INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-601 **Course Title**: Additive Manufacturing
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Autumn **7. Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge about the part fabrication from design to product using different additive manufacturing routes.

10. **Details of the Course**

S.No.	Contents	Contact hours
1.	Role of additive manufacturing in product design and development, geometric modeling, curves design, surface designs and various solid modeling techniques for additive manufacturing, transformations for computer graphics	10
2.	Process planning for additive manufacturing, STL file generation, defects in STL files, repairing algorithms, slicing, slicing techniques like local and adaptive slice.	10
3.	Classification of additive manufacturing (AM) processes, AM based rapid prototyping (RP) Systems like Stereo-lithography, Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), 3-D Printing, laser-engineered net shaping (LENS), direct metal deposition (DMD).	12
4.	Accuracy issues in additive manufacturing, properties of metallic and non-metallic additive manufactured surfaces, stresses induced in additive manufacturing (AM) processes. Surface roughness problem in rapid prototyping, part deposition orientation, issues like accuracy, surface finish, build time, support structure, cost etc.	10
Total		**42**

11. **List of Experiments**

1. Part drawing using solid modelling techniques
2. Part fabrication using FDM
3. Part fabrication using SLA
4. Effect of machining parameters on the surface roughness of 3D printed parts
5. Term project on product design

12. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Chua, C.K., Leong, K.F., Rapid Prototyping: Principles and Applications in Manufacturing, John Wiley and Sons Inc.	2000
2.	Pham, D.T., Demov, S.S., Rapid Manufacturing: The Technologies and Applications of Rapid Prototyping and Rapid Tooling, Springer-Verlag London Limited.	2001
3.	Zeid, I., Mastering CAD/CAM, Tata Mc Craw Hill, 2006	2006
4.	Gibson, I., Software Solutions for Rapid Prototyping, Professional Engineering Publication Ltd.	2002
5.	Mortenson, M.E., Geometric Modelling, John Wiley and Sons, Inc.,	1997

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-613 **Course Title**: Fusion Joining Technologies
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Autumn **7. Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge of fundamentals of joining, underlying principles, mechanisms related to fusion-joining technologies like arc heating, resistance heating, and radiation heating for developing sound joints.

10. Details of the Course

S.No.	Contents	Contact hours
1.	Fundamentals: Introduction, principles of fusion joining, heat sources, power density, weld pool protection, weld thermal cycle and joint performance, metal properties and weldability, weld and heat affected zone, gas metal and slag metal reactions and solid state transformation in weld and HAZ	10
2.	Arc: Fundamentals of arc welding, physics welding arc, arc forces, metal transfer, arc efficiency, dilution, bead geometry, principle, process parameters and performance of joints by welding processes: GMAW, GTAW, PAW, SAW and their variants like P-GTAW, A-GTAW, hot wire GTAW, P-GMAW, FCAW, NGW	12
3.	Resistance: Fundamentals of resistance welding, spot, seam, protection, HF induction and resistance welding, flash-butt, stud welding	8
4.	Radiation: Fundamentals of radiation based welding processes, melt-in and key hole modes, principle, process parameters and performance of joints by LBW, EBW, selection of power density and scanning speed in LBW, vacuum for EBW, application and limitation of radiation based welding process	5
5.	Misc. processes: Fundamentals, principles, parameters and joint performance of ES/GW, brazing and soldering, thermite welding, cutting, weld surfacing	7
Total		**42**

11. List of Experiments

1. Effect of welding parameters of SAW GMAW and GTAW processes on joint characteristics.
2. Effect of shielding gases on performance characteristics of GMAW process.
3. Effect of welding fluxes in submerged arc welding process on joint characteristics
4. Effect of welding parameters of spot welding of steel sheets on joint characteristics.
5. Effect of welding parameters on dilution, bead geometry and wear resistance of the weld surfacing
6. Effect joint design overlays, clearance on braze / solder joint characteristics

12. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	J. Norrish: Advanced Welding Processes, Woodhead publishing	2006
2.	Lancaster J. F., "The Metallurgy of Welding", 6th Ed., William Andrew Publishing.	1999
3.	Welding Handbook, Volumes 1, 2 & 3, 9th Ed., American Welding Society.	2001
4.	ASM Metals Handbook", Vol. 6, ASM International Publication.	1993
5.	Larry J. and Jeffus L., "Welding Principles and Application", 5th Ed., Delmer Publication.	2002
6.	Messler R. W., "Principles of Welding (Processes, Physics, Chemistry and Metallurgy)", John Wiley & Sons	1999
7.	Richard L Little, Welding and welding technology, Mc Graw Hill,	2020

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-614 **Course Title**: Solid State Joining Technologies
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Autumn **7. Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge of fundamental approaches to solid state joining technologies, underlying principles, mechanisms related to solid state joining technologies like micro and macro scale deformation, diffusion, adhesion for developing sound joints.

10. Details of the Course

S.No.	Contents	Contact hours
1.	Fundamentals: Introduction, feasibility and applications, comparison with fusion joining technologies, principles of solid state joining, metal properties and weldability by solid state joining, weld and heat affected zone, deformation and its effect on microstructure and properties of weld and HAZ	10
2.	Macro-deformation based joining: Fundamentals of macro-deformation joining, forge welding, friction welding, friction stir welding and its variants	8
3.	Micro-deformation based joining: Fundamentals of micro-deformation joining, ultrasonic welding, explosive welding, roll bonding	8
4.	Diffusion based joining: Fundamentals of diffusion based joining process, diffusion bonding and its variants like transient liquid phase bonding, mechanisms, interlayers, surface cleaning, process parameters, approaches to improve the productivity of diffusion bonding	6
5.	Adhesive joining: Fundamentals, design of adhesive joint, joint configuration, overlap, adhesive thickness, principles, procedure, adhesives, curing, applications and limitations	4
6.	Heat treatment of weld joints for improving joint performance: Principle, Fe-C diagram CCT diagram, stress relieving, normalizing, tempering, precipitation hardening, effect of PWHT on microstructure and properties of weld joints	6
Total		**42**

11. List of Experiments

1. Effect of welding parameters of FSW processes on joint characteristics.
2. Effect of welding parameters of ultrasonic welding on joint characteristics.
3. Effect of surface conditions and diffusion bonding parameters on joint characteristics
4. Effect of adhesive joint design on load carrying capacity of adhesive joints

5. Effect of procedure of adhesive joining on characteristic of adhesive joints
6. Effect PWHT on microstructure and characteristics of joint interface and HAZ

12. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	J. Norrish: Advanced Welding Processes, Woodhead publishing	2006
2.	Richard L Little, Welding and welding technology, Mc Graw Hill	2020
3.	Welding Handbook, Volume 2 & 3, 9th Ed., American Welding Society.	2001
4.	ASM Metals Handbook", Vol. 6, ASM International Publication.	1993
5.	Larry J. and Jeffus L., "Welding Principles and Application", 5th Ed., Delmer Publication.	2002
6.	Messler R. W., "Principles of Welding (Processes, Physics, Chemistry and Metallurgy)", John Wiley & Sons.	1999
7.	Procedure Handbook of Arc Welding", Lincoln Electric Co., USA.	2004
8.	Tylecote R.F., "The Solid phase welding of Metals", Edward Arnold Pub. Ltd.	1968

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-615 **Course Title**: Material Characterization and Testing
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Autumn **7. Subject Area:** PCC
8. **Pre-requisite:** Nil
9. **Objective:** To give students a thorough and conceptual understanding of various materials characterization and testing techniques.

10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Introduction:** Engineering materials, properties of materials; crystal structure, strengthening mechanisms in metals; fundamentals of materials characterization; basic sample preparation and interpretation of data.	3
2.	**Optical Microscopy:** Fundamentals of optics, optical microscope and image formation, depth of field and depth of focus; specimen preparation, metallographic principles, applications.	5
3.	**Electron Microscopy:** Scanning electron microscopy- working principle, electron specimen interaction, instrumentation and applications of SEM, chemical analysis in SEM (EDS & WDS), electron backscatter diffraction, applications of EBSD; transmission electron microscopy- instrument details and imaging modes, specimen preparation methods.	8
4.	**X-ray Diffraction:** Properties of x-rays, geometry of crystals, Bragg's law, diffraction methods, intensity of diffracted beams, structure factor calculations, diffractometer measurement; applications of XRD- phase identification, crystal structure and phase diagram determination, crystallite size, and lattice parameter determination.	10
5.	**Thermal and Thermomechanical Methods:** Thermal gravimetric analysis (TGA), differential thermal analysis (DTA), differential scanning calorimetry (DSC), and dynamic mechanical analysis (DMA), thermomechanical analysis (TMA).	9
6.	**Mechanical Testing:** Uniaxial tension test, compression test, three and four point bending test, hardness tests, impact tests, creep and stress rupture tests, fatigue test and failure analysis.	7
Total		**42**

