid on the two sides of the mould, one for resin infusion and other for suction. The completed lay-up is covered with a vacuum bag and sealed. The resin is then infused by connecting one side of the tube to the resin tank and applying vacuum through other side. The resin flows and fills the cavity. When the resin flows out through the other side, the resin flow is cut off and the vacuum is maintained until the resin cures.

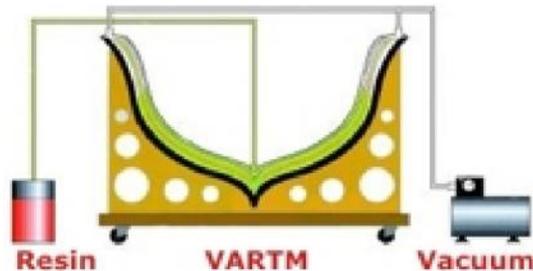


Fig: 4.4.11 Vacuum Assisted Resin Transfer Moulding

Materials

Resins : Any resin with low viscosity, e.g. epoxy, polyester, vinyl ester

Fibres : Fabrics made from carbon, Kevlar, Quartz, glass and polyester fibre.

Advantage

- Vacuum assisted resin transfer moulding (VARTM) is ideal for the manufacture of large-scale composite structures.
- The advantages of the VARTM process over the RTM process are scalability and affordability for the fabrication of large composite structures.
- Cored structures can be produced in one operation.
- Cost-effective: Much lower tooling cost due to one half of the tool being a vacuum bag.

Disadvantages

- Relatively complex process to perform well.
- Resins must be very low in viscosity, properties, thus compromising mechanical
- Un-impregnated areas can occur resulting in very expensive scrap parts.

Application

VARTM applications including marine, wind mill blades, ground transportation and infrastructure parts

Continuous processes

Pultrusion : Pultruded composites consist of fibres predominantly in axial directions impregnated by resins in order to form a most efficient composite product. Surface mats are used for surface appearance and also to improve chemical and weather resistance. Polyester resins are widely used in the pultruded products. The pultrusion process generally consists of pulling of roving/ mats through a preforming fixture to take its shape of the product and then heated where the section is cured continuously.

The following are the parts of pultrusion machine

Creel - Creel generally consists of bookcase type shelves where roving from individual packages are pulled out for a resin bath. Metal book shelves are best.

Resin bath: The resin bath is a tank which contains resin through which the fibres are passed to get impregnated with resin before forming. A grid or comb is attached at the entry and exits of resin bath in order to maintain horizontal alignment and also to avoid the excessive resin.

Preforming Fixtures: These fixtures consolidate the reinforcements and move them closer to the final shape provided by the die. Generally, fluorocarbon or ultra high molecular weight polyurethanes are used as fixtures since these are easy to manufacture and also it is easy to clean it for later purpose.

Heated Dies: The chrome plated electrically heated matched metal die through which the fibre impregnated with resin are pulled and extruded. In case of thick section the curing can be speeded up by using both radio frequency (RF) radiation and conductive heat.

Pulling Section: A pair of continuous caterpillar belts containing pads are used for pultrusions. A double set of cylinders with pad pullers can be synchronized for an intermittent pull.

Cut-Off saw: A conventional saw with an abrasive or a continuous rim diamond wheel with coolant is generally used for cutting the desired product.

The pultruded sheet consists of both continuous strand roving as well as mat layers. Mat layers are added to increase the transverse strength. Generally, the matrix materials used in pultrusion are polyester and vinyl ester from thermoset polymers (epoxy has long cure time) and PEEK and polysulfone from thermoplastic polymers.

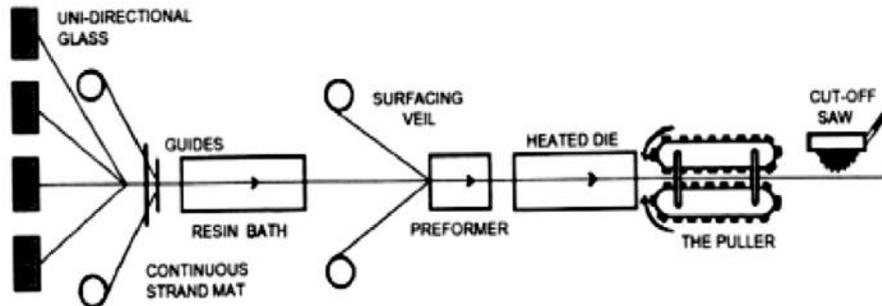


Fig: 4.4.12 Pultrusion process

The reinforcing fibres are pulled through a liquid resin bath to thoroughly wet every fibre. The reinforcements are then guided and formed, or shaped, into the profile to be produced before entering a die. As the material progresses through the heated die, which is shaped to match the design profile, the resin changes from a liquid to a gel, and finally, into a cured, rigid plastic.

A pulling device grips the cured material and pulls the material through the die. It is the power source for the process. After the product passes through the puller, it is sawed into desired lengths. Although pultrusion is ideally suited for custom shapes, some standard products include solid rods, hollow tubes, flat sheets, hat sections bars, angles, channels, and I-beams.

Applications of Pultrusion:

- Electrical application including transformers.
- Supports in bridges and structures.
- Automobiles.
- Pipes and rods.

Advantages of Pultrusion

Pultrusion is the most cost-effective method for the production of fibre-reinforced composite structural profiles. The primary advantages of pultruded FRP profiles are listed as below:

- Production is continuous.
- Material scrap rate is low.
- The requirement for support material is eliminated i.e., breathers, bleeder, cloth, separator film, bagging film, edge tape, etc.
- Labour requirements are low.
- Products with high fibre content can be produced

Disadvantages

- Limited to constant or near constant cross-section components.
- Heated die costs can be high
- Wear of die is high.

Braiding

The braiding process involves the weaving of fibres into shape by repeatedly crossing them back and forth over a mandrel. The use of braiding process in the aircraft industry is generally restricted to non-structural applications. The braiding process has been utilized extensively for covering of the electrical wires and fuel lines. The primary advantage is that braiding offers a rapid, automated method for forming an interwoven structure. The braiding carriers follow a zigzag path in a large circle surrounding the mandrel. The surface of the mandrel is tightly woven with the fibres in a helical pattern. Due to high level of conformability and the damage resistance capability of braided structures, the composite industry had found structural applications of braided composites ranging from rocket launchers to automotive parts to aircraft structures.

Thickness is built up by over braiding previously braided layers similar to a ply lay-up process. Braiding can take place vertically or horizontally. A schematic of a horizontal braider is shown in Figure 4.4.13. Although braiding is similar to filament winding, the major difference between braiding and filament winding is that braids are interlaced structures having as many as 144 or more interlacing per braiding cycle.

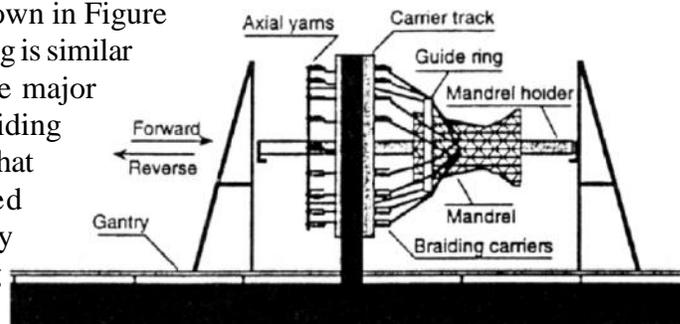


Fig: 4.4.13 Schematic of a horizontal braider

DETAILING OF PRACTICALS

- 1) Produce FRP roofing sheets by hand lay-up process.
- 2) Produce FRP winnows using hand lay up
- 3) Produce FRP flower pots
- 4) Produce FRP kitchen zins
- 5) Produce FRP Sheets by vacuum Infusion
- 6) Field visit to filament winding, pultrusion, marine products manufacturing units

Procedure

The procedure for the manufacture of FRP products are detailed under manufacturing methods

ASSESSMENT ACTIVITIES

- 1) Field visit report on FRP manufacturing methods
- 2) Group discussion – Faults causes and remedies in FRP processing.

Theory Evaluation Questions

- 1) A number of FRP manufacturing methods are available. Classify the various methods as open mould, closed mould and continuous process
- 2) Hand lay-up is the simplest FRP processing method.
Explain the hand lay-up process for making laminates. Discuss the advantages and disadvantages of hand lay up
- 3) Which of the following FRP product is made by filament winding
 - a) Tanks
 - b) Pipes
 - c) Tubs
 - d) All of the above
- 4) Which of the following process require low labor content
 - a) Hand lay-up
 - b) Vacuum bag moulding
 - c) Resin transfer moulding
 - d) Pultrusion
- 5) Vacuum infusion is an FRP processing method which is gaining importance today. Explain the vacuum infusion process?
- 6) Discuss the faults causes and remedies in hand layup process.
- 7) Discuss the advantages and disadvantages of pultrusion process

Unit V

QUALITY AND SAFETY IN FRP PROCESSING

Over view of the unit

The essential difference between FRP composites and almost all other structural materials is that, whilst the chemical composition and properties of other materials e.g. steel or aluminium, are mainly determined by the manufacturer, with reinforced plastics, the fabricator determines these properties himself i.e. he makes his own material. Quality control is therefore extremely important if high quality mouldings are to be produced consistently, economically and safely. This section deals with aspects of quality control from the storage of materials through the various stages of moulding production to the delivery of quality moulded parts.

Learning outcomes

The learner :

- Identifies and practices safe storage of FRP raw materials
- Practices good housekeeping and follow work instructions
- Observes health and safety practices during FRP processing.
- Explains the different process control parameters in FRP processing.
- Prepares and maintain simple moulds using plaster of paris
- Does minor repairs of FRP products

Storage of raw materials

Resins, curing agents and associated solvents should be stored separately, in cool, dry, well ventilated places away from the working area.

Resin should be stored in the dark in suitable closed containers. It is recommended that the storage temperature should be less than 20°C where practical, but should not exceed 30°C. Ideally, containers should be opened only immediately prior to use, and should never be left open. Where containers have to be stored outside, they should be protected to prevent any ingress of water, or possible early polymerisation from the effects of direct sunlight.

After several months or years of storage, polyester resins will set to a rubbery gel, even at normal ambient temperatures. This storage life or shelf life varies depending on the resin type, but provided that the recommendations above are followed, most

Crystic resins will have a storage life of at least 3 months (for pre-accelerated resins) or 6 months (for non-accelerated resins).

Organic peroxide catalysts should be segregated from resins and accelerators. Containers should be stored in a well ventilated, flameproof area at a maximum temperature of 20°C. Bulk storage should ideally be in a secure brick building, but smaller quantities can be stored in suitable metal cabinets. Containers should be opened only immediately prior to use, and should never be left open.

Accelerators should be stored in a well ventilated, flameproof area at a maximum temperature of 20°C. Containers should be opened only immediately prior to use and should never be left open.

All storage areas should be kept clean and free from combustible materials such as rags. Good standards of hygiene should be observed. Any accidental spillages must be dealt with immediately.

Reinforcements can be kept in the main workshop as long as they are stored and tailored away from the moulding area. All reinforcements should be stored in their original packaging in a warm, dry, dust free environment.

Stock Control

All containers and packaging should be appropriately marked, designated and documented. Good stock control is important as the use of stocks in strict rotation helps to avoid storage times longer than the manufacturer recommends, thus ensuring that materials are always used in their optimum condition.

Workshop Conditions

Any building where composite manufacturing is carried out should be dry, adequately heated and well ventilated. Ideally, the building should be spacious, to allow adequate room for all operations, and have a high ceiling. The temperature of the building should be controlled between 15°C and 25°C, at all times, and fluctuations in temperature must be avoided. Ventilation should be good by normal standards, but draughts should be avoided. Doors and windows should not, therefore, be used for ventilation control. Although diffused daylight lighting is the preferred type, fluorescent lighting is an acceptable alternative and is most commonly used.

The working area should be divided into sections as follows:-

1. Reinforcement Preparation area

It is important to tailor reinforcing fibres in a cool, dry environment away from the general moulding and trimming / finishing areas. Moisture and dust must be avoided

as they may affect the moulding characteristics of the reinforcement, resulting in poor quality mouldings.

2. Compounding & Mixing area

The compounding and/or mixing of resins is best kept to a separate section of the workshop, preferably in the charge of one responsible person. Accurate weighing apparatus and a low shear mechanical mixer are required, as well as suitable catalyst dispensing equipment. If accelerators and catalyst are to be added, separate dispensers must be used as catalyst and accelerator can react with explosive violence. All measuring and mixing should be restricted to this one area, which should be kept as clean as possible to prevent contamination.

3. Mould Preparation and Moulding area

The layout of the workshop can be fairly flexible to allow for different types and sizes of moulding. As with most other kinds of manufacturing operations, it is best for the operators to remain in one place and the moulds to move from station to station as the moulding operation is completed, although this is not always possible. It is important to keep moulds away from direct sunlight, as this may cause premature gelation of the resin. Any fluorescent lighting should be installed as far above the moulds as possible, as it can also affect the cure of the resin. Cleanliness is important for the health of the operators and for preventing contamination of resin and reinforcement. Containers of resin, solvents, etc. must not be left open. Any spillages should be attended to immediately and contaminated waste material should be removed and disposed of safely.

The health and safety at working atmosphere and is also important, in particular, attention should be paid to the concentration of styrene vapour in moulding shops. Developments in resin technology mean that resins with low styrene emissions and low styrene contents, are now available. Although these resins significantly reduce the amount of styrene in the atmosphere during lamination and consolidation, adequate extraction facilities are still essential in this area of the workshop.

4. Trimming and finishing area

Effective dust extraction is essential in this area of the workshop, and should preferably be of the downdraught type. A good standard of cleanliness is also important, to prevent contamination of partly cured mouldings.

Mould Care

The production of quality composite mouldings will depend to a great extent on the

quality of the moulds used for their manufacture. It is therefore important to ensure that moulds are properly maintained throughout their life. Moulds should be cleaned regularly, particularly where wax release agents are used, as any wax build up may result in a dulling of the mould surface. This will then transfer to the surface of the moulding, creating dull areas which are difficult, if not impossible, to remove. Impacting the back surface of a mould in order to remove a moulding is not recommended as it can result in cracking of the gel coated surface of the mould. Whilst these cracks will not affect the mould structure, they are unsightly and will transfer to the surface of any mouldings taken from the mould. Great care should be taken when repairing any damage to moulds, particularly in the gel coat surface, and repairs should be carried out as soon as is practical after the damage occurs. The development of mould re-surfacing products, such as those in the Crystic range, means that the life of moulds can now be extended even if the gel coat is damaged beyond repair.

The Curing Reaction

Different resin types exhibit different cure characteristics, but whichever resin type is being used, it is important that the recommended cure cycle is followed. The cure of a polyester resin will begin as soon as a suitable catalyst is added, but the speed of cure will depend on the resin and the activity of the catalyst. Without the presence of an accelerator, heat or ultraviolet radiation, the catalysed resin will have a pot life of hours or sometimes days. This rate of cure is too slow for practical purposes, so for room temperature conditions an accelerator is used to speed up the reaction. Although these days the vast majority of resins are pre-accelerated by the manufacturer, some of the more specialised resin systems still require the addition of an accelerator to facilitate cure. In these cases, the quantity of accelerator added will control the time to gelation and the rate of hardening. For many of today's processes, the limited pot life of a catalysed resin is impractical, and in these instances it is advisable to add the accelerator to the resin first. The accelerated resin will remain usable for days or even weeks, and quantities can be catalysed as and when required. The curing reaction of a polyester resin is exothermic, and the temperature of an unfilled resin casting can rise to over 150°C, though this temperature rise would be considerably less in a laminate. The resins and catalysts available today have been specially developed to dramatically reduce exotherm temperatures, enabling moulders to produce larger and thicker composite structures without the problems associated with heat buildup. There are three distinct phases in the curing reaction of a polyester resin:

1. **Gel time.** This is the time between the addition of the curing agent (catalyst or accelerator/catalyst) and the setting of the resin to a soft gel.
2. **Hardening Time.** This is the time from the setting of the resin to the point where the resin is hard enough to allow a moulding to be released from its mould.
3. **Maturing Time.** This is the time taken for the moulding or laminate to acquire its full hardness, chemical resistance and stability, and can vary from hours to days to weeks depending on the resin and the curing system used. Maturing will take place at room temperature, but post curing a moulding at elevated temperatures will accelerate this process. When post curing is used, it is recommended that the moulding is allowed to mature at room temperature for a period of 24 hours before exposure to elevated temperatures. Figure 16 shows equivalent post cure times and temperatures. Resin properties are improved by post curing. For critical applications such as those requiring maximum heat resistance, post curing is essential, preferably by increasing temperature in stages up to the required operating temperature.

Hot Curing

Polyester resins are often hot moulded in the form of dough or sheet moulding compounds, or in continuous processes such as pultrusion (see Processes section). However, a simple hot moulding formulation is possible, using Benzoyl peroxide as the catalyst. These catalysts, which normally contain 50% benzoyl peroxides, are available in powder or paste form, and should be added at 2% into the resin. The catalyst must be thoroughly dispersed in the resin, and the catalysed mix will remain usable for about a week at room temperature (18°C to 20°C). Cure should take place at temperatures between 80°C and 140°C, but for most applications, 120°C will be satisfactory. The actual moulding time will depend on the bulk or thickness of the moulding, the type of resin used, and the heat capacity of the moulds. Insufficient heat or time will result in an under cured moulding. Whilst the resin cannot be over cured, it is not advisable to raise the temperature above 140°C.

Cold Curing

The great majority of composite mouldings are manufactured using cold cure techniques, and adequate cure is vital if high quality mouldings with optimum properties are to be produced. Most of today's polyester resins are pre-accelerated, and require only the addition of a suitable catalyst to initiate the curing reaction, though some more specialised resins still require the addition of an accelerator as well as a catalyst. Cobalt accelerators are the most common, though others, such as those based on tertiary amines, are also used. The most common cold curing catalysts are methyl

ethyl ketone peroxides (MEKP). These are supplied as liquid dispersions differing only in their activity, reactivity and hardening rates. Cyclohexanone peroxide (CHP), available as a stable paste dispersion, and acetyl acetone peroxide (AAP), are also widely used in applications where their effect on cure characteristics are more appropriate.

Resin to Glass Ratios

Resin to glass ratio has more affect on the physical properties of a fully cured laminate than any other single factor. As a general guide, a high glass content will result in a high strength laminate, whilst a high resin content will produce a laminate with better chemical, water and weather resistance.

Process Control

Irrespective of the processing method, the following parameters have to be controlled for achieving good quality products:

1. Binder solubility
2. Fibre wetting
3. Pot life-gel time
4. Peak exotherm temperature
5. Cure time
6. Viscosity
7. Degree of cure

Binder solubility time (BST) is the time taken to dissolve the binder in Chopped Strand Mat by the matrix resin. Binders are used in chopped strand mats to hold the fibers in position. CSM with higher binder solubility is used where complete wet out is required in a short time with short gel time resins. BST Depends on types of binder, viscosity of resin

$BST < \text{Wetting time} < \text{Gel time}$

Wetting time is the time taken to completely wet the fibre layers. Wetting is to be ensured in moulding compounds and prepregs during their preparation and not at the processing stage. Wetting time depends on type of fibre, type of size, mat thickness / roving size, BST of CSM and Viscosity of resin

Pot life is the time from addition of catalyst/hardener to gel time. Pot life depends on Reactivity of Epoxy Resins, Inhibitor in USP, Catalyst in USP, Heat / Temperature. Pot life can be adjusted by selecting hardener / moulding temperature in epoxy , percentage of catalyst in USP

Peak exotherm temp. (PET) is the maximum temperature reached during cure due to the heat of reaction. PET depends on Reactivity of resin, Amount of catalyst, Heat dissipation during cure Type of catalyst. Excess temperature due to PET can cause shrinkage, warping, residual stress, degradation of polymer ,smoke, resin cracking or even fire. PET can be reduced by selecting a low exotherm resin, controlling catalyst, controlling heat dissipation

Cure time is the time from addition of catalyst /hardener until in the resin attains initial cure of 95% of total cure. Cure time depends on reactivity of resin, hardener system, type and amount of catalyst, exotherm, external heat. Faster cure causes shrinkage of the product, increase peak exotherm temperature. Cure time can be controlled by selecting the suitable hardener, using high/medium reactivity resins and controlling mould heat

Viscosity of a liquid indicates the resistance to flow of liquid. When viscosity is high resistance to flow is high.

Polyesters have viscosity around 400-800 cP, where as epoxies have viscosity more than 1200 cP. Viscosity of polyesters can be reduced by adding more styrene. But high styrene content than what is required for reaction is not good. Viscosity of epoxies can be reduced by heating and/or by adding reactive diluents such as low viscosity glycidyl ethers. Fillers, chopped fibres, thixotropic additives and chemical thickeners can increase viscosity

Degree of Cure

Some variability in properties can be caused by differences in the degree of cure of a resin. Severe undercure in a laminate will be obvious since the laminate will be noticeably soft, and will have a characteristic smell reminiscent of almonds. Slight undercure, however, is often more difficult to detect, and whilst there may be little or no affect on mechanical properties, undercured laminates exposed to weather will deteriorate rapidly. A surface hardness test is the most practical method of assessing degree of cure under workshop conditions, and the best instrument for measuring this is a Barcol Impressor. Although Barcol hardness is not an absolute measure of cure, it can highlight differences between well cured and poorly cured laminates. Fully cured, unfilled cast polyester resins generally exhibit a Barcol hardness figure between 40 and 50 (35 to 45 for gel coat resins), and average readings of less than 25 on a laminate would suggest undercure.

Tooling for composites

The moulds used for forming composites, also known as tools, can be made from

virtually any material. For parts cured at ambient or low temperature, or for prototyping, where tight control of dimensional accuracy isn't required, materials such as fiberglass, high-density foams, machinable epoxy boards or even clay or wood/plaster models often are suitable.

Tooling costs and complexity increase as the part performance requirements and the number of parts to be produced increase. Plaster of Paris mould is good for one piece. Wooden mould requires finishing after every cycle of moulding, FRP and cast epoxy moulds are good for intricate shapes and last for up to 300 pieces. Metallic moulds are required for making large number of pieces, intricate shapes and for heating.

Sometimes, the shape of the part that you want to copy means that you can't make a simple one-piece mould and in this case you will need to make a multi-part 'split mould' which can be bolted together to lay-up the part and then unbolted and split apart to remove the part.

Preparation of fiber glass moulds

Fiberglass moulds can be created in many different shapes and forms. Like any other moulds it is most important to have no blind or reverse angles that can trap your subject within the mould. To accomplish this we must plan to create the mould in sections. Using a release agent that works with the resin is also very important.

The process of mould making starts once the pattern is ready. The pattern can be made with plaster of paris, wood or a product itself, if we are going to replicate an existing product. The pattern has to be coated with a mould release agent such as wax or PVA. Once the mould release has been applied, then we can start applying the resin, glass fibre layers. First a gel coat or a tooling coat is applied and allowed to dry for 30 minutes. Above this successive layers of fibreglass and resin are applied to build up the mould. Once the desired thickness is achieved, the resin is allowed to cure. Once the whole system solidifies, the mould can be released from the pattern and final finishing is done before using for production.

Repair

Some moulding faults can be rectified at the trimming and finishing stage of production. Cracks, dents and small holes in the gel coat surface can be repaired using gel coat filler (such as that in the Crystic range), a mixture of lay - up resin and filler powder or, where better 'gap-filling' properties are required, a repair dough consisting of resin and chopped glass fibre strands.

Repairing Gel coat Scratches

1. Ensure the damaged area is clean, dry and free of oil, wax or grease, then tape round with masking tape to protect the surrounding surface.
2. Mix the required quantity of gel coat filler and pigment paste thoroughly.
3. Add the appropriate amount of hardener and mix thoroughly.
4. Using a wooden spatula, press the gel coat filler firmly into the scratch, filling proud of the surface. Remove the masking tape before the filler sets, and leave to cure thoroughly for at least two hours.
4. When cured, rub down with wet and dry paper then use polishing compound to restore the surface gloss.

Filling Dents and Cracks

Cracks, dents and even small holes can be repaired using mixtures of lay-up resin and fillers. Care should be taken to use filler appropriate to the application - in boat hulls for instance, glass bubbles should be used as most other fillers absorb water.

1. Remove any loose resin and reinforcement and ensure the damaged area is clean, dry and free of grease.
 2. Mix pigmented resin with filler powder or glass fibres until a paste of the required consistency is achieved.
 3. Add the correct amount of hardener (based on resin weight NOT resin/ filler weight).
 4. Tape around the damaged area then fill the dent using the resin/filler or resin/ glass fibre mix.
 5. Leave to harden, then sand using progressively finer grades of wet and dry paper, and use polishing compound to restore surface gloss.
- Repairing Laminate Damage

When damage is not confined to the surface, resin and reinforcement should be laid up, overlapping the edges to ensure good adhesion over a wide area. If the laminate is fractured, the following procedure should be used, to effect a repair.

1. Remove the damaged area and chamfer the edges so that the hole is larger on the gel coat side than on the reverse.
2. Abrade and clean the surrounding area to ensure adhesion.
3. If a large surface area is involved, a temporary mould should be built up on the

exterior surface (see Figure 21). For smaller areas, polyester release film can be used as a moulding surface.

- Where damage is extensive, the moulding should be placed in its original mould before repairs are carried out.

An example of Laminate repair method

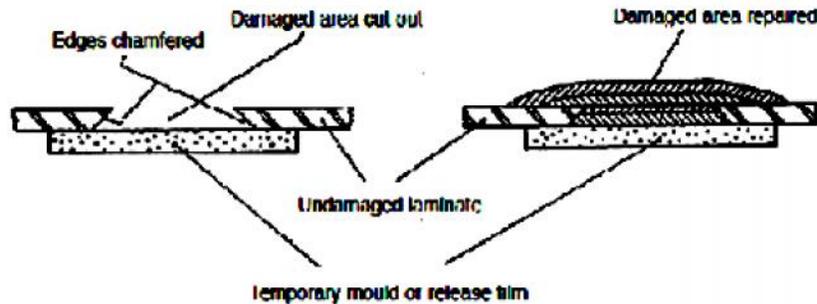


Fig: 4.5.1 Repair of laminates

The visual inspection of mouldings should scrutinise the following:-

- Surface imperfections and general appearance.
- Entrapment of air bubbles in the laminate. The use of non-pigmented resins facilitates this inspection.
- Dimensions - assessment of any shrinkage or distortion.

The physical testing of laminates, i.e. mechanical and chemical testing, can be a problem for the fabricator, as it involves the use of specialised test equipment. These tests are, therefore, normally carried out by either the raw material supplier or independent test houses.

The properties considered to be of most importance are:-

- Ultimate tensile strength
- Tensile modulus
- Flexural strength (also known as bend or cross breaking strength)
- Modulus in bend
- Impact strength
- Shear strength

None of these properties should be considered in isolation. For instance, it is possible, by using a high glass content, to produce a laminate with a high tensile strength.

However, such a laminate would be so thin that it would lack rigidity, so would be unsuitable for use. Minimum thickness and resin to glass ratios are therefore also important properties.

DETAILING OF PRACTICALS

- 1) Prepare a sample FRP mould with Plaster of paris
- 2) Perform a minor repair on an FRP laminate.

ASSESSMENT ACTIVITIES

- 1) Laboratory work
- 2) Assignment of the health and safety practices in FRP industry.

Theory Evaluation Questions

- 1) Briefly explain the safety practices to be observed in the storage of FRP raw materials
- 2) Explain the process of gel coat repair on an FRP laminate.

List of References:

1. Fundamentals of Plastics processing (Vol.1) Injection and blow moulding by Sanjay K Nayak.
2. Plastics Engineering Handbook By Fradoes J
3. Injection Moulding by A.S.Athalye
4. Injection Moulding Machines by F.Johannaber
5. Plastics Processing Handbook by J.A.Brydson
6. Plastics Processing Data Handbook by Donald V.Rosato & Dominick V.Rosato
7. Extrusion of Plastics - Fisher
8. Plastic Materials and Processing - A. Brent Strong
9. Lee, N. C., Plastic blow Moulding Handbook, Van Nostrand Reinhold.
10. Engineered Materials Handbook, ASM International Handbook committee, USA.
11. Polymer Processing by Baird
12. Advanced composite materials by Lalit Gupta
13. FRP Technology by Weatherhead
14. Fiber Reinforced composites by PK Mallick
15. Engineering composite materials by Bryan Harris.