

NNA UNIVERSITY, CHENNAI
NON- AUTONOMOUS COLLEGES
AFFILIATED TO ANNA UNIVERSITY
M.TECH. PLASTICS TECHNOLOGY
REGULATIONS 2025

PROGRAMME OUTCOMES (POs):

PO	Programme Outcomes
PO1	An ability to independently carry out research /investigation and development work to solve practical problems
PO2	An ability to write and present a substantial technical report/document.
PO3	Students should be able to demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate bachelor program

PROGRAMME SPECIFIC OUTCOMES(PSOs):

PSO	Programme Specific Outcomes
PSO1	Ability to analyze and characterize polymers and composites for developing innovative plastic products with enhanced performance.
PSO2	Capability to integrate theoretical knowledge and practical skills in plastic processing and testing for effective industrial application and problem-solving.



ANNA UNIVERSITY, CHENNAI

POST GRADUATE CURRICULUM (NON.AUTONOMOUS AFFILIATED INSTITUTIONS)

Programme: M.Tech. Plastics Technology

Regulations: 2025

Abbreviations:

BS – Basic Science (Mathematics)
ES – Engineering Science (General (G),
 Programme Core (PC), Programme
 Elective (PE))
SD – Skill Development
SL – Self Learning

L – Laboratory Course
T – Theory

LIT – Laboratory Integrated Theory
PW – Project Work

TCP – Total Contact Period(s)

Semester I

S. No.	Course Code	Course Title	Type	Periods per week			TCP	Credits	Category
				L	T	P			
1.	PA25101	Mathematics for Plastic Technologists	T	3	1	0	4	4	ES (PC)
2.	PA25102	Plastics Materials Technology	T	4	0	0	4	4	ES (PC)
3.	PA25103	Manufacture of Plastic Products	T	3	0	0	3	3	ES (PC)
4.	PA25104	Polymer Characterization	T	3	0	0	3	3	ES (PC)
5.	PA25105	Polymer Characterization Laboratory	L	0	0	4	4	2	ES (PC)
6.	PA25106	Plastic Processing Laboratory	L	0	0	4	4	2	ES (PC)
7.	PA25107	Technical Seminar	-	0	0	2	2	1	SD
Total Credits							24	19	

Semester II

S. No.	Course Code	Course Title	Type	Periods per week			TCP	Credits	Category
				L	T	P			
1.	PA25201	Plastics Materials & Products Testing	T	3	0	0	3	3	ES (PC)
2.	PA25202	Polymer Composites	T	3	0	0	3	3	ES (PC)
3.	PA25203	Plastics Product and Mould Design	T	3	1	0	4	4	ES (PC)
4.	---	Programme Elective I	T	3	0	0	3	3	ES (PE)
5.	---	Industry Oriented Course I	-	1	0	0	1	1	SD
6.	PA25204	Plastics Testing Laboratory	L	0	0	4	4	2	ES (PC)
7.	PA25205	Product Design Laboratory	L	0	0	4	4	2	ES (PC)
8.	PA25206	Industrial Training [#]	---	---	---	---	---	---	SD
9.	---	Self-Learning Course	---	-	-	-	-	1	-
Total Credits							21	19	

Evaluation will be done in third semester for the summer internship.

Semester III

S. No.	Course Code	Course Title	Type	Periods per week			TCP	Credits	Category
				L	T	P			
1.	---	Programme Elective II	T	3	0	0	3	3	ES (PE)
2.	---	Programme Elective III	T	3	0	0	3	3	ES (PE)
3.	---	Programme Elective IV	T	3	0	0	3	3	ES (PE)
4.	--	Programme Elective V	T	3	0	0	3	3	ES (PE)
5.	---	Industry Oriented Course II	-	1	0	0	1	1	SD
6.	PA25301	Project Work I	---	0	0	12	12	6	SD
7.	PA25206	Industrial Training [#]	-	-	-	-	-	1	SD
Total Credits							25	20	

Semester IV

S. No.	Course Code	Course Title	Type	Periods per week			TCP	Credits	Category
				L	T	P			
1.	PA25401	Project Work II	---	0	0	24	24	12	SD
Total Credits							24	12	

Total Credits for the Programme = 67

Programme Elective Courses (PE)

S. No.	Course Code	Course Title	Periods			Total Contact Periods	Credits
			L	T	P		
1.	PA25001	Rheology of Polymer Processing	3	0	0	3	3
2.	PA25002	Plastics Packaging Technology	3	0	0	3	3
3.	PA25003	Additives and Compounding	3	0	0	3	3
4.	PA25004	Thermodynamics of Polymer synthesis	3	0	0	3	3
5.	PA25005	Polymer Reaction Engineering	3	0	0	3	3
6.	PA25006	Polymer nanocomposites	3	0	0	3	3
7.	PA25007	Rubber Technology					
8.	PA25008	Science and Technology of Advanced Coatings	3	0	0	3	3
9.	PA25009	CAD/CAM/CAE Applications in Mould / Die Designs	3	0	0	3	3
10.	PA25010	Reverse Engineering and Rapid Prototyping	3	0	0	3	3
11.	PA25011	Advanced Plastics Processing	3	0	0	3	3
12.	PA25012	Fracture Mechanisms and Analysis in Polymers	3	0	0	3	3
13.	PA25013	Biomedical Plastics	3	0	0	3	3
14.	PA25014	Shape Memory Polymers	3	0	0	3	3
15.	PA25015	Conducting Polymers	3	0	0	3	3
16.	PA25016	Liquid Crystalline Polymers	3	0	0	3	3
17.	PA25017	Plastics recycling and waste management	3	0	0	3	3
18.	PA25018	Bioplastics and Biodegradable Polymers	3	0	0	3	3
19.	PA25019	Applications of AI and ML in Plastic Industries	3	0	0	3	3

Semester I

PA25101	Mathematics for Plastic Technologists	L	T	P	C
		3	1	0	4
Course Objectives: <ul style="list-style-type: none"> To understand the basic concept of numerical methods in solving ordinary differential equations. To understand the basic concept of numerical methods in solving partial differential equations. To understand the concept of probability and common probability distributions. To apply statistical methods like curve fitting, correlation, and regression. To learn how to test assumptions using hypothesis testing methods. 					
Numerical Methods of Ordinary Differential Equations: Solution of first order ordinary differential equation, Taylor's method, Euler's method, Runge, Kutta method of fourth order, Predictor, Corrector Methods, Introduction to numeric use of the above techniques in plastics engineering and calculations. Activity: Write a simple program (in MATLAB or Python) to solve a first-order ODE using Euler's method and compare results with Runge-Kutta 4th order.					
Numerical Methods of Partial Differential Equations: Classification of second order linear partial differential equations, Elliptic equations, Solution of Laplace equations Activity: Use finite difference method to solve Laplace's equation on a 2D grid and visualize the solution using contour plots.					
Probability and Distributions: Probability, Addition theorem, Multiplication theorem, Conditional probability, Baye's theorem, Distribution functions, Binomial distribution, Poisson distribution, Normal distribution Activity: Collect sample data from a plastics manufacturing process and calculate the probability of defects using Binomial and Poisson distributions.					
Statistical Analysis and Curve Fitting: Curve fitting, Fitting a straight line and second degree curve, Fitting a non linear curve, Correlation and regression., Activity: Fit a linear and quadratic curve to sample stress-strain data from plastics testing and analyze the goodness of fit using correlation coefficients.					
Testing of Hypothesis: Sampling distribution, Large sample and small samples Testing of null hypothesis, Type I and Type II errors, "t" test and Chi square test - Goodness of fit. Activity: Conduct a hypothesis test (t-test) to compare the mean tensile strength of two different plastic materials using sample data.					
Weightage: Continuous Assessment: 40%, End Semester Examinations: 60%					
Assessment Methodology: Quiz (20%), Assignments (30%) and Internal Examinations (50%)					

References:

1. Burden, R. C., & Faires, J. D. (2016). *Numerical analysis* (9th ed.). Cengage Learning.
2. Johnson, R. A., Miller, I., & Freund, J. (2016). *Miller and Freund's probability and statistics for engineers* (9th ed.). Pearson Education Asia.
3. Gupta, S. C., & Kapoor, Y. K. (2020). *Fundamentals of mathematical statistics* (12th ed.). Sultan Chand & Sons.
4. Gross, D., Shortle, J. F., Thomson, J. M., & Harris, C. M. (2014). *Fundamentals of queuing theory* (4th ed.). Wiley.

	Description of CO	PO	PSO1	PSO2
CO1	Develop computational skills to solve differential equations used in plastic engineering applications.	PO1(3), PO2(2)	3	2
CO2	Understand and apply key probability distributions in the context of material science and plastics.	PO1 (3), PO2(2), PO4(2)	2	3
CO3	Utilize regression and correlation techniques to analyze and interpret experimental data.	PO1 (3), PO2(2), PO4(2)	2	1
CO4	Evaluate hypotheses and perform statistical tests to support quality control and research in plastics technology.	PO1 (3), PO2(2), PO4(2)	2	2

PA25102	Plastics Materials Technology	L	T	P	C
		4	0	0	4
<p>Course Objectives:</p> <ul style="list-style-type: none"> To understand the mechanism of polymerization, techniques of polymerization and the significance of different molecular weight averages. To provide in depth knowledge about different kinds of plastic materials based on their structure and properties To make the student familiar about properties and end application of different plastics materials To apply knowledge of thermoplastics for industrial applications. To understand the role of polymer blends & alloys in current scenario 					
<p>Introduction to Polymer Materials: Introduction to polymers and their Classification homopolymers, Copolymers. Different types of polymerizations, addition, condensation and stereoregular polymerization. Initiators, important steps involved, kinetics and mechanism of addition, condensation and stereoregular polymerizations. Copolymerization and its kinetics. Polymerization techniques, emulsion, bulk, solution and suspension, Molecular weight & its determination.</p> <p>Activity: Classify given polymers into homopolymers, copolymers, and stereoregular polymers with reasoning.</p>					
<p>Commodity Thermoplastics: Introduction, source of raw materials, Manufacture, General Properties, processing and applications of Olefine Polymers such as Polyethylenes, Polypropylene and their copolymers, Styrene Polymer such as Polystyrene and Copolymers (Styrene Acrylonitrile, Acrylonitrile Butadiene Styrene), Vinyl polymers such as Poly (Vinyl Chloride), Poly (vinyl acetate, Acrylics and copolymers- Cellulose Polymers Cellulose acetate cellulose nitrate cellulose butyrate.</p> <p>Activity: Compare and list the physical and chemical properties of polyethylene and polypropylene and relate to their applications.</p>					
<p>Engineering and High Performance Thermoplastics: Introduction, source of raw materials, Manufacture, General Properties, processing and applications of engineering thermoplastics such as-Acetal-Homopolymer & Co-polymer , polycarbonates, polyamides- Nylon 6, 6 6, 6 10, 11 and 12, Polyesters (Poly Ethylene Terephthalate & Poly (Butylene Terephthalate) polyimides, Poly (benzimidazoles), polyphenylene oxide, Poly(aryl ether ketone), Poly (ether ether ketone), Poly(aryl ether sulfone), poly (phenylene sulfides), Polysulfones, Fluoropolymers Poly (Vinyl Fluoride, Poly (Vinylidene Fluoride, Polytetrafluoro ethylene, Polychlorotrifluoro Ethylene), Liquid crystalline polymers and Thermoplastic Polyurethanes.</p> <p>Activity: Research and present a case study on the use of polycarbonates in automotive or aerospace industries.</p>					

Thermosetting Plastics: Introduction, source of raw materials, Manufacture, General Properties, processing and applications of Phenolic resin, Urea Formaldehyde, Melamine Formaldehyde, Unsaturated Polyesters, DMC BMC SMC Epoxy resins, Crosslinking reactions Polyurethane and Silicones Cyanate esters.

Activity: Observe or simulate the curing process of epoxy resin and explain the role of crosslinking on material properties.

Polymer Blends and Alloys: Introduction to polymer blends and alloys- Definitions, compatibilization mechanism and methods, criteria for making polymer blends, Selection of polymer for blend, Types of polymer blends. Thermodynamics of polymer miscibility, Blend preparation techniques, Commercial polymer blends such as plastic-plastic, rubber-plastic, rubber-rubber blends, High performance polymer blends Interpenetrating polymer networks (IPN)

Activity: Analyze a given polymer blend and identify factors affecting its compatibility and performance.

Weightage: Continuous Assessment: 40%, End Semester Examinations: 60%

Assessment Methodology: Quiz (20%), Assignments (30%), Internal Examinations (50%)

References:

1. Gowriker, V. R., Viswanathan, N. V., & Sreedhar, J. (n.d.). *Polymer science*. New Age Publications.
2. Brydson, J. A. (1999). *Plastics materials*. Butterworth-Heinemann.
3. Paul, D. R., & Bucknall, C. B. (2000). *Polymer blends: Vol. 1*. Wiley.
4. Utracki, L. A. (2003). *Polymer blends handbook*.
5. Singh, R. P. S., Das, C. K., & Mustafi, S. K. (2002). *Polymer blends and alloys: An overview*. Asian Books Pvt.
6. Simon, G. P. (Ed.). (2019). *Polymer blends and alloys*. Routledge.
7. Gilbert, M., & Brydson, J. A. (2017). *Brydson's plastics materials*.

	Description of CO	PO	PSO1	PSO2
CO1	Explain and classify different types of polymers and their polymerization techniques.	PO1(3), PO2(2)	2	3
CO2	Describe the properties, processing, and applications of commodity and engineering thermoplastics.	PO1 (3), PO2(2), PO4(2)	2	2
CO3	Explain the chemistry, manufacturing, and uses of thermosetting plastics and crosslinking reactions.	PO1 (3), PO2(2), PO4(2)	3	2
CO4	Analyze polymer blends and alloys, including their compatibility and preparation methods.	PO1 (3), PO2(2), PO4(2)	1	2

PA25103	Manufacture of Plastic Products	L	T	P	C
		3	0	0	3

Course Objectives:

- To understand the functions of each of these additives, technical requirements, types & mechanism, and their effective evaluation are dealt with in this subject.
- To select suitable plastics material compounding and mixing techniques like two roll milling, internal blender, single / twin screw extruder, etc.
- To learn the fundamentals of compression moulding & transfer moulding.
- To impart knowledge on basic processing of thermoplastics
- To analyze the various processing techniques of plastics materials

Compounding of Thermoplastics: Compounding-Importance, ingredients, master batch, equipments, Twin screw extrusion, compression moulding and compounding lines, compounding of polyolefins, polystyrene and styrene copolymers, engineering thermoplastics (e.g., PA, PC, PBT), natural fiber filled plastics. Post-compounding operations: pelletizing, drying, storage, and blending.

Activity: Prepare a sample of compounded polyolefin using twin-screw extrusion and analyze the effect of different masterbatch ingredients on the mechanical properties of the final product.

Injection Moulding and Extrusion Process: Injection Moulding: processing outline- Types-effect of processing parameters on moulding quality, Troubleshooting. Basic principles of extrusion, Types of extruders, general features of extruders. Melt fracture & Bambooning. Production of blown film, cast film/slot film, BO film, coextruded film. Tube/pipe-sizing take off equipment, extrusion coating, wire & cable covering-pretreatment of conductor, cooling, constructional features of dies for the above processes and trouble shooting. Applications of extrusion and new developments.

Activity: Conduct an injection moulding trial varying processing parameters (temperature, pressure) and document the effect on moulding defects and quality.

Blow Moulding, Compression & Transfer Moulding Process: Basic principles of blow moulding, Injection Blow moulding, extrusion blow moulding, Parison programming, Advantage & disadvantage of blow moulding. Basic principles of compression and transfer moulding-Bulk factor-Curing time-Mould temperature and Pressure requirements-Preforms and preheating-Techniques of preheating- Machines used-Types of compression mould-Common moulding faults and their correction. Advantages of transfer moulding over compression moulding- Equipment used-Moulding faults, causes and remedies.

Activity: Perform a compression moulding experiment with different curing times and mould temperatures; identify common faults and propose corrective measures.

Thermoforming, Calendering and Roto Moulding process: Basic principles-Raw materials & types of thermoforming processes, Thermoforming moulds processing parameters, faults, causes and remedies. Calendering-Principle and process description, types of calendar units 2, 3 and 4 rolled calendars, Design of calendar roll, Heating and temp control, roll crown, roll crossing and roll bending, materials for calendering, calendering

sheets and films, embossing, coating and lamination by calendar. Rotational moulding, Introduction-principle-process-machinery used-materials-moulds process parameters-merits & demerits of rotomoulding.

Activity: Visit a thermoforming or calendaring unit (or simulate process if lab unavailable), observe operational parameters, and prepare a report on fault diagnosis and process optimization.

Selective Laser Sintering (SLS) Process : Principle, process, Indirect and direct SLS-powder structures, materials, post processing, surface deviation and accuracy. Applications; Laser Engineered Net Shaping (LENS): Processes, materials, products, advantages, limitations and applications. Other Additive Manufacturing Systems: Shape Deposition Manufacturing (SDM), Ballistic Particle Manufacturing (BPM), Selective Laser Melting, Electron Beam Melting;

Activity: Design and 3D print a simple part using SLS technology; analyze surface finish and dimensional accuracy, then discuss potential applications.

Weightage: Continuous Assessment: 40%, End Semester Examinations: 60%

Assessment Methodology: Quiz (20%), Assignments (30%), Internal Examinations (50%)

References:

1. Fisher, E. G., & Whitfield, E. C. (1976). Extrusion of plastics.
2. Hornsby, P. R. (1988). Plastics extrusion technology (F. Henson, Ed.). Carl Hanser Verlag.
3. Rossato, D. V. (1995). Injection moulding handbook. International Thomson Publishing Co.
4. Welling, M. S. (1981). Injection moulding technology. VDI-Verlag GmbH.
5. Schwartz, S. S., & Goodman, S. H. (1982). Plastics materials and process. Van Nostrand Reinhold Company.
6. Stevenson. (1996). Innovation in polymer processing.
7. Giles, H. H., & others. (2004). Extrusion: The definitive processing guide and handbook.
8. Iyeseu, A. I. (n.d.). Compression molding.
9. Bruins. (n.d.). Basic principle of rotational molding.
10. Bryce, D. M. (n.d.). Basic principle of thermoforming.

	Description of CO	PO	PSO1	PSO2
CO1	Understand and perform compounding of thermoplastics using extrusion techniques.	PO1(3), PO2(2)	2	3
CO2	Apply injection moulding and extrusion processes for plastic product manufacturing.	PO1 (3), PO2(2), PO4(2)	2	2
CO3	Explain blow moulding, compression moulding, and thermoforming methods.	PO1 (3), PO2(2), PO4(2)	3	2
CO4	Describe Selective Laser Sintering and other additive manufacturing processes.	PO1 (3), PO2(2), PO4(2)	1	2

PA25104	Polymer Characterization	L	T	P	C
		3	0	0	3

Course Objectives:

- To develop knowledge of National & International standards for testing methods.
- To create the knowledge about the conditioning of samples and sample preparation techniques for testing various properties of plastics materials.
- To enable the students to learn about the evaluation of mechanical & thermal properties of plastics materials.
- To enable the students to learn about the evaluation of electrical & optical properties of plastics materials.
- To enable the students to understand the testing of raw materials and components for evaluating various properties; testing the products for predicting product performance

Molecular Weight Determination: Molecular weight averages - Molecular weight determination techniques like End-group analysis, Colligative Properties-Ebulliometry, Osmometry and Vapour phase Osmometry, Light scattering techniques, Solution viscometry, and Gel Permeation Chromatography.

Activity: Determine the molecular weight of a polymer using solution viscometry.

Spectroscopic Characterization: Introduction to Spectroscopic techniques, Ultraviolet, Visible Spectroscopy, Infra Red-Raman Spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR), Nuclear Magnetic Resonance (NMR) Spectroscopy, Electron Spin Resonance Spectroscopy, X-Ray Diffraction

Activity: Analyze a polymer sample using FTIR to identify key functional groups.

Microscopic and Chromatographic Characterization: Light Microscopy, Scanning electron microscopy (SEM) and Transmission electron Microscopy (TEM) Analysis of residual monomer like VCM, Acetaldehyde, Acrylonitrile and Styrene content in Polymers by Gas Chromatography (GC)

Activity: Observe polymer surface morphology with Scanning Electron Microscopy (SEM).

Thermal Characterization: The basis of Thermal Analysis, Differential Thermal Analysis (DTA) and Differential Scanning Calorimetry (DSC), Thermo-mechanical Analysis (TMA), Thermo gravimetric Analysis (TGA) and Dynamic Mechanical Thermal Analysis (DMA).

Activity: Use Differential Scanning Calorimetry (DSC) to find the melting point of a polymer.

Rheological Characterization: Melt Viscosity measurements, Melt flow tests (MFI and MFR), Capillary Rheometer, Cone and Plate viscometer, torque rheometer, oscillating disc rheometer, cup flow and spiral flow tests for determination of flow behaviour of resins. Viscosity of solutions and resins, Brookfield Viscometer, Ubbelohde viscometer, Ostwald viscometer.

Activity: Measure the Melt Flow Index (MFI) of a polymer sample.

Weightage: Continuous Assessment: 40%, End Semester Examinations: 60%

Assessment Methodology: Quiz (20%), Assignments (30%), Internal Examinations (50%)

References:

1. Campbell, D., & White, J. R. (1989). *Polymer characterization: Physical techniques*. Chapman and Hall.
2. Seidel, A. (2008). *Characterization and analysis of polymers*. Wiley Interscience.
3. Pethrick, R. A., & Viney, C. (2003). *Techniques for polymer organization and morphology characterization*. Wiley Interscience.
4. Mirau, P. A. (2005). *A practical guide to understanding the NMR of polymers*. Wiley Interscience.
5. Turi, E. A. (1982). *Thermal characterization of polymeric materials* (2nd ed., Vols. 1–2).
6. Allen, W. S., & Baker, P. N. (2004). *Handbook of plastics technology: Volume 2, Identification testing & recycling of plastics*. CBS Publishers and Distributors.
7. Brown, P. F. (Ed.). (1988). *Handbook of plastics test methods*. Longman Scientific and Technical.
8. Brown, R. P. (Ed.). (1999). *Handbook of polymer testing*. Marcel Dekker.
9. ASTM. (2002). *ASTM test standards for plastics* (Vols. 8.01–8.04, 9.01 & 9.02).
10. International Organization for Standardization. (1998). *ISO test standards*.
11. Shah, V. (1984). *Handbook of plastics testing technology*. John Wiley and Sons. (SPE Monograph)

	Description of CO	PO	PSO1	PSO2
CO1	Understand and apply various molecular weight determination techniques for polymers.	PO1(3), PO2(2)	3	2
CO2	Interpret polymer structures using spectroscopic methods like FTIR, NMR, and UV-Vis.	PO1 (3), PO2(2), PO4(2)	2	2
CO3	Analyze polymer morphology and composition using microscopic and chromatographic tools.	PO1 (3), PO2(2), PO4(2)	1	3
CO4	Evaluate thermal and rheological properties to assess polymer performance and processing behavior.	PO1 (3), PO2(2), PO4(2)	2	1

PA25105	Polymer Characterization Laboratory	L	T	P	C
		0	0	4	2
Course Objectives: <ul style="list-style-type: none"> To get practice in testing the Physico-mechanical properties of plastic materials. To provide hands on experience on various polymerization techniques. To make the student understand simple experimental procedures to determine molecular weight and molecular weight distribution of polymers. To make the student familiarize with the thermal properties of polymers. To make the student understand simple techniques to identify the plastic materials. 					
List of Experiments: <ol style="list-style-type: none"> Identification of Plastics materials. Density and moisture analysis. Melt flow Test (MFI/MFR) FTIR Analysis Measurement of viscosity of polymer solutions and determination of molecular weight of the polymer. End group analysis. Determination of acid value of a resin. Study of Molecular weight distribution (GPC). Determination of cure of a phenolic moulding (percentage acetone soluble matter). Study of Thermal Stability of polymers. Determination of K-value for PVC. Determination of Filler content 					
Weightage: Continuous Assessment: 60%, End Semester Examinations: 40%					
Assessment Methodology: Project (30%), Assignment (10%), Practical (30%), Internal Examinations (30%)					
Equipment Required: Glassware for reactions and spot tests, Ostwald/Ubbelohde viscometer,					
References: <ol style="list-style-type: none"> ASTM. (2002). ASTM test standards for plastics (Vols. 8.01–8.04, 9.01 & 9.02). International Organization for Standardization. (1998). ISO test standards. Shah, V. (1998). Handbook of plastics testing technology. John Wiley & Sons. Saunders, K. J. (1970). The identification of plastics and rubbers. Chapman and Hall. Brown, R. P. (1981). Handbook of plastics test methods. George Godwin Ltd. 					

	Description of CO	PO	PSO1	PSO2
CO1	Identify and characterize polymers using FTIR, viscosity, and molecular weight analysis.	PO1(3), PO2(2)	2	3
CO2	Analyze polymer properties such as thermal stability and melt flow.	PO1 (3), PO2(2), PO4(2)	1	2
CO3	Evaluate polymer curing and processing behaviors.	PO1 (3), PO2(2),	3	2

PA25106	Plastic Processing Laboratory	L	T	P	C
		0	0	4	2
Course Objectives:					
<ul style="list-style-type: none"> To gain practical knowledge about hand operated injection moulding, semi automatic & automatic injection moulding machine, Blow moulding process. To identify defects, causes & remedies of the process. To select the suitable process parameters for a particular process. To learn about microprocessor controlled injection moulding machines, Blow moulding process, rotational moulding, thermoforming with different moulds and material. To understand the possible defects, its causes and setting of process parameters. 					
List of Experiments					
<ol style="list-style-type: none"> Injection Moulding (Hand Operated ,Semi-Automatic) Microprocessor controlled Injection moulding operation Extrusion Process Compression Moulding Blow Moulding and stretch blow moulding Vacuum Forming Rotational Moulding Coating of Plastics Welding & Sealing of Plastics FRP, Hand layup process Co-extrusion process Machine Maintenance Mould Study 					
References:					
<ol style="list-style-type: none"> Athaly, A. S. (1997). <i>Injection moulding practice</i>. Multi-Tech Publishing Co. Lee. (1998). <i>Blow moulding design guide</i>. Hausar Publishers. Hensen, F. (1988). <i>Plastics extrusion technology</i>. Hansar Publishers. Rubin, I. (1972). <i>Injection moulding theory and practice</i>. Wiley Interscience. 					
Weightage: Continuous Assessment: 60%, End Semester Examinations: 40%					
Assessment Methodology: Project (30%), Assignment (10%), Practical (30%), Internal Examinations (30%)					

Laboratory Requirements

1. Injection moulding machine (conventional, semi automatic) - 2Nos.
2. Plastic tube extrusion machine - 1No.
3. Plastic film extrusion machine - 1No.
4. Compression moulding machine - 1No.
5. Microprocessor controlled injection moulding machine - 1 No.
6. Blow moulding machine (Automatic) - 1 No.
7. Vacuum forming machine - 1 No.
8. Rotational moulding machine - 1 No.
9. Plastics coating machine - 1 No.
10. Ultrasonic welding machine - 1 No.
11. Plastic sealing machine - 1 No.
12. Printing machine (on plastics) - 1 No.
13. Machine maintenance kit - 1 No.
14. Moulds maintenance kit - 2 Nos.
15. Moulds for plastic products - 1 No.
16. FRP hand layup kit - 1 No.
17. Plastic co-extrusion film plant - 1 No.

	Description of CO	PO	PSO1	PSO2
CO1	Demonstrate proficiency in operating and controlling plastic manufacturing processes such as injection moulding, extrusion, and blow moulding.	PO1(3), PO2(2)	3	2
CO2	Analyze and optimize the performance of plastic manufacturing equipment through techniques like welding, coating, and maintenance.	PO1 (3), PO2(2), PO4(2)	2	1
CO3	Evaluate and implement process improvements for enhanced product quality and operational efficiency in plastic production.	PO1 (3), PO2(2),	2	2

PA25201	Plastics Materials and Products Testing	L	T	P	C
		3	0	0	3

Course Objectives:

- Impart in-depth knowledge of mechanical, thermal, electrical, optical, and chemical testing methods for plastics.
- Familiarize students with national and international standards (ASTM, ISO, BIS, etc.) for testing plastic materials and products.
- Enable students to select appropriate test methods based on the application and product performance requirements.
- Train students in the interpretation of test results for quality control and R&D.
- Develop the ability to evaluate processing–structure–property relationships using testing data.

Identification of Plastics and Standards

Identification of various plastics by simple physical methods, chemical methods and analytical tools. Application of national and international standards (BIS, ASTM, ISO, DIN) for testing and their significance, Knowledge and exposure on Sectorial Testing Standards. Laboratory accreditation (NABL), Quality standards - Standard and specification-Test specimen preparation-Preconditioning and test atmosphere.

Mechanical Properties

Dimensions-Hardness, density, tensile strength, compressive strength, shear strength, flexural strength, impact strength, dynamic stress-strain properties, creep-stress relaxation, friction and wear, abrasion test, fatigue, burst strength, tear strength and folding endurance,

Thermal and Ageing Properties

Specific heat and thermal conductivity, thermal dependent properties- thermal Endurance-glass transition temperature, Heat deflection temperature, Vicat softening temperature, Marten’s heat resistance test-low temperature brittle point and flexibility test-coefficient of thermal expansion-shrinkage-Thermal stability- Thermal ageing and flammability, UL 94 test, Permanence Properties: Water absorption-soluble and insoluble matter-chemical resistance environmental stress cracking resistance-ageing-gas permeability-water vapour permeability and weathering.

Optical and Electrical Properties

Refractive index, light transmission, haze, clarity, gloss, opacity, Electrical Properties- Insulation resistance-power factor-permittivity – dielectric strength- comparative tracking resistance-arc resistance and antistatic test, volume and surface resistivity.

Testing of Plastics Products

Testing of plastic films, sheets, laminates, pipes - HDPE, PVC, OPVC, PPR pipes- water tanks, Hygiene and migration tests for food grade products, IS 9845, Testing of biodegradable or compostable films as per IS 17088 and other standards.

Course Outcomes:

At the end of the course, students will be able to

- CO1 Classify plastic products and identify relevant testing protocols.
- CO2 Interpret mechanical, barrier, and optical test data for flexible products.
- CO3 Assess structural integrity and long-term performance of pipes and tanks.
- CO4 Evaluate electrical, thermal, and fire properties of engineering plastic components.
- CO5 Apply regulatory and safety testing to medical, food-contact, and consumer plastic products.

REFERENCES:

1. V. Shah, Handbook of Plastics Testing Technology, Wiley
2. Brown, R., Physical Testing of Plastics, Springer
3. ASTM/ISO/IS Standards relevant to each product category
4. R.G. Griskey, Polymer Process Engineering, Springer
5. M. Kutz (Ed.), Handbook of Materials Selection, Wiley
6. Handbook of Plastic Testing and Failure Analysis, Vishu Shah
7. IS 9845:1986, Evaluation of plastics for food contact applications

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	2	2	2	1	2	2	2	2	1	-	2
CO2	2	2	1	2	2	2	1	1	2	2	1	2
CO3	2	1	1	2	2	2	2	1	1	2	1	2
CO4	2	2	1	2	2	2	1	1	1	2	1	2
CO5	2	1	1	2	2	2	2	1	2	2	1	2
AVg.	2	1.6	1.2	2	1.8	2	1.6	1.2	1.6	1.8	0.8	2

1-low, 2-medium, 3-high, ‘-‘- no correlation

PA25202	Polymer Composites	L	T	P	C
		3	0	0	3

Course Objectives:

- To impart knowledge of various types of composites and its advantages and needs.
- To understand the knowledge of various resins materials used in processing of composites
- To make the student understand the various types of fiber materials and its applications for making Composites.
- To acquire knowledge about various processing methods of composites
- To enable the students understand the basic destructive and non-destructive testing of composites

Matrix and Reinforcement Materials

Introduction–Resins for composites as matrix materials – unsaturated polyester resins, epoxy resin, phenolic Resins, vinyl ester resins, alkyd resins. cyanate esters Reinforcements for composites– Natural fibers, jute sisal , coir, banana fibre synthetic fibers, glass Fibers, carbon fibers, aramide fibres, graphite fibers, polyethylene fibers, silicon carbide and boron fibers.

Additives for Composites

Additives for composites, catalysts, hardners for room temperature and elevated temperature curing, accelerators, coupling agents, fillers, flame retardants, biocides, toughening agents, UV stabilizers, anti oxidants, thixotropic agents mould release agents.

Mechanical Properties of Composites

Theory of composite materials - calculation of composite properties- mechanism of load transfer, minimum and critical fibre content, critical fibre length- Rule of mixtures–Halpin -Tsai - equation.

Processing of Composites

Processing of composites–Important processes like hand lay-up, spray-up, resin transfer moulding, vacuum bag, pressure bag moulding, centrifugal casting, pultrusion, filament winding, compression moulding moulding compounds–SMC, DMC, BMC.

Testing of Composites

Testing Quality control & end use of plastics–Testing for mechanical, electrical, thermal, optical and chemical properties, Determination of shelf life and gel time–Non-destructive testing methods. Application of FRP products - in marine, chemical, railways, electrical and electronic industry, space structures–Robotics.

OUTCOMES:**At the end of the course, students will be able to****CO1** Acquire knowledge of various types of composites and their advantages and needs.**CO2** Familiarize with resins used in the FRP system**CO3** Know various types of fibers and their applications in making composite products.**CO4** Acquire knowledge of various processing operations for composites**CO5** Gain knowledge of the basic destructive and non-destructive testing of composites**REFERENCES:**

1. Mallick, Pankaj K., ed. *Composites engineering handbook*. CRC Press, 1997.
2. Hollaway, L. C., ed. *Handbook of polymer composites for engineers*. Woodhead publishing, 1994.
3. Åström, B. Tomas. *Manufacturing of polymer composites*. Routledge, 2018.
4. Barbero, Ever J. *Introduction to composite materials design*. CRC press, 2010.
5. Clyne, Trevor William, and Derek Hull. *An introduction to composite materials*. Cambridge university press, 2019.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO 9	PO10	PO11	PO12
CO1	3	2	2	2	1	2	2	1	---	1	1	2
CO2	2	2	1	2	2	2	2	1	---	1	1	2
CO3	2	2	3	2	2	2	2	1	---	1	1	2
CO4	2	3	1	2	3	2	2	1	2	2	2	2
CO5	2	2	2	2	3	2	2	1	2	2	2	2
AVg.	2.2	2.2	1.8	2	2.2	2	2	1	0.8	1.4	1.4	2

1-low, 2-medium, 3-high, ‘-‘- no correlation

PA25203	Plastics Product and Mould Design	L	T	P	C
		3	1	0	4

Course Objectives:

- To understand basic concepts of product design
- To learn the design concepts for various mould elements.
- To acquire knowledge about various moulds for different processing techniques
- To learn the basic design aspects related to Injection Mould, Compression Mould, Transfer Mould, Blow Mould.
- To learn the basic design aspects related to extrusion dies

Product Design

Principles & Methodical approach for Product Design – Concept design, engineering validation, material/process selection, product life cycle assessment, Product Design finalization- Tooling Aspects on Product Design — Cost Analysis for Product Design. Features: Geometry Features - Wall thickness, Taper & Draft, Radii, Fillets, Ribs, Bosses Holes, Undercuts – External & Internal - Moulded threads- Inserts - Shrinkage- Assembly Features - Fits & Tolerances - Snap Fits - Hinges — Types -Design of Integral hinges - Welding - Bonding. Structural Elements: Design of Tension bars, Columns, Beams, Pipes, Plates and Shells - Design of Joints — Bolted joints and bonded joints- Design of plastics under Static load & dynamic load Design of plastic Gears, Bearings, springs.

Injection Mould Design

Introduction – Types of Injection Moulds: Cold Runner – Hot Runner – Hand – Semi Automatic – Automatic Two plate - Three Plate – Moulds for Internal & External Undercuts Stack mould, multi shot moulds

Elements of Injection Mould - Factors considered for Mould Design- -Shot Capacity-Clamping Force- Injection Time – hold on time Cooling Time - Number of Cavities –Layout of Cavities. Design of Injection mould systems–Parting surface and its types - Core–Cavity – Bolster construction methods for core & cavity-Guide pillar- Guide bush - Sprue bush - Locating Ring Standard Mould System – Mould alignment – Mould Assembly – Mould Clamping. Feed System: Sprue – types of sprue – Runner – types of runner - cross section and size of runner –runner layout – balancing of runners – semi hot runner and hot runner Gates - Gate location and balancing - types of gates – Mould Venting.

Mould Cooling System Design

Mould cooling types : Parallel cooling, take off, : Introduction -Heat Transfer Fluids- Chillers- Temperature Controllers - Factors Affecting the Cooling Cycle -Cooling Efficiency - Mould Cooling Variables -Cooling Calculations -Cooling of Integer type mould plates - Cooling of Insert Bolster assembly -cooling of other mould parts- connections of cooling channels and seals. Mould Temperature Control System water and oil medium.

Mould Ejection System Design

Types of Ejection Systems: parallel ejection, sleeve ejection pin ejection, blade ejection, stripper plate ejection, air ejection, Requirements — Elements of Ejection system - Ejector grid, Ejector plate assembly, Ejection techniques — Ejection from fixed half - Sprue Pullers- Ejection Force Calculation - Ejection Assembly Actuation. Interfacing of robots for part removal.

Design of Compression & Transfer Moulds

Compression Mould Design: Introduction -Types - Open flash, Semi-positive, Positive moulds, Bulk factor - Design of loading chambers and Pressure pad - Calculations of Flash thickness, Projected area, Compression Pressure, Clamping Force, No. of impressions- Design of heating system - Transfer Mould Design: Introduction -Types — Design of Pot and Plunger - Calculations of Projected area, Transfer Pressure, clamping force - Design of Pressure pad and Feed system.

Design Of Blow, Rotational Moulds & Dies

Blow Mould Design: Introduction-Types of blow moulds-Blow ratio - Parison design–Pinch off design - parting line-mould cooling-mould alignment. Rotational Mould Design: Introduction — Construction- Extrusion Die Design: Types of extrusion dies Principles of extrusion - construction of die - die geometry - die swell–die land design - sizing die.

OUTCOMES:

At the end of the course, students will be able to;

CO1 Understand the basics of plastics product design.

CO2 Understand the basics of plastics mould design.

CO3 Acquire knowledge about various moulds for different processing techniques.

CO4 Apply the basic design aspects related to Injection Mould, Compression Mould, Transfer Mould, Blow Mould

CO5 Apply the basic design aspects related to extrusion die

REFERENCES:

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2. Peter Jones, the Mould Design Guide, Smithers Rapra Technology Limited, Shawbury, Shrewsbury, Shropshire, SY4 4NR, UK, 2008,
3. Belofsky, H, "Plastics Product Design and Processing Engineering, Hanser Publishers, Munich Vienna New York, 1994.
4. Dym J.B Injection Mould & Moulding A practical manual, Springer, 2nd ed. XVIII, 396P, 1987.
5. Nayak, Sanjay K, Pratap C. Padhi, and Y Hidayathullah. *Fundamentals of Plastics Mould Design*. New Delhi: Tata McGraw Hill Education, 2012.
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MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	2	2	2	2	2	2	1	---	1	1	2
CO2	3	2	2	2	2	1	2	1	---	1	1	2
CO3	2	2	2	3	2	1	1	1	---	1	1	2
CO4	1	2	2	2	2	1	1	1	1	1	1	2
CO5	1	2	2	2	2	1	1	1	1	1	1	2
AVg.	2	2	2	2.2	2	1.2	1.4	1	0.4	1	1	2

1-low, 2-medium, 3-high, '---' no correlation

PA25204	Plastics Testing Laboratory	L	T	P	C
		0	0	4	2

Course Objectives:

- To train the students in testing of plastics for properties. The various testing methods of plastics materials as per the ASTM standards.
- To prepare sheet specimens by Contour cutting & Punching
- To learn about the compounding of plastics materials
- To get practice in testing the Physico-mechanical properties of plastic materials.
- To understand the various testing done on different plastics products.

LIST OF EXPERIMENTS

1. Specimen Preparation: Specimen preparation using injection moulding — Compression moulding – Two-roll mill and Contour cutter.
2. Mechanical properties of plastics : Tensile strength – Flexural strength – Compression strength –Tear strength - Impact strength – Hardness
3. Compounding, Blending using Two Roll Mill and Specimen
4. Determination of Carbon Black Content
5. Determination of HDT and VSP
6. Determination of environmental stress cracking resistance for olefins
7. Testing of HDPE/UPVC/OPVC/PPR Pipes
8. Testing of Water Storage Tanks/Containers
9. Testing of Films/Sheets
10. Testing of HDPE/PP Woven Sacks/Tapes
11. Testing of PET/PP/HDPE bottles

LABORATORY REQUIREMENTS

1. Carbon black content tester - 1 No.
2. Environmental stress cracking resistance tester - 1 No.
3. Injection moulding machine and specimen moulds - 1 No each.
4. Compression moulding machine - 1 Nos.
5. Two roll mill - 1 No.
6. Contour cutter - 1 No.
7. Scrap grinder - 1 No.
8. Blender - 1 No.
9. Universal testing machine - 1 Nos.
10. Tear strength tester - 1 No.
11. HDT/VSP Tester
12. Impact strength tester - 1 Nos.
13. Shore A – Hardness tester - 1 No.
14. Shore D – Hardness tester - 1 No.
15. Rockwell Hardness tester - 1 No.
16. Abrasion resistance tester - 1 No.
17. Folding endurance tester - 1 No.
18. Burst strength tester - 1 No.
19. Humidity chamber - 1 No.
20. Gas permeability tester - 1 No.
21. Sieve analysis apparatus - 1 No.
22. Volume and Surface resistivity-1 No
23. Dielectric strength-1 No
24. Arc Resistance-1 No
25. Haze meter-1 No

OUTCOMES:

At the end of the course, students will be able to

- CO1** Prepare specimen by injection moulding and contour cutting
- CO2** Gain knowledge about compounding of plastics with additives
- CO3** Learn how the plastics materials are tested for its mechanical, electrical, optical, properties.
- CO4** Practice on testing of various plastic products

REFERENCES:

1. ASTM test standards for plastics Vol.8.01 to 8.04, 9.01 & 9.02, 2002.
2. ISO test standards, 1998.
3. J. S. Anand, K. Ramamurthy, K. Palanivelu & C. Brahatheeswaran, How to Identify Plastics by Simple Methods, 1997.
4. Vishu Shah, Handbook of Plastics Testing Technology, John Wiley & Sons. Inc. New York, 1998. R.P. Brown, Handbook of Plastics Test Methods, George Godwin Ltd., London, 1981.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO 9	PO10	PO11	PO12
CO1	3	1	3	1	3	2	1	1	2	1	1	3
CO2	3	3	3	2	3	2	2	1	2	2	1	3
CO3	3	3	3	3	3	2	2	2	2	2	1	3
CO4	3	3	3	3	3	3	2	2	2	2	2	3
AVg.	3	2.5	3	2.25	3	2.25	1.75	1.5	2	1.75	1.25	3

1-low, 2-medium, 3-high, ‘-‘- no correlation

PA25205	Product Design Laboratory	L	T	P	C
		0	0	4	2

Course Objectives:

- To learn the use of Computer Aided Design in Plastic products and mould designing.
- To analysis the flow behavior and temperature control of plastics materials while processing using mold flow software.

LIST OF EXPERIMENTS

I. Plastics Product Design using CAD

1. 2D and 3D modeling using CAD.
2. Product drawing practice.
3. Design for specific Plastic components.

II. Mold Design using CAD/CAM

1. Design of core, cavity inserts.
2. Design of feed systems
3. Design of cooling systems
4. Design of ejection systems
5. Design of moulds:
 - a) Two plate Injection Mould.
 - b) Three plate Injection Mould
 - c) Split type and other Injection Moulds.
 - d) Compression Mould.
 - e) Blow Mould.
6. Design of Extrusion Dies.

III. Moldflow Analysis using CAE

1. Wall thickness optimization
2. Best gate location
3. Feed system optimization
4. Fill, cool, warp analysis
5. Shrinkage Analysis
6. Optimization of Mould design and Process parameters using Moldflow Software

Outcomes:

At the end of the course, students will be able to

- CO1 Design and develop the Plastic products and moulds using CAD/ CAM/CAE software.
 CO2 Design and develop extrusion dies
 CO3 Predict the flow behavior and temperature control of the materials in the designed mould.

References:

1. R.G.W.Pye, Injection Mould Design, SPE Publication.
2. P.S.Cracknell and R.W.Dyson, Hand Book of thermoplastics injection mould design, Chapman & Hall, 1993.
3. Herbert Rees, Mould Engineering, Hanser publishers, Munich, Vienna N.Y. 1994.
4. Technical Directory on Design and Tooling for plastics, CIPET, Guindy, Chennai.
5. Design calculations for Compression moulds, Machinery publications, Yellow series, U.K.
6. Mould Flow Manual & Part - Adviser Manual - MOULD FLOW.
7. LaszcoSors and ImreBlazs, Design of Plastic Moulds and Dies, Elsevier, Amsterdam - Oxford - Tokyo - NY, 1989.
8. Jay Shoemaker "Moldflow Design Guide: A Resource for Plastics Engineers", Volume 10, Hanser, 2006

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO 9	PO10	PO11	PO12
CO1	3	3	3	3	3	1	1	2	2	2	1	3
CO2	3	3	3	3	3	1	1	2	2	2	1	3
CO3	3	3	3	3	3	1	1	2	2	2	1	3
AVg.	3	3	3	3	3	1	1	2	2	2	1	3

1-low, 2-medium, 3-high, '-'- no correlation

PA25301	Project Work I	L	T	P	C
		0	0	12	6

Course Objectives:

The course aims to enable the students to

- identify the problem/process relevant to their field of interest that can be carried out
- search databases and journals to collect and analyze relevant data
- plan, learn and perform experiments to find the solution
- prepare project report

Individual students will identify a problem relevant to his/her field of study, collect and analyze literature, design, and carryout experiment, collect data, interpret the result and prepare the project report.

OUTCOMES:

At the end of the course the students will be able to

- CO1 Identify the research/industrial problems
- CO2 Collect and analyze the relevant literature
- CO3 Design, conduct experiment and analyse the data
- CO4 Prepare project report

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO 9	PO10	PO11	PO12
CO1	3	1	2	1	2	2	1	1	2	2	1	3
CO2	3	3	2	2	3	2	2	1	1	2	1	3
CO3	3	3	3	3	3	2	2	2	2	2	1	3
CO4	3	3	2	3	2	3	2	2	2	2	2	3
AVg.	3	2.5	2.25	2.25	2.5	2.25	1.75	1.5	1.75	2	1.25	3

1-low, 2-medium, 3-high, '-'- no correlation

PA25401	Project Work II	L	T	P	C
		0	0	24	12

Course Objectives:

The course aims to enable the students to

- train students to analyze the problem/ think innovatively to develop new methods/product /process
- make them understand how to find solutions/ create products economically and in an environmentally sustainable way
- enable them to acquire technical and experimental skills to conduct experiment, analyze the results and prepare project report
- enable them to effectively think about strategies to commercialize the product

Individual students will identify a problem relevant to his/her field of study, collect and analyze literature, design, and carryout experiment, collect data, interpret the result and prepare the project report.

OUTCOMES:

At the end of the course the students will be able to

- CO1 Formulate and analyze problems for developing new methods/solutions/processes.
- CO2 Plan and conduct experiments to find solutions in a logical manner
- CO3 Analysis and interpretation of the results.
- CO4 Prepare project report/know the strategies for commercialization

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO 9	PO10	PO11	PO12
CO1	3	2	3	2	2	2	1	1	2	2	2	3
CO2	3	3	2	2	3	2	2	1	1	2	1	3
CO3	3	3	3	3	3	2	2	2	2	2	1	3
CO4	3	3	2	3	2	3	2	2	2	2	2	2
AVg.	3	2.75	2.5	2.5	2.5	2.25	1.75	1.5	1.75	2	1.5	2.75

1-low, 2-medium, 3-high, '-'- no correlation

PA25001	Rheology of Polymer Processing	L	T	P	C
		3	0	0	3

Course Objectives:

- To understand the polymer Rheology, elastic, viscous and viscoelastic materials.
- To simulate the deformations in elastic, viscous and viscoelastic materials using various models.
- To understand fundamental flow properties and methods used to investigate the flow behaviour of polymer melts.
- To familiarize with the measurement of rheological properties.
- To apply the concept of melt rheology to specific polymer processing techniques

Introduction to Polymer Rheology

Introduction to polymer rheology – types of mechanical deformation – Elastic materials – Viscous materials – Viscoelasticity – effect of temperature, rate of strain and time on mechanical behaviour of viscoelastic materials – typical stress strain curves for polymeric materials - creep – stress relaxation – Boltzman super position principle – time temperature super position – WLF equation.

Mechanical Models

Mechanical models – stress strain response of spring and dashpot – viscoelastic models – Maxwell element – Voigt kelvin element – response to creep and stress relaxation – four-parameter model – dynamic mechanical properties – behavior of Maxwell element and relaxation spectra.

Rheology of Polymer Melts

Fundamentals of fluid mechanics - classification of fluids - Newtonian and non Newtonian fluids - shear stress, shear strain and shear rate, shear modulus, bulk modulus - zero shear viscosity - dependance of viscosity on temp, shear stress, shear rate - fluid flow through circular channels – laminar flow of Newtonian fluids – simple shear flow – power law fluids - elastic effects in polymer melt flow - die- swell and melt fracture – entrance and exit effects - Weissenberg effect – normal stress difference – Elongational viscosity.

Rheological Measurements

Methods to determine melt viscosity by capillary rheometer, cone and plate viscometer, cup and bob viscometer, torque rheometers - measurement of normal stresses. Theories of viscosities of dilute (De-bye Bueche theory) and conc. Solutions (Grasselley’s entanglement theory), (Entanglement concern).

Rheology of Polymer Processing

Rheological behaviour of important thermoplastics (PE,PVC,PS,PP,nylons and PC) -applications of rheology to polymer processing - Injection moulding -Extusion: Film extrusion, sheet extrusion and blow moulding.

OUTCOMES:

At the end of the course, students will be able to;

- To understand the polymer Rheology,.
- To simulate the deformations in using various models.
- To understand fundamental flow properties and methods used to investigate the flow behaviour of polymer melts.
- To familiarize with the measurement of rheological properties.
- To apply the concept of melt rheology to specific polymer processing techniques

REFERENCES:

1. Elements of Physical Chemistry: S. Glasstone and D. Lewis, Macmillan India Press, Madras, 1995.
2. Crawford, Roy James, and Patrick J. Martin. Plastics Engineering. Butterworth-Heinemann, 2020.
3. Introduction to Polymer Viscoelasticity: J.J. Alkonis and W.J.Macknight–Wiley InterScience, New York, 1982.
4. Polymer Melt Rheology: F.N.Cogswell, George Goodwin Ltd. and P. R. Londo, John Wiley and Sons, 1981.
5. Polymer physics: Michael Rubinstein and R.H. Colby, Oxford University press ,2003
6. Polymer Physics: Ulf W. Gedde, Chapman & Hall, 1995
7. Rheology of Polymers: G.V.Vinogradov and A.YaMalkin, Mir Pub, Moscow, 1980.
8. Viscoelasticity of Polymers: D.D.Ferry III Edn. John Willey and Sons, New York, 1981.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	2	2	1	2	1	1	1	2	2	1	2
CO2	2	2	1	3	1	1	1	2	2	1	1	2
CO3	2	2	1	2	2	1	1	1	1	1	1	2
CO4	1	2	1	3	2	1	2	2	2	1	1	2
CO5	2	2	2	2	1	2	1	1	1	2	1	2
AVg.	1.4	2	1.4	2.2	1.6	1.2	1.2	1.4	1.6	1.4	1	2

1-low, 2-medium, 3-high, '-'- no correlation

PA25002	Plastics Packaging Technology	L	T	P	C
		3	0	0	3

Course Objectives:

- To study about the functions of packaging.
- To enable the students to understand the concepts testing of packaging material.
- To know about the different packaging materials like cans, bottles, flexible films etc.
- To study about the various methods of packaging to improve the shelf life of the products.
- To learn about the testing of packaging.

Plastics Materials for Packaging

Introduction to Packaging – Functions of packaging –Properties and Applications of major packaging materials viz. Polyolefins, Polystyrene, Polyvinyl Chloride, Polyesters, Polyamides (Nylons), Polycarbonate and Newer materials such as High Nitrile polymers, Polyethylene Naphthalate (PEN), Polyetherimide (PEI) and LCP.

Processing of Packaging Materials

Adhesives, heat sealing types, sealing method, extrusion blown film and cast film and sheet co extrusion, surface treatment testing and evaluation of films, flexible packaging, pouches, bulk and heavy duty bags, thermoforming, thin sheet thermoforming, blow moulding, extrusion and injection blow moulding, foams, cushioning and distribution packaging.

Bio Based Packaging Materials

Edible and bio-based food packaging materials, Edible film and coating, Polysaccharide based coatings, Lipid based coatings, Protein based coating, First, Second and Third bio-based packaging materials. Permeability of thermoplastic polymers, Multilayer films, Processing, Deteriorative reaction in foods, Enzyme reactions, Chemical reactions, Physical change, Biological change, shelf life of foods, Factors controlling shelf life.

Applications of Packaging

Aseptic packaging of foods, Sterilization of packaging materials, Packaging of microwavable foods, Active and intelligent packaging, Modified atmospheric packaging, Packaging of fresh foods, Packaging of horticultural products. Packaging of dairy products, Packaging of cereal, snack foods and confectionery, Packaging of beverages, Comparison of polymer packaging with paper, metal and glass materials, printing processes, Safety and legislative aspect of packaging.

Testing of Packaging Materials

Mechanical properties–Tensile properties, Impact properties, Tear strength, Burst strength, Stiffness, Crease or flex resistance, Co-efficient of friction, Blocking, Orientation and shrinkage. Optical Properties–Clarity, Haze and gloss Barrier Properties–Oxygen transmission, Water vapour transmission rate – Migration.

OUTCOMES:

At the end of the course, students will be able to

- CO1 Gain knowledge on the plastic packaging process and materials.
- CO2 Familiarize with the testing of plastic packaging.
- CO3 Attain knowledge of Biobased packaging
- CO4 Understand the concepts of plastics materials used in packaging industries
- CO5 Understand the machinery used in packaging field and testing equipments used for packaging products.

REFERENCES:

1. Gordon L. Robertson, Food Packaging Principles and Practice, Marcel Dekker, Inc., New York 1993.
2. Louis T. Manzione, Plastic Packaging of Microelectronic Devices, Van Nostrand Reinhold, New York, 1990
3. Plastics films -Technology and packaging applications-Kenton R, Osborn, Wilmer A Jenkins, Institute of Packaging professionals, CRC Press.2019.
4. Understanding Plastics Packaging Technology (Hanser Understanding Books) , Hanser; First edition (September 1, 1997).
5. Plastic Films in Food Packaging, 1st Edition-Materials, Technology and Applications-SinaEbnesajjad, Elsevier, December 2012,

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	1	1	2	2	1	2	2	--	1	1	1	2
CO2	2	1	2	2	1	1	1	--	1	1	1	2
CO3	2	1	2	2	1	1	1	--	1	1	1	2
CO4	2	1	2	2	1	1	1	--	1	1	1	2
CO5	2	2	2	1	1	1	1	--	2	2	2	2
AVg.	1.8	1.2	2	1.8	1	1.2	1.2	1.2	1.2	1.2	1.2	2

1-low, 2-medium, 3-high, ‘--’- no correlation

PA25003	Additives and Compounding	L	T	P	C
		3	0	0	3

Course Objectives:

- To know about various additives like Lubricants, Fillers, Fibres, flame retardants, colourants, anti-oxidants, UV-stabilizers, plasticizers, anti-blocking agents, Nucleating agents, Flow promoters, Anti static agents etc.
- To understand the functions of each of these additives, technical requirements, types & mechanism, and their effective evaluation are dealt with in this subject.
- To select suitable plastics material compounding and mixing techniques like two roll milling, internal blender, single / twin screw extruder, etc.
- To understand the mechanism of degradation of polymers and stabilizing additives.
- To know the various compounding methodologies for plastics materials and learn the maintenance of compounding machinery.

Introduction to Additives

Introduction-Chemistry and Mechanism- Selection Criteria-Selection of Polymers and Compounding ingredients-General objectives-possibilities and limitations of mixing and compounding. General effect on Properties-Evaluation and functions of additives.

Additives

Fillers and Reinforcement– Antioxidants-Thermal Stabilisers, Ultraviolet stabilizer– Impact Modifiers/ toughening agents. Colourants-Fire retardants-Coupling agents-blowingagents Plasticizers- Antistatic agents-Anti blocking agents-Slip and antislip agents-processing aids - Lubricants- mould releasing agents Additives for recycling.

Compounding Equipments

Methods of incorporation of additives into polymer materials. Mixing and mixing equipment's. Principles- Operating characteristics- Machine construction-Specifications -Process control systems and working details of Batch mixers and continuous mixers–High speed mixer -Two roll mill-Banbury Mixer–Ribbon blender – Planetary mixers-Single Screw extruder-Twin Screw extruder.

Formulations and Techniques

Compounding of PVC, Rubber, Polyolefins, Biodegradable plastics, Engineering plastics. Alloys and blend production - color, filler, reinforcement compounding. Reactive extrusion.

End Use Market for Plastics

Case studies on material suitability (e.g., Plastic Gears, Feeding Bottle, Bowels for microwave ovens). Survey and uses of plastics with reasons for their importance in major industries like Agriculture, Packaging, Building, Transport, Electrical, Electronics and Telecommunications, Medical and Furniture.

Outcomes:**At the end of the course, students will be able to**

CO1 Understand the fundamental of additives

CO2 Select the suitable additive as per requirement.

CO3 Identify the suitable compounding techniques to make different grades of Plastics compounds

CO4 Formulate the compound to solve the environmental related problems.

CO5 Learn about various applications of Plastics by using different additives..

References:

1. Muralisrinivasan, Natamai S. Introduction to Polymer Compounding, Volume 2: Machinery and Technology. , 2015.

2. Murphy, John. Additives for Plastics Handbook. Elsevier Advanced Technology, 2003.

3. Enrique Saldívar-Guerra and Eduardo Vivaldo-Lima, Polymer Additives, 2013

4. Zweifel, H., Maier, R., Schiller, M. Plastics Additives Handbook, 2009

5. Plastics Additives- Geoffrey Pritchard, Springer-1998.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	1	2	1	1	1	1	--	1	1	1	2
CO2	2	2	1	1	1	1	2	--	1	1	2	2
CO3	2	1	1	1	1	1	1	--	1	1	2	2
CO4	2	2	1	1	1	1	2	--	1	1	2	2
CO5	2	1	2	2	1	1	1	--	1	1	1	2
AVg.	2	1.4	1.4	1.2	1	1	1.4	--	1	1	1.6	2

1-low, 2-medium, 3-high, '-'- no correlation

PA25004	Thermodynamics of Polymer Synthesis	L	T	P	C
		3	0	0	3

Course Objectives:

- Introduce the fundamental concepts of thermodynamics relevant to polymer systems.
- Develop understanding of free energy, entropy, and enthalpy changes during polymerization.
- Apply thermodynamic principles to chain-growth and step-growth polymerization mechanisms.
- Analyze equilibrium and phase behavior in polymer solutions and melts.
- Interpret thermodynamic data to control polymer synthesis and processing outcomes.

Thermodynamic Principles and Applications to Polymers

First and second laws of thermodynamics, Thermodynamic state functions: Enthalpy, entropy, Gibbs free energy, Helmholtz energy, Criteria of spontaneity and equilibrium, Chemical potential and its significance in polymer systems, Thermodynamics of mixing – ideal and non-ideal systems, Heat capacity and phase transitions in polymers

Thermodynamics of Polymerization Reactions

General thermodynamic considerations for polymerization, Free energy and equilibrium constants in polymer formation, Chain-growth vs. step-growth polymerization: Thermodynamic differences, Entropy-driven and enthalpy-driven polymerizations, Ceiling temperature and floor temperature concepts; Examples: Polycondensation, free radical, ionic and coordination polymerizations

Equilibrium in Polymerization Systems

Reversible polymerization and dynamic equilibrium, Degree of polymerization and its relation to equilibrium conversion, Effect of temperature, pressure, and monomer structure on equilibrium, Thermodynamic control vs. kinetic control in polymer synthesis, Catalysis and its thermodynamic implications in polymerization

Phase Behavior in Polymer Systems

Phase equilibria and phase diagrams for polymer solutions, Polymer–solvent interactions: Flory–Huggins theory, Thermodynamics of mixing and demixing, LCST and UCST behavior, Crystallization and melting thermodynamics of polymers, Phase separation in blends and copolymers

Thermodynamic Tools in Synthesis and Characterization

Thermodynamic modeling in polymer synthesis, Use of calorimetry (DSC, TGA) for thermodynamic property evaluation, Thermodynamic parameters from spectroscopic and titrimetric data, Applications: Designing energy-efficient polymerization processes, Case studies: Synthesis of high-performance polymers, green polymerization processes, Recent trends in thermodynamic control for sustainable polymer synthesis

OUTCOMES:

At the end of the course, students will be able to

CO1 Understand core thermodynamic concepts and apply them to polymer systems.

CO2 Analyze thermodynamic feasibility and reversibility of polymerization reactions.

CO3 Predict polymerization equilibrium and conversion behavior under varying conditions.

CO4 Interpret phase behavior in polymer–solvent and polymer–polymer systems using thermodynamics.

CO5 Utilize thermodynamic tools and models for optimizing polymer synthesis and processing.

REFERENCES:

1.P. J. Flory, Principles of Polymer Chemistry, Cornell University Press

2.George Odian, Principles of Polymerization, Wiley

3.R. T. Sanderson, Chemical Bonds and Bond Energy, Academic Press

4.M. Rubinstein & R. H. Colby, Polymer Physics, Oxford University Press

5.Paul C. Painter & Michael M. Coleman, Fundamentals of Polymer Science, CRC Press

6.Kalyan Sehanobish, Polymer Thermodynamics: Phase Behavior and Properties, Wiley
(Recent Reference)

7.Recent journal articles from Polymer, Macromolecules, and Journal of Polymer Science

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	2	1	2	2	0	1	0	1	1	0	2
CO2	3	3	2	3	2	1	1	0	1	1	0	2
CO3	3	3	2	3	3	0	2	0	1	1	0	2
CO4	3	2	2	3	3	1	2	0	1	1	0	2
CO5	3	3	3	3	3	1	3	1	2	2	1	3
AVg.	3	2.6	2	2.8	2.6	0.6	1.8	0.2	1.2	1.2	0.2	2.2

1-low, 2-medium, 3-high, ‘-‘- no correlation

PA25005	Polymer Reaction Engineering	L	T	P	C
		3	0	0	3

Course Objectives:

- To understand the fundamental principles of polymerization reaction engineering.
- To analyze different types of polymerization processes and their reactor design.
- To apply kinetic models to predict polymer properties and reactor performance.
- To evaluate the influence of process parameters on polymer molecular weight, composition, and structure.

Fundamentals of Polymerization Kinetics

Overview of polymerization mechanisms: Step-growth, chain-growth, coordination, ring-opening, Kinetics of free radical, cationic, anionic, and coordination polymerizations, Molecular weight distribution and average molecular weights, Effect of temperature, initiator, and monomer concentration, Thermodynamics of polymerization reactions

Polymerization Reactor Types and Design

Batch, semi-batch, continuous stirred tank reactor (CSTR), plug flow reactor (PFR), Tubular and loop reactors for high-pressure polymerization, Design equations for ideal reactors applied to polymer systems, Heat and mass transfer in polymer reactors, Safety considerations in reactor design

Bulk, Solution, Suspension, and Emulsion Polymerization

Characteristics and comparative analysis of each process, Kinetics and mechanism of suspension and emulsion polymerizations, Reactor modeling and industrial applications, Role of surfactants and stabilizers, Reactor instabilities and process control

Copolymerization and Advanced Kinetics

Copolymerization mechanisms: random, alternating, block, and graft copolymers, Reactivity ratios and composition control (Mayo-Lewis equation), Kinetics of copolymerization reactions, Advanced kinetic modeling and simulation tools, Living/controlled radical polymerization (ATRP, RAFT)

Industrial Case Studies and Process Optimization

Polymerization processes for polyethylene, polypropylene, polystyrene, PVC, PET, and nylons, Reactor configurations used in industry, Quality control, process optimization, and troubleshooting, Role of software tools (e.g., Aspen Plus, POLYMATH) in process simulation, Sustainability and green polymerization techniques

OUTCOMES:

At the end of the course, students will be able to;

CO1: Describe and analyze various polymerization mechanisms and kinetics.

CO2: Design appropriate reactors for different polymerization processes.

CO3: Apply kinetic models for molecular weight prediction and control.

CO4: Evaluate industrial polymerization processes with case studies.

CO5: Use simulation tools for polymer process design and optimization.

REFERENCES:

1. Polymer Process Engineering – R. Grulke
2. Polymer Chemistry – Malcolm P. Stevens
3. Chemical Reaction Engineering – H. Scott Fogler (Selected Chapters)
4. Modeling of Polymerization Reactions – C.A. Finch

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3	2	2	1	0	1	0	1	1	0	2
CO2	3	3	3	3	2	1	1	0	2	1	1	2
CO3	3	3	2	3	3	0	1	0	1	1	0	2
CO4	3	2	2	3	2	1	2	1	2	2	1	2
CO5	3	2	3	3	3	1	3	1	2	2	2	3
AVg.	3	2.6	2.4	2.8	2.2	0.6	1.6	0.4	1.6	1.4	0.8	2.2

1-low, 2-medium, 3-high, ‘-‘- no correlation

PA25006	Polymer Nanocomposites	L	T	P	C
		3	0	0	3

Course Objectives:

- To understand the basics and chemistry of nano size materials. and their
- Explain the different nano material synthesis, characterization.
- To study different manufacturing techniques of dispersion of nano particles such as sonication, high shear mixing, centrifugal mixer, twin-screw extrusion.
- To study different manufacturing techniques to produce real-life component.
- To learn about the flow behavior of nanofiller/polymer systems and their processing and applications.

Introduction To Nanomaterials

Nanomaterials, Uniqueness of nanomaterials, classification of nanomaterials based on dimension (0D,1D, 2D, 3D), different types of nanomaterials: carbon based materials (carbon nanotubes, Carbon Nanofibers, fullerenes), metal based materials (quantum dots, nanogold, nanosilver, nanoaluminium oxide, nano titanium oxide) dendrimers, inorganic nanomaterials (Montmorillonitenanoclays,, POSS [polyhedral oligomeric silsesquioxane], Nanosilica) -properties. Polymer Matrices: Thermoplastic based nanocomposites, Thermoset based nanocomposites, Elastomer based nanocomposites, ceramic matrix nanocomposites, metal matrix nanocomposites.

Synthesis of Nanomaterials

Preparation – top down and bottom up approach - C60, Carbon nanofibers, Carbon Nanotubes, Graphene and Cellulose nanofibers.- functionalization of nanomaterials, Characteristics of Polymer nanostructures materials. Processing of nanoparticles, binding mechanisms in nanoparticles, dispersion of nanoparticles, and stabilization of nanoparticles.

Preparation of Polymer Nanocomposites

Processing and fabrication of polymer nanocomposites, Melt blending, solvent casting, In-situ polymerization, solution polymerization, template synthesis, high shear mixing. Homogeneous/heterogeneous nucleation, plasma promoted nucleation. Polymer nanocomposites with structural, gas barrier and flame retardant properties, carbon fibre reinforced polymer nanocomposites, elastomer and thermoplastic elastomer nanocomposites.

Characterization of Polymer Nanocomposites

X-ray diffraction, Small angle X-ray Scattering, Optical Microscopy, Scanning Electron Microscopy (SEM), Scanning Probe Microscopy (SPM), TEM and EDAX analysis, X-ray photoelectron spectroscope (XPS), Scanning Tunneling Microscopy (STM), Atomic force Microscopy (AFM). Thermal properties of polymer nanocomposites using DSC,TGA, TMA, DTMA, Mechanical and Electrical properties of polymer nanocomposites.

Application of Polymer Nanocomposites

High temperature applications: flame retardant nanocomposite applications, Thermoset nanocomposites for rocket ablative materials, nanomodified carbon-carbon composites for semiconductor and aerospace applications, Thermoplastic Elastomer nanocomposites for propulsion systems. Biomedical implants, tissue engineering scaffolds, EMI shielding applications – energy conversion and storage.

Outcomes:

At the end of the course, students will be able to

- CO1 Have a clear understanding of nanocomposites.
- CO2 Gain knowledge about different structures and properties of nanocomposites
- CO3 Have an idea about preparation technologies and applications of nanocomposites.
- CO4 Know different characterization and testing techniques and interpretation of results
- CO5 Demonstrate the importance of different nano materials used to make polymer nanocomposites for specific applications

References:

1. Pradeep, T., 2007. Nano: the essentials: understanding nanoscience and nanotechnology. McGraw-Hill Education.
2. Ebrahimi, F. ed., 2012. Nanocomposites: new trends and developments. BoD–Books on Demand.
3. Gogotsi, Y., 2006. Nanomaterials handbook. CRC press.
4. Tsakalakos, L., 2010. Nanotechnology for photovoltaics. CRC press.
5. Properties and Applications of Polymer Nanocomposites-Clay and Carbon Based Polymer Nanocomposites- Kumar Tripathy, Deba, Prasad Sahoo, Bibhu (Eds.), Springer 2017.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	1	2	2	1	1	1	--	1	1	1	2
CO2	2	1	1	2	1	1	1	--	1	1	1	2
CO3	2	1	1	2	1	1	1	--	1	1	2	2
CO4	2	1	1	2	1	1	1	--	1	1	2	2
CO5	2	2	2	2	1	2	1	--	1	1	2	2
AVg.	2	1.2	1.4	2	1	1.2	1	--	1	1	1.6	2

1-low, 2-medium, 3-high, '--'- no correlation

PA25007	Rubber Technology	L	T	P	C
		3	0	0	3

Course Objectives:

- To provide the students with basic knowledge on the natural rubber and various synthetic rubbers and their processing.
- To enable the students to understand the need of various additives and compounding of rubbers and vulcanization.
- To acquire knowledge about various Thermoplastic elastomers and its applications
- To enable the students to learn the basic processing of rubber products like hose conveyor belts etc.
- To learn the basic processing of latex products like latex gloves, latex threads etc

Natural Rubber

Various sources of natural rubber, Latex-physical nature and chemical composition, biosynthetic pathway of natural rubber production, Tapping latex, Preservation of latex, Processing of Latex (Centrifuging, creaming), Dry rubber production (Smoked sheet, air dried sheet, ISNR) Grading of rubbers - Modified forms of natural rubber.

Synthetic Elastomers

Manufacturing, structure, properties, compounding, curing and applications: Polyisoprene, Polybutadiene, SBR, EPDM, Butyl rubber, Neoprene, Nitrile rubber, Silicone rubber, Fluoroelastomer, Polysulphide rubber, polyurethane rubber, Acrylic rubber, EVA,

Thermoplastic Elastomers

Basic structure, Manufacture, Morphology, Commercial grades and Applications–Thermoplastic styrene block copolymers, Polyester thermoplastic elastomers, polyamide thermoplastic elastomer, thermoplastic Polyurethanes.

Compounding of Rubbers

Principles of rubber compounding. Compounding to meet vulcanisate properties. Introduction to dry rubber and latex compounding ingredients, Sulphur and non-sulphur vulcanization, vulcanization systems - accelerators, activators, promoters, antioxidants, antiozonants, processing aids, extenders, fillers and effect of fillers, Blowing agents, Equipments used in rubber compounding, rubber Processability tests.

Rubber Product Manufacturing

Manufacturing of Dry rubber Products: Tyres, Belting, Hoses, Footwear, Rubber metal bonded items, sports goods, cellular rubber. Manufacturing of Latex Products: Latex Gloves, Latex threads, Latex foam rubber, latex adhesives

OUTCOMES:**At the end of the course, students will be able to**

- Acquire knowledge of natural rubber and other synthetic elastomers.
- Understand the basics of rubber compounding and vulcanization
- Comprehend various Thermoplastic elastomers and its applications
- Acquire knowledge about the rubber products manufacturing
- Understand the basics of latex products manufacturing

REFERENCES:

1. Blow, C M. Rubber Technology and Manufacture. London u.a: Butterworths, 1987.
2. Morton, Maurice. Rubber Technology. Dordrecht: Springer Netherlands, 1999.
3. Natural rubber agro management and crop processing [2000] George, P.J. (ed.); Rubber Research Institute, Kottayam, India
4. Handbook of Elastomers - New Developments & Technology, Anil .K. Bhowmic, Howard L. Stephens (Edt), Marcel Decker Inc. New York 1988.
5. Blackley, D. C. Polymer latices: science and technology. 1997.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	2	2	1	1	1	1	---	---	2	---	3
CO2	2	3	2	3	2	2	2	1	---	2	1	3
CO3	2	3	1	2	1	1	1	---	---	2	1	3
CO4	3	2	2	3	2	2	2	1	1	1	1	3
CO5	3	2	2	3	2	2	2	1	1	1	1	3
AVg.	.4	2.4	1.8	2.4	1.6	1.6	1.6	0.6	0.4	1.6	0.8	3

1-low, 2-medium, 3-high, ‘-’- no correlation

PA25008	Science and Technology of Advanced Coatings	L	T	P	C
		3	0	0	3

Course Objectives:

- To provide theoretical basis of the process of coatings and characteristics of coatings.
- To make the students aware of the different essential components of paints and coatings.
- To introduce to the different kinds of natural and synthetic resins and their applications.
- To understand various preparation technics and characterization of surface coatings.
- To make the students familiar with the basic and recent advancements in coating technologies.

Introduction to Coatings

Concepts & terminologies, Interfacial tension, Free energy changes, wetting, dispersion, adhesion theories – Mechanical theory, adsorption theory, electrostatic theory, diffusion theory, weak-boundary layer theory. Advantages and disadvantages of Adhesive bonding.

Concept of Dyes & Pigments

Theory of Color; Important Physico-Chemical Characteristics of Pigments, Analysis & testing of pigments, Inorganic Pigments; Chemistry, Properties and Applications of carbon black, metallic and metal oxide pigments, Organic Pigments, High Performance Pigments & Special Effect Pigments (IR Reflective, anticorrosive, thermo chromic, pearlescent), driers, additives, solvents, plasticizers.

Chemistry and Technology of Resins

Natural resins like rosin, shellac, Bitumen, Asphalts and Coal tar–Their modifications & uses, Synthetic resins viz. Alkyds, Polyester, Phenolics, Amino, Acrylic & Vinyl resins: Raw materials for these resins, Chemistry of synthesis of these resins, processing techniques, properties & applications of these resins for surface coatings.

Manufacture of Paints & Powder Coatings

Components of paints – paint preparation and formulations- Different types of paints –mechanism of paint film formation - oil based distempers and paints - water borne paints other stiff paints, putties. Powder Coatings, dry distempers, cement paints, Marking and labeling of packaged products, Solvent emission, recovery and disposal, environmental, health and safety issues.

Various Surface Coatings

Preparation and characteristics of Coil Coating, UV cured coating, Waterborne PU Coatings, Non Stick coatings, Smart Coatings, super hydrophobic coatings, electro wetting, Hygienic Coatings, protective coatings, marine coatings, automotive and aerospace coatings, Study of important characteristics of surface coating : Rheological properties, Optical Properties, Adhesion and Mechanical properties, Corrosion and Chemical resisting properties, Film thickness, Liquid Paint analysis according to ASTM, BIS and BS Standards, Characterization of Varnishes according to ASTM, BIS and BSS Standards.

OUTCOMES:

At the end of the course, students will be able to

- Appreciate the economical and societal importance of paints and coatings.
- Familiarize with the components used in paints and will be able to predict the properties with varying compositions of the components.
- Learn about different kinds of natural and synthetic resins and its applications
- Gain knowledge about the manufacturing techniques for paints and coatings and the advancements in coating technologies.
- Understand different characteristics of surface coatings

REFERENCES:

1. Arthur A. Tracton (Ed.), Coatings Technology Handbook, CRC press, 2006.
2. Werner Freitag, Dieter Stoye (ed.), Paints, Coatings and Solvents, 2nd edition, Wiley-VCH, 2008.
3. Güngör Gündüz, Chemistry, Materials, and Properties of Surface Coatings: Traditional and evolving technologies. DEStech Publications, Inc., 2016.
4. Philip A. Schweitzer, P.E., Paint and Coatings: Applications and Corrosion Resistance, Taylor& francis group, 2005.
5. Swaraj Paul, Surface coatings: Science & Technology, Wiley, 1996.
6. R Lambourne, T A Strivens (Ed.) Paint and Surface Coatings: Theory and Practice, 2nd Edition, Woodhead publishing ltd, 1999.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	2	2	2	3	2	2	1	1	2	---	3
CO2	2	3	2	1	1	2	2	1	1	2	1	3
CO3	2	2	2	1	1	2	2	1	---	1	---	3
CO4	3	3	3	3	3	1	1	1	1	2	1	3
CO5	3	3	3	3	2	1	1	2	---	2	---	2
AVg.	2.4	2.6	2.4	2	2	1.6	1.6	1.2	0.6	1.8	0.4	2.8

1-low, 2-medium, 3-high, '---' no correlation

PA25009	CAD/CAM/CAE Applications In Mould / Die Design	L	T	P	C
		3	0	0	3

Course Objectives:

- To enable the students to provide an overview of how computers are being used in Design of Plastic Component,
- Manufacturing of Tool and Analysis of mould flow.
- To study about different NC machines and its working principle
- To develop the knowledge of computer aided manufacturing.
- To understand various CAM software packages

Computer Graphics

Over view of graphic systems and softwares – Output primitives - Points, lines, curves - Analytical Curves- circle and conics- Synthetic Curves Bezier and B-spline curves – Geometric Transformations (2-D and 3D), Homogeneous Coordinates- Windowing, Viewing and clipping transformation Hidden Line and Surface Removal Algorithms. Graphics Standards: Standards for computer graphics-Open Graphics Library (OpenGL) - Data exchange standards IGES, STEP, STL - Communication standards.

Computer Aided Design (CAD)

Introduction to CAD – Geometric modelling techniques – wire frame modelling, Surface modeling: Bezier and B-Spline surface- Bi- linear surface- Boundary Representation Sweep representation. Solid modeling: Primitives- Boolean set operations- Boundary Representation– Constructive Solid Geometry, User interface for solid modeling. Concepts of Assembly modelling.

Computer Aided Manufacturing (CAM)

Introduction to CAM – CNC and DNC - Controllers and CAM softwares - CNC machines, configuration of CNC machines – types of CNC machines - G Codes & M Codes – Part programming for CNC Turning Centre and CNC Machining Centre. Tool path generation – APT programme.

Finite Element Analysis (FEA)

Introduction to Finite Element Analysis (FEA), Types of analysis - Procedure for finite element analysis -Finite Element Analysis packages, and its application; Analysis of One Dimensional Bar elements- Derivation of Shape function and Stiffness matrix and force vector – Assembly of matrix – Field problems.

Mold Flow Analysis

Introduction to Moldflow analysis- Design principles- Product design and Moldflow - Sequence of analysis- Moldflow concepts- Meshes used in Moldflow analysis- Types, Requirement- Geometry Creation- Importing Geometry – wall thickness analysis - fill analysis, cooling analysis, Shrinkage and Warpage analysis – Analysis of Part defects - optimization of design.

OUTCOMES:**At the end of the course, students will be able to**

- Acquire knowledge of computer-aided design and manufacturing of moulds for plastics processing.
- Comprehend various CNC machining processes used in Mould manufacturing.
- Gain knowledge of computer-aided manufacturing
- Attain knowledge of various CAM software packages
- Learn about various types of analysis involved in Mould flow

REFERENCES:

1. Chris McMahon and Jimmie Browne "CAD/CAM Principles", "Practice and Manufacturing management " Second Edition, Pearson Education, 1999.
2. Donald Hearn and M. Pauline Baker "Computer Graphics". Prentice Hall, Inc, 1992.
3. Ibrahim Zeid "Mastering CAD CAM" Tata McGraw-Hill Publishing Co.2007.
4. Jay Shoemaker "Moldflow Design Guide: A Resource for Plastics Engineers", Volume 10, Hanser, 2006.
5. Radhakrishnan, P. & Subramanyan. S "CAD/CAM/CIM", (Wiley Eastern Ltd., 1994).
6. Rao P N, Tiwari N K, Kundra T, "Computer Aided Manufacturing" Tata McGraw Hill 2014.
7. Seshu. P, "Text book of Finite Element Analysis" PHI learning Private limited, 2008.
8. Jay Shoemaker "Moldflow Design Guide, A resource for Plastic Engineers" Hanser Publications.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	3	3	3	3	1	2	1	1	2	1	3
CO2	2	2	2	2	3	1	1	1	1	2	---	3
CO3	2	2	2	2	1	1	1	1	---	2	---	3
CO4	1	2	3	3	3	1	1	1	---	2	1	3
CO5	1	3	3	3	3	1	2	1	---	2	1	3
AVg.	1.6	2.4	2.6	2.6	2.6	1	1.4	1	0.4	2	0.6	3

1-low, 2-medium, 3-high, '---' no correlation

PA25010	Reverse Engineering and Rapid Prototyping	L	T	P	C
		3	0	0	3

Course Objectives:

- To Understand basic engineering systems.
- To learn the students to apply the concepts of reverse engineering
- To learn about the Reverse Engineering Process and data analysis
- To learn about acceptance legality of reverse engineering.
- To Understand the terminologies related to re-engineering, forward engineering, and reverse engineering.

Introduction

Historical Background, Industrial Evolution- Reinvention of Engineering Marvels from Nature- Reverse Engineering in Modern Industries-Reverse Engineering vs. Machine Design-Motivation and Challenge- Analysis and Verification-Accreditation-Part Criticality-Applications of Reverse Engineering.

Geometrical Form

Surface and Solid Model Reconstruction-Scanning Instruments and Technology-Principles of Imaging- Cross-Sectional Scanning-Digital Data-Computational Graphics and Modeling-Data Refinement and Exchangeability-Dimensional Measurement-Case Studies-Part Tolerance-Prototyping-Additive Prototyping Technologies-Subtractive Prototyping Processes-Rapid Injection Molding-Steps of Geometric Modeling

Material Characteristics and Analysis

Alloy Structure Equivalency-Phase Formation and Identification-Mechanical Strength-Hardness Part Durability and Life Limitation Part Failure Analysis-Fatigue-Creep and Stress Rupture-Environmentally Induced Failure

Material Identification & Data Process Analysis

Material Specification-Composition-Determination-Microstructure Analysis-Manufacturing Process Verification
 Data Process and Analysis
 Statistical Analysis-Data Analysis-Reliability and the Theory of Interference-Weibull Analysis-Data Conformity and Acceptance,-Data Report

Part Performance and Acceptance Legality

Performance Criteria-Methodology of Performance Evaluation-System Compatibility Acceptance and Legality
 Legality of Reverse Engineering-Legal Definition of Reverse Engineering-Legal Precedents on Reverse Engineering-Patent-Copyrights-Copyright Codes-Legal Precedents on Copyrights-Trade Secret-Case Study of Reverse Engineering Trade Secret-Third-Party Materials

Outcomes:**At the end of the course, students will be able to**

- Understand the reverse engineering methodologies and apply for product development
- Determine the functional requirements and working principles of reverse engineering
- Understand the principles behind the design of the product, ways to redesign and improve the performance of the system
- Understand the legality of reverse engineering
- Gain expertise in depth analysis of the products and extraction of real time data

References:

1. Wego Wang, "Reverse Engineering: Technology of Reinvention", ISBN-13: 978-1439806302, CRC Press.
2. Kevin Otto , "Product Design : Techniques in Reverse Engineering and New Product Development", ISBN-13: 9788177588217, Dorling Kindersley
3. Robert Messler, "Reverse Engineering: Mechanisms, Structures, Systems & Materials", McGraw Hill Education, ISBN: 9780071825160.
4. Raja, Vinesh, Fernandes, Kiran J. , "Reverse Engineering An Industrial Perspective" ISBN978- 1-84628-856-2, Springer

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	2	3	-	3	-	-	-	-	-	-	1
CO2	3	2	3	3	3	-	-	-	1	-	-	1
CO3	3	2	3	3	3	-	-	-	-	-	-	1
CO4	3	3	3	3	3	-	-	-	-	-	-	3
CO5	3	3	3	3	3	-	-	-	-	-	-	1
AVg.	3	2.4	3	3	3	-	-	-	1	-	-	1.4

1-low, 2-medium, 3-high, '-'- no correlation

PA25011	Advanced Plastics Processing	L	T	P	C
		3	0	0	3

Course Objectives:

- To understand the specialized injection moulding process viz., Co-injection moulding, Two colour injection moulding process, Gas assisted Injection Moulding, Reaction Injection Moulding, Liquid injection moulding, structural foam moulding and to understand the effect of shrinkage, merit & demerits of the process.
- To understand advanced blow moulding process.
- To expertise the student with sufficient background for selection of processing techniques.
- To understand advanced Extrusion process
- To gain knowledge on the applications of advanced injection moulding & Extrusion processes.

Advanced Injection Molding Techniques

Injection molding of high-performance polymers (PEEK, LCP, PPS, PEI), Gas-assisted and water-assisted injection molding, Variotherm (Rapid Heat Cycle) molding, Co-injection and multi-material molding, Micro-injection molding for precision components, Injection molding of fiber-reinforced and nanocomposites, Defect diagnostics and advanced mold design principles, Process simulation using Autodesk Moldflow and Moldex3D

High-End Extrusion and Hybrid Extrusion Techniques

Rheology of polymers in extrusion – shear thinning, die swell, melt fracture, Advanced screw and die designs for multilayer co-extrusion, Reactive extrusion for in-situ compatibilization and grafting, Profile and pipe extrusion with foaming and reinforcement, Single-screw vs. twin-screw extruders: Process modelling and throughput analysis, Supercritical fluid-assisted extrusion, Inline monitoring: torque, pressure, residence time distribution (RTD), Computational fluid dynamics (CFD) in extrusion modelling

Advanced Thermoforming and Blow Molding Processes

Thermoforming of advanced composites and multilayer structures, Plug-assist and vacuum-pressure hybrid thermoforming, Infrared heating control systems and cycle optimization, 3D blow molding and stretch blow molding of engineering plastics, multi-layer parison programming in extrusion blow molding, Simulation of parison behaviour and wall thickness distribution, Heat transfer and crystallization control during blow molding

Emerging & Unconventional Processing Techniques

Microcellular foaming (MuCell) and SCF foaming, Additive manufacturing of plastics: FDM, SLA, SLS – Process–structure correlation, Ultrasonic and microwave-assisted polymer processing, Electrospinning of polymeric fibers and membranes, Solid-state shear pulverization and cryogenic grinding, Powder bed fusion of thermoplastics, High-speed rotational molding and centrifugal casting, Industrial 3D printing with filled/reinforced polymers

Process Integration, Simulation & Smart Manufacturing

Integrated manufacturing cells: Automation, robotics in plastics processing, Advanced sensors for real-time data logging and control (IoT for plastics), Digital twin models for predictive maintenance, AI and machine learning in defect prediction and quality control, Lifecycle analysis (LCA) and energy modeling of processing lines, Circular processing: Recycling-friendly design, closed-loop reprocessing, Industry 4.0 applications in plastics: smart injection presses, MES, SCADA systems, Case studies on advanced industrial applications (automotive, aerospace, biomedical, packaging)

Outcomes:**At the end of the course, students will be able to**

- Select the advanced processing technique as per the requirement.
- Acquire knowledge of processing plastic materials by advanced injection moulding processes.
- Apply the knowledge of processing plastic materials by advanced extrusion moulding processes.
- Acquire knowledge of advanced processing techniques, end product application & its importance with industrial relevance.
- Evaluate the applications of various processing techniques.

References:

1. Charles A Harper Handbook of plastics Processes.
2. Crawford, R.J., Plastics Engineering, 3rd Ed., Elsevier India Pvt. Ltd., New Delhi 2006.
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4. Fisher, E.G., Extrusion of Plastics, 2nd Ed., Little Books Pvt. Ltd., London, 1964.
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6. Hensen, Freidhelm, Plastics Extrusion Technology, 2nd Ed., Hansen Publishers, Munich 1997.
7. James F. Stenvension, Innovation in Polymer Processing Moulding, Hanser Publishers, New York, 1996.
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12. Rubin, Irvin I., Injection Molding Theory & Practice, Johnwiley & sons Inc.,US, 1972.
13. Schar, J., Press blowing option for tough to blow parts, SPE ANTEC April'87.
14. Strong, Brent A., Plastics – Materials & Processing, 3rd Ed., Pearson Education Ltd., Newyork, 2006.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	1	1	1	3	1	-	-	-	-	-	-
CO2	3	1	1	1	3	1	-	-	-	-	-	-
CO3	3	1	1	1	3	1	-	-	-	-	-	-
CO4	3	1	1	1	3	1	-	-	-	-	-	3
CO5	3	1	1	1	3	1	-	-	-	-	-	3
AVg.	3	1	1	1	3	1	-	-	-	-	-	3

1-low, 2-medium, 3-high, '-'- no correlation

PA25012	Fracture Mechanisms & Analysis In Polymers	L	T	P	C
		3	0	0	3

Course Objectives:

- To impart knowledge on mechanics of cracked components of different modes by which these components fail under static load conditions.
- To identify the role of deformation of materials in fracture.
- To understand about crack growth curve
- To evaluate various crack arrest mechanisms.
- To evaluate various applications of fracture mechanics

Elements of Solid Mechanics

The geometry of stress and strain, elastic deformation, plastic and elasto-plastic deformation – limit analysis–Airy’s function – field equation for stress intensity factor.

Stationary Crack Under Static Loading

Two dimensional elastic fields–Analytical solutions yielding near a crack front–Irwin’s approximation - plastic zone size–Dugdale model–determination of J-integral and its relation to crack opening displacement.

Energy Balance and Crack Growth

Griffith analysis–stable and unstable crack growth–Dynamic energy balance–crack arrest mechanism– K1c test methods - R curves - determination of collapse load.

Fatigue Crack Growth Curve

Empirical relation describing crack growth law–life calculations for a given load amplitude – effects of changing the load spectrum--rain flow method– external factors affecting the K1c values.- leak before break analysis.

Applications of Fracture Mechanics

Crack Initiation under large scale yielding – thickness as a design parameter – mixed mode fractures - crack instability in thermal and residual stress fields - numerical methods.

OUTCOMES:

At the end of the course, students will be able to

- Familiarize with the design of components that contain cracks under static load conditions
- Understand cracking under various loading conditions.
- Acquire knowledge about energy balance in crack growth.
- Conduct various analysis on crack growth
- Acquire knowledge of applications of fracture mechanics

References:

1. David Broek, "Elementary Engineering Fracture Mechanics ", Fifth off and Noerdhoff International Publisher, 1978.
2. John M. Barson and Stanely T. Rolfe Fatigue and fracture control in structures Prentice hall Inc. Englewood cliffs. 1977.
3. Kare Hellan, "Introduction of Fracture Mechanics", McGraw-Hill Book Company, 1985.
4. Preshant Kumar, "Elements of Fracture Mechanics", Wheeler Publishing, 1999.
5. Tribikram Kundu, "Fundamentals of Fracture Mechanics", Ane Books Pvt. Ltd. New Delhi/ CRC Press, 1st Indian Reprint, 2012.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	2	3	3	2	1	-	-	-	-	-	3
CO2	3	2	3	3	2	1	-	-	-	-	-	3
CO3	3	2	3	3	2	1	-	-	-	-	-	3
CO4	3	2	3	3	2	1	-	-	-	-	-	3
CO5	3	2	3	3	2	1	-	-	-	-	-	3
AVg.	3	2	3	3	2	1	-	-	-	-	-	3

1-low, 2-medium, 3-high, '-'- no correlation

PA25013	Biomedical Plastics	L	T	P	C
		3	0	0	3

Course Objectives:

- To learn about various types of biopolymers produced from starch and microbes.
- To understand various natural and synthetic polymers used for biomedical applications.
- To learn about the plastics that are used as implants in cardiovascular, dental, ophthalmology, and other artificial organs.
- To be familiarized with evaluation methods of biomedical polymers and their interaction with human system in in-vivo and in-vitro environments.
- To understand various natural and synthetic polymers used for biomedical applications and their compatibility with biological system

Materials Used in Medical Applications

Introduction - Silicone Biomaterials: History and Chemistry, Medical Fibers and Biotextiles, Hydrogels, Bioresorbable and Bioerodible Materials, Natural Materials, Metals, Ceramics, Glasses, and Glass-Ceramics, Composites, Textured and Porous Materials, Surface-Immobilized Biomolecules.

Biological Testing of Biomaterials

Introduction to Testing of Biomaterials, In Vitro Assessment of Tissue Compatibility, In Vivo Assessment of Tissue Compatibility, Evaluation of Blood-Material Interactions, Microscopy for Biomaterials Science

Degradation of Materials in Biological Environment

Introduction: Degradation of Materials in the Biological Environment, Chemical and Biochemical Degradation of Polymers, Degradative Effects of the Biological Environment on Metals and Ceramics, Pathological Calcification of Biomaterials.

Application of Materials in Medicine, Biology, and Artificial Organs

Introduction, Nonthrombogenic Treatments and Strategies, Cardiovascular Medical Devices, Implantable Cardiac Assist Devices, Extracorporeal Artificial Organs, Orthopedic Applications, Dental Implantation, Adhesives and Sealants, Ophthalmological Applications, Intraocular Lens Implants, Burn Dressings and Skin Substitutes, Sutures, Drug Delivery Systems, Cochlear Prostheses, Biomedical Sensors and Biosensors, Overview of Tissue Engineering, Synthetic Bioresorbable Polymer Scaffolds.

Practical Aspects of Biomaterials

Introduction, Sterilization of Implants and Devices, Implant and Device Failure, Correlation, Surfaces and Biomaterials Science, Development and Regulation of Medical Products Using Biomaterials, Ethical Issues in the Development of New Biomaterials, Legal Aspects of Biomaterials.

OUTCOMES:

At the end of the course, students will be able to

- Understand the production of bio-plastics from bio-based feed stocks.
- Know about various plastics that are used for biomedical applications such as cardiovascular, dental, ophthalmology, and other artificial organs.
- Understand the methods and standards used for the evaluation of biomedical polymers.
- Describe the criteria for the selection of biomedical polymers
- Explain the biomedical applications of polymers

REFERENCES:

1. Ratner, B.D., Hoffman, A.S., Schoen, F.J. and Lemons, J.E., 2004. Biomaterials science: an introduction to materials in medicine. Elsevier.
2. Park, J.B., 2012. Biomaterials science and engineering. Springer Science & Business Media.
3. Williams, D., 2014. Essential biomaterials science. Cambridge University Press.
4. Pignatello, R. ed., 2011. Biomaterials science and engineering

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	1	2	1	3	2	3	-	-	-	-	-
CO2	3	1	2	1	3	2	3	-	-	-	-	-
CO3	3	1	2	1	3	2	3	-	-	-	-	-
CO4	3	1	2	1	3	2	3	-	-	-	-	-
CO5	3	1	2	1	3	2	3	-	-	-	-	-
AVg.	3	1	2	1	3	2	3	-	-	-	-	-

1-low, 2-medium, 3-high, '-'- no correlation

PA25014	Shape Memory Polymers	L	T	P	C
		3	0	0	3

Course Objectives:

- To gain all the information about current status of the materials.
- To know all the advance direction for the materials.
- To understand about processing of advanced materials.
- To acquire knowledge about super alloys
- To learn about plasma synthesis techniques & their applications

Smart Materials

Smart system, Piezoelectric materials, Shape memory alloys and shape memory polymers, Magnetostrictive materials, pH-sensitive polymers, Halochromic materials, Chromogenic-systems, Ferrofluid, Rheological fluid, applications of different smart materials. Nanotechnology: Micro-to-nano history, nanoscience, nanotechnology, Nano particle, nanostructured materials, Nanocomposites.

Super Alloys

Classification of Nanomaterials, fabrication of nanomaterials, Applications of Nanomaterials. Classification of super alloys, Development of different phases in super alloys, Ni-based super alloys, commercially available pure nickel alloys, Co-based super alloys, Fe-based super alloys, Ti alloys, Al- Li alloys.

Biomaterials

Functional and Engineering Ceramics: Ceramics and their classifications, cutting tool materials, diverse applications of cutting tool, Cermets, Cubic Boron Nitride, polycrystalline diamond. Metallic biomaterials like 316L stainless steel, Co-Cr Alloys, Titanium Ti6Al4V, Ceramic biomaterials like Alumina, Zirconia, Carbon Hydroxyapatite, Polymeric biomaterials like Ultra high molecular weight polyethylene, Polyurethane.

Ultra-Light Materials

Bulk metallic glasses (BMG): Various methods for BMG production, Classification of BMG, Properties and behaviors of BMG, Thermodynamic aspects of stability, Potential applications of BMG. Aerogels, Aerographite, Metallic Foams, Polymeric Foams, Metallic Microlattices, their synthesis, properties and applications.

Plasma Surface Engineering

Plasma, plasma synthesis techniques, Energy associated with plasma, Kinetics in plasma, different types of plasma spraying, cold plasma, applications of plasma. Energy generation and energy storage: battery cell, Self-charging battery, Battery both generates and stores energy, Flow battery.

OUTCOMES:

At the end of the course, students will be able to

- Know the current-development/advances-in-materials in the metallurgical field.
- Be aware of the advances in materials related to interdisciplinary areas.
- Understand the different types of crystal structures in biomaterials
- Gain knowledge about different ultralight engineering materials and their applications
- Apply the concept of plasma surface engineering and their applications

REFERENCES:

1. R E Smallman, A.H.W., Butterworth-Heinemann, Physical Metallurgy and Advanced Materials, Elsevier, ISBN: 0750669063.
2. Mark J. Hampden-Smith Wiley-VCH, Chemistry of Advanced Materials: An Overview, Wiley, ISBN-10: 0471185906 ISBN-13: 978-0471185901.
3. M. Meyers, M Sarikaya, R. Ritchie, Nano and Microstructural Design of Advanced Materials, Elsevier , ISBN-13: 978-0-08-044373-7, ISBN-10: 0-08-044373-7
4. Feiyu Kang, Hidetaka Konno, Masahiro Toyoda, and Michio Inagaki, Advanced Materials Science and Engineering of Carbon, Elsevier , eBook ISBN: 9780124078383

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	1	1	1	3	1	-	-	-	-	-	3
CO2	3	1	1	1	3	1	-	-	-	-	-	3
CO3	3	1	1	1	3	1	-	-	-	-	-	3
CO4	3	1	1	1	3	1	-	-	-	-	-	3
CO5	3	1	1	1	3	1	-	-	-	-	-	3
AVg.	3	1	1	1	3	1	-	-	-	-	-	3

1-low, 2-medium, 3-high, '-'- no correlation

PA25015	Conducting Polymers	L	T	P	C
		3	0	0	3

Course Objectives:

- To enable the students to understand the basic concepts on conducting polymers
- To impart knowledge about synthesis mechanism and applications of conducting polymers
- To learn about various types of characterization methods
- To gain knowledge about doping concepts
- To elucidate various applications of conducting polymers

Introduction To Conducting Polymers

Conducting polymers - conduction mechanism - discovery of polyacetylene- Concept of doping- Charge carriers: polarons, bipolarons and solitons. Types of dopants, oxidative dopants and reductive dopants, mechanism of doping, p-type doping and n-type doping, inorganic and organic dopants, effect of doping on the dielectric properties of conducting polymers. Important properties of conjugated polymers-electrical conductivity, photoconductivity, charge storage capacity, photoluminescence, and electroluminescence.

Synthesis Of Conducting Polymers

Electrically conducting polymers-Chain growth polymerisation, step growth polymerization, electrochemical polymerization, Metathesis polymerization (Ring opening metathesis polymer (ROMP). Advantages and disadvantages of conducting polymers, methods to enhance the processability of conducting polymers

Conducting Polymers

Synthesis and properties of conducting polymers-Polyacetylene, Poly p-phenylene, Polyheterocyclic and polyaromatic conducting polymers like polythiophene, poly vinyl carbazole, polypyrene, polyaniline, Polypyrrole, Poly phenylene vinylene, Polypyridine.

Characterization and Processability of Conducting Polymers

Characterization methods - elemental analysis for dopants - IR - UV (electro chemical) scanning electron microscopy (SEM)-electrochemical characterization-cyclic voltammetry- electrochemical quartz crystal microbalance (EQCM) - probe beam deflection (PBD) -Langmuir - Blodgett technique.

Applications of Conducting Polymers

Applications of conducting polymers- electro active applications Polymer rechargeable batteries, sensors, electrochemical actuators, electro luminescent applications. Conductivity applications - antistatic coatings, conducting adhesives, artificial nerves. Electronic applications- EMI shielding, Frequency selective surfaces, satellite communication links, Dielectric properties of conducting polymers in the high and very high frequency fields (a.c field), ultra high frequency field (Microwave field). Recent trends in conducting polymer and conducting polymer nanocomposites

OUTCOMES:

At the end of the course, students will be able to

- Understand the basic concepts and the mechanism of conduction in polymers
- Synthesise conducting polymers by various methods.
- Characterize the conduction in polymers
- Understand the application of conductive polymers in various devices.
- Familiarize with the recent and future trend of conducting polymers.

REFERENCES:

1. Reynolds, J.R., Thompson, B.C. and Skotheim, T.A. eds., 2019. Conjugated Polymers: Properties, Processing, and Applications. CRC press.
2. J. Margolis, Conducting Polymers and Plastics, Chapman and Hal, London 1993.
3. Baeriswyl, D., Campbell, D.K., Clark, G.C., Harbeke, G., Kahol, P.K., Kiess, H., Mazumdar, S., Mehring, M. and Rehwald, W., 2012. Conjugated conducting polymers (Vol. 102). Springer Science & Business Media.
4. Linford, R.G. ed., 1990. Electrochemical science and technology of polymers (Vol. 2). Elsevier Applied Science.
5. Di Bari, G.A., Schlesinger, M. and Paunovic, M., 2000. Modern electroplating. New York), M. Schlesinger and M. Paunovic, Eds., John Wiley & Sons, Inc.
6. Barford, W., 2013. Electronic and optical properties of conjugated polymers (Vol. 159). Oxford University Press.
7. Mullen, K., Reynolds, J.R. and Masuda, T. eds., 2014. Conjugated polymers (No. 9). Royal Society of Chemistry.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	1	3	1	3	1	-	-	-	-	-	3
CO2	3	1	3	1	3	1	-	-	-	-	-	3
CO3	3	1	3	1	3	1	-	-	-	-	-	3
CO4	3	1	3	1	3	1	-	-	-	-	-	3
CO5	3	1	3	1	3	1	-	-	-	-	-	3
AVg.	3	1	3	1	3	1	-	-	-	-	-	3

1-low, 2-medium, 3-high, "-- no correlation

PA25016	Liquid Crystalline Polymers	L	T	P	C
		3	0	0	3

Course Objectives:

- To make the student to acquire knowledge in liquid crystalline polymers for special application.
- To provide exposure to the students about advanced polymeric materials.
- To acquire knowledge about various theories of LCP
- To learn about processing & identification of LCP
- To elucidate various applications of LCP

Introduction

Definition of LCP, Types of liquid crystalline polymers, order and classification, Chemistry and physics of liquid crystalline polymers, Synthesis of liquid crystalline polymers, Properties of liquid crystalline polymers.

Stability of Liquid Crystalline Polymers

Thermotropic liquid crystals-Rigid-rods to main-chain polymers, development of side-chain liquid crystalline polymers, Stability of liquid crystalline polymers, Factors limiting liquid crystallinity in rigid rod-like molecules, Control of mesophase stability in main-chain thermotropic liquid crystalline polymers, Lyotropic rigid-rod polymers, Polymers with mesogenic side-chains, Liquid crystalline polymers with more complex molecular architectures.

Theories of Liquid Crystallinity

Theories of liquid crystallinity in polymers: Steric theory of rod-like liquid crystals, Virial theories: the Onsager approach, Flory's lattice model, Orientation dependent interactions: the Maier-Saupe theory, Theories for main-chain polymers with semi-rigid chains, Theories of side-chain liquid crystalline polymers, Phenomenological theories of phase transitions.

Processing of Structural Liquid Crystalline Polymers

Processing of structural liquid crystalline polymers: Rheology, Processing and the consequences of flow alignment, Liquid crystalline polymers as structural materials, Liquid crystalline polymers in blends and composites, Identification of LCP by DSC, Microscopy and XRD.

Applications of Functional Liquid Crystalline Polymers

Applications of functional liquid Crystalline polymers: Liquid crystalline polymers as Optoelectronic materials, Liquid crystalline polymers in displays, Semiconducting liquid crystalline polymers, Laser writeable devices, nonlinear optical applications, Sensors and actuators. Applications and uses Electrical/ Electronic Applications, Automotive Applications, Engineering Parts, Appliances, Food Containers, Industrial Applications etc.

OUTCOMES:**At the end of the course, students will be able to**

- Know about preparation and properties of liquid crystalline polymers.
- Methodically discuss application of liquid crystalline polymers.
- Appreciate the uses of polymers for specialty applications
- Evaluate various applications of liquid crystalline polymers
- Identify different LCP

REFERENCES:

1. Raynes, Peter. "LIQUID CRYSTALS—Second Edition, by S Chandrasekhar, Cambridge University Press,(1992),
2. Dierking, I., 2017. Handbook of liquid crystals.
3. Chanda, M. and Roy, S.K., 2008. Industrial polymers, specialty polymers, and their applications. CRC press.
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5. Martellucci, S. and Chester, A.N. eds., 1992. Phase Transitions in Liquid Crystals (p. 439). New York: Plenum Press.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	1	3	1	3	1	-	-	-	-	-	3
CO2	3	1	3	1	3	1	-	-	-	-	-	3
CO3	3	1	3	1	3	1	-	-	-	-	-	3
CO4	3	1	3	1	3	1	-	-	-	-	-	3
CO5	3	1	3	1	3	1	-	-	-	-	-	3
AVg.	3	1	3	1	3	1	-	-	-	-	-	3

1-low, 2-medium, 3-high, '-'- no correlation

PA25017	Plastics Recycling and Waste Management	L	T	P	C
		3	0	0	3

Course Objectives:

- To provide an in-depth understanding of the environmental and industrial significance of plastics recycling.
- To analyze various methods and technologies for recycling thermoplastics, thermosets, composites, and multilayer packaging.
- To critically evaluate global waste management practices and policies for plastic waste minimization.
- To apply techno-economic and environmental analysis tools for plastic recycling systems.
- To explore innovative and sustainable solutions for circular economy and zero-waste targets.

Plastic Waste Generation, Sources, and Classification

Types and sources of plastic waste: industrial, post-consumer, post-industrial, Classification of plastic waste: thermoplastics, thermosets, composites, multilayer films, Global and Indian plastic waste statistics and trends, Environmental impacts of mismanaged plastic waste, Regulatory frameworks: Extended Producer Responsibility (EPR), Plastic Waste Management Rules (India), Basel Convention, Life Cycle Assessment (LCA) of plastic products and waste

Plastic Recycling Technologies

Mechanical recycling: collection, sorting, washing, shredding, reprocessing, Advanced sorting technologies: NIR, triboelectric separation, density separation, Thermal degradation and energy recovery: pyrolysis, gasification, incineration, Chemical recycling: depolymerization, solvolysis, glycolysis, enzymatic depolymerization, Solvent-based recycling, feedstock recycling, Devulcanization and reuse of rubber waste, Case studies: PET bottle recycling, multilayer film delamination

Processing Of Recycled Plastics

Challenges in processing recycled plastics: degradation, contamination, odor, Compounding and reprocessing of recyclates using twin-screw extrusion, Stabilizers, compatibilizers, and performance modifiers, Quality control and mechanical testing of recycled plastics, Rheological behavior and viscosity correction methods, Application of recycled plastics: automotive, construction, textiles, packaging, Standards for recycled plastics: IS/ISO/ASTM

Integrated Waste Management and Circular Economy

Concepts of waste hierarchy: reduce, reuse, recycle, recover, Integrated plastic waste management systems: segregation, collection, logistics, Design for recycling: mono-materials, redesigning for dismantling, Business models: buyback schemes, informal sector integration, reverse logistics, Circular economy for plastics: cradle-to-cradle, closed-loop recycling, Plastic neutrality, product stewardship, take-back programs, Industry case studies: Loop Industries, Terracycle, Plastics for Change

Sustainability, Policy, and Future Technologies

Sustainable plastic materials: biodegradable, compostable, oxo-degradable plastics, International approaches: EU Green Deal, U.S. Plastics Pact, Japan recycling model, Plastic bans, alternatives, and socio-economic implications, Artificial intelligence and robotics in waste sorting and recycling, Blockchain for waste traceability and credit systems, Role of academia, government, and industry in promoting plastic sustainability, Research trends: upcycling, biorefineries, enzymatic degradation

OUTCOMES:

At the end of the course, students will be able to;

CO1 Understand global challenges, regulations, and strategies in plastic waste management.

CO2 Analyze and compare various plastic recycling technologies and their technical limitations.

CO3 Apply recycling and waste minimization principles in designing sustainable plastic products.

CO4 Evaluate recycled materials for reuse in high-value and engineering applications

CO5 Integrate waste management strategies with circular economy and policy frameworks.

REFERENCES

1. Trutzschler, K., Plastic Recycling – Challenges and Opportunities, Wiley
2. Al-Salem, S. M., Lettieri, P., Baeyens, J., Recycling and Recovery Routes of Plastic Solid Waste (PSW), Waste Management
3. Scheirs, J., Polymer Recycling: Science, Technology and Applications, Wiley
4. Hopewell, J., Dvorak, R., Kosior, E., Plastics Recycling: Challenges and Opportunities, Philosophical Transactions B
5. Recent journal articles from Waste Management, Resources, Conservation and Recycling, and Journal of Cleaner Production

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	2	1	2	1	3	3	2	1	1	0	2
CO2	3	3	2	3	3	2	2	1	1	1	0	2
CO3	3	2	3	3	3	2	3	2	2	1	1	2
CO4	3	3	2	3	2	2	3	2	1	1	1	2
CO5	2	2	2	2	3	3	3	3	2	2	1	3
AVg.	2.8	2.4	2	2.6	2.4	2.4	2.8	2	1.4	1.4	0.6	2.2

1-low, 2-medium, 3-high, ‘-’- no correlation

PA25018	Bioplastics and Biodegradable Polymers	L	T	P	C
		3	0	0	3
<p>Course Objectives:</p> <ul style="list-style-type: none"> • Introduce students to the fundamentals of bioplastics and biodegradable polymers, including their chemistry, sources, and processing techniques. • Provide a deep understanding of the various types of biodegradable polymers and their degradation mechanisms. • Evaluate the environmental impact, life cycle analysis, and sustainability aspects of bioplastics. • Explore recent advances in research, commercial applications, and policy frameworks related to biodegradable materials. • Enable students to critically analyze the industrial feasibility and challenges in the bioplastics sector 					
<p>Introduction to Bioplastics and Biodegradability</p> <p>Definitions and differences: Bioplastics, biodegradable plastics, compostable plastics, Environmental impact of conventional plastics, Need for bioplastics – Global scenario and Indian context, Overview of sources: biomass-based, microbial, agro-waste based, Introduction to biodegradation: mechanisms and influencing factors</p> <p>Types of Biodegradable Polymers</p> <p>Natural biodegradable polymers: Starch, cellulose, chitosan, alginate, proteins, Synthetic biodegradable polymers: PLA, PCL, PGA, PBAT, PBS, PHB, PHBV, Microbial polymers: Bacterial polyesters, PHA family, Copolymers and blends of biopolymers, Characterization techniques for biopolymers (FTIR, TGA, DSC, GPC, SEM)</p> <p>Processing and Fabrication Techniques</p> <p>Thermoplastic and thermoset biopolymers, Compounding and blending with natural fibers/fillers, Conventional processing: Extrusion, injection molding, film blowing, thermoforming, Processing challenges: moisture sensitivity, thermal stability, shelf life, Additives, and plasticizers for biodegradable systems</p> <p>Degradation Mechanisms and Testing</p> <p>Mechanisms: Hydrolytic, enzymatic, oxidative, microbial degradation, Standard degradation test methods: ASTM D6400, ISO 14855, OECD 301, Composting vs soil burial vs aquatic degradation, Biodegradation kinetics and modelling, Environmental and health safety of degradation products</p> <p>Life Cycle Assessment, Regulations, and Applications</p> <p>Life cycle assessment (LCA) of bioplastics, Comparative study with petroleum-based plastics, Global and Indian regulatory landscape: EPR, CPCB, BIS standards, Industrial applications: packaging, agriculture, medical, consumer goods, Recent developments: marine degradable plastics, algae-based plastics, biodegradable nanocomposites</p>					

OUTCOMES:

At the end of the course, students will be able to;

CO1 Understand the definitions, classification, and global need for biodegradable and bioplastics.

CO2 Distinguish between various natural and synthetic biodegradable polymers based on chemistry and origin.

CO3 Demonstrate knowledge of processing technologies and challenges in working with bioplastics

CO4 Evaluate the degradation mechanisms and interpret results from standard biodegradation tests.

CO5 Analyze life cycle assessment and interpret regulatory and industrial perspectives on bioplastics.

REFERENCES

1. Sorrentino, A., Gorrasi, G., Vittoria, V. – Potential Perspectives of Bio-based Polymers for Food Packaging Applications, Trends in Food Science & Technology.
2. Scott, G. – Polymers and the Environment, Royal Society of Chemistry.
3. Chiellini, E. (Ed.) – Environmentally Compatible Food Packaging, Woodhead Publishing.
4. Averous, L., Pollet, E. – Environmental Silicate Nano-Biocomposites, Springer.
5. Kabir, E., Kaur, R. J. – Bioplastics and Biodegradable Plastics: Challenges and Perspectives, Academic Press.
6. Journals: Polymer Degradation and Stability, Journal of Polymers and the Environment, Waste Management.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO 8	PO 9	PO10	PO11	PO12
CO1	3	2	1	-	-	2	3	1	2	1	2	1
CO2	3	3	2	-	-	2	3	1	2	1	2	1
CO3	2	3	3	2	2	2	2	2	1	1	1	2
CO4	3	3	2	2	1	3	3	1	2	2	2	1
CO5	2	3	3	3	3	3	3	2	1	1	1	2
AVg.	2.6	2.8	2.2	1.4	1.2	2.4	2.8	1.4	1.6	1.2	1.6	1.4

1-low, 2-medium, 3-high, '-'- no correlation

PA25019	Applications of AI And ML In Plastic Industries	L	T	P	C
		3	0	0	3

Course Objectives:

- Introduce the fundamental concepts of Artificial Intelligence and Machine Learning and their relevance in polymer and plastics industries.
- Familiarize students with various AI/ML algorithms and tools for data-driven decision-making in processing and material development.
- Enable the integration of AI/ML in predictive modeling, process optimization, defect analysis, and quality control in plastic manufacturing.
- Develop critical skills in applying ML to industrial data using platforms such as Python, MATLAB, or cloud tools.
- Encourage the adoption of AI technologies for sustainability, smart manufacturing, and Industry 4.0 transformation in plastics engineering.

Introduction To AI AND ML

Basics of Artificial Intelligence and Machine Learning, Types of learning: supervised, unsupervised, reinforcement, Data acquisition and preprocessing techniques, AI/ML in the context of manufacturing industries, Case studies in materials science and polymer applications

AI/ML Algorithms and Tools

Regression, Classification (Linear, Logistic), Decision Trees, Random Forest, Support Vector Machines (SVM), Clustering techniques: K-Means, DBSCAN, Neural Networks and Deep Learning (ANN, CNN, RNN) – Overview, Tools & Platforms: Python (Scikit-learn, TensorFlow, Keras), MATLAB, AutoML, Google Colab

Applications In Polymer Processing and Manufacturing

Process optimization in extrusion, injection molding, blow molding, Real-time process control using AI/ML, Prediction of material behavior under varying processing conditions, Predictive maintenance of machinery and smart scheduling, Defect detection using machine vision and pattern recognition

Materials Discovery and Property Prediction

AI for polymer property prediction (e.g., tensile strength, melt flow index), ML for polymer formulation optimization (fillers, additives, blends), AI in structure–property relationship modeling, Use of databases: Polymer Genome, Materials Project, Integration with molecular simulation and finite element analysis

Smart Manufacturing, Sustainability & Future Scope

Digital twins and AI-driven smart factories in plastics, Waste reduction, recycling, and AI for environmental monitoring, AI for supply chain optimization in polymer industries, Role of AI/ML in Industry 4.0 and 5.0 for polymer engineers, Challenges, ethics, and scope of AI in plastics domain

OUTCOMES:

At the end of the course, students will be able to;

CO1 Understand AI and ML fundamentals and their relevance to polymer and plastics industries.

CO2 Apply machine learning techniques to predict, analyze, and optimize polymer properties and processes.

CO3 Analyze complex industrial data using AI tools for defect detection and process automation

CO4 Design AI-based models for predictive maintenance and smart manufacturing in plastics.

CO5 Evaluate the future scope of AI/ML in sustainable polymer manufacturing and Industry 4.0 integration.

REFERENCES

1. Russell, S., Norvig, P. – Artificial Intelligence: A Modern Approach, Pearson.
2. Aurelien Geron – Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, O'Reilly.
3. Yao, Y., et al. – Machine Learning in Materials Informatics: Recent Applications and Prospects, npj Comp. Materials.
4. Patel, S. et al. – Application of AI in Polymer Science and Engineering, Recent Trends in Engineering & Materials.
5. Selected articles from Journal of Intelligent Manufacturing, Polymer Testing, Computational Materials Science.

MAPPING OF CO'S WITH PO'S

Course outcome Statement	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO 8	PO 9	PO10	PO11	PO12
CO1	3	2	-	-	-	1	3	1	2	1	2	1
CO2	3	3	3	2	2	2	2	1	2	1	2	1
CO3	2	3	3	2	3	2	2	2	1	1	1	2
CO4	3	3	3	3	3	2	2	1	2	2	2	1
CO5	2	2	2	3	3	3	3	2	1	1	1	2
AVg.	2.6	2.6	2.2	2	2.2	2	2.4	1.4	1.6	1.2	1.6	1.4

1-low, 2-medium, 3-high, ‘-‘- no correlation