11. List of Experiments

1. Sample preparation for optical and SEM observations.
2. Grain size determination of given metallic sample using optical microscopy.
3. Microstructural study and chemical analysis using SEM.
4. To demonstrate the TEM sample preparation and TEM analysis.
5. Determination of phases in multiphase powder sample using XRD.
6. DSC/DTA analysis.
7. To study dynamic mechanical behavior of polymers.
8. To determine the tensile properties of given samples.
9. To determine the hardness of given metallic sample by Brinell, Vikcers, and Rockwell hardness tester.
10. To determine the impact strength of given metallic sample by Izod and Charpy methods.
11. To perform fatigue test on given sample.

12. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Leng, Y., "Materials Characterization: Introduction to Microscopic and Spectroscopic Methods", John Wiley & Sons	2019
2.	Douglas B. Murphy, "Fundamentals of Light Microscopy and Electronic Imaging", Wiley Liss Inc. USA	2001
3.	Cullity, B. D. and Stock, S. R., "Elements of X-Ray Diffraction", Pearson Education Limited	2014
4.	Williams, D. B. and Carter, C. Barry, "Transmission Electron Microscopy", Springer	1996
5.	Bhargava, A. K. and Sharma, C. P., "Mechanical Behaviour and Testing of Materials", PHI Learning Pvt. Ltd, Delhi	2014

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-622 **Course Title**: Metallurgical aspects in joining and additive manufacturing
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge of physical metallurgy related to heat affected zone and weld zone, interfaces in case of joining and additive manufacturing.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Physical metallurgy:** Basic terminology, importance of metallurgical changes in metal joining and additive manufacturing, effect of material characteristics namely composition, mechanical properties, physical properties on joining and additive manufacturing, metallurgical transformation in fusion zone and heat affected zone, autogenous and heterogeneous welding, carbon equivalent and hardenability, relevance of Fe-C, CCT and Schaffer in fusion, metal strengthening mechanisms	12
2.	**Solidification and weld zone:** Gas metal reactions, liquid metal reactions, solidification mechanisms, grain refinement techniques, inoculation, arc pulsation, external excitation, cleanliness of weld metal, affinity of atmospheric gases with molten metals, approaches for protection of molten weld metal, solidification cracking, porosity and inclusions	10
3.	**Heat affected zone:** Transformation in HAZ, factors affecting changes in microstructure and mechanical properties of HAZ, HAZ of weld joint of precipitation hardened, transformation hardened and dispersion hardened metals, liquation cracking, hardening and softening of HAZ	10
4.	**Metallurgical aspects of solid state joining:** Deformation induced metallurgical transformation, grain refinement, work hardening, metallurgical discontinuities related to solid state joining, factors determining the joint performance of solid state joints	6
5.	**Additive manufacturing of metal:** Re-melting, need of shielding in additive manufacturing, solidification, heat source and quality, metallurgical transformation and anisotropy in AM components, sintering during power metallurgy	4
Total		**42**

11. List of Experiments

a) Study of microstructure and hardness profile of fusion weld joint.
b) Study of microstructure and hardness profile of joint by solid state joining.
c) Effect of shielding gases and basicity index on soundness of the weld joint.
d) Metallurgical transformation weld and HAZ of fusion weld joints of PH aluminium alloy and carbon steel.
e) Effect of heat input on metallurgical transformation in fusion weld joints.
f) Study of sintering conditions of microstructure during AM using power metallurgy route.

12. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Lancaster J F., "Metallurgy of Welding", Allen & Unwin Co.	2000
2.	S D Avner, "Introduction to physical metallurgy", TMH	2011
3.	ASM Handbook "Welding, Brazing and soldering", Vol. 6, ASM International, ASM, Ohio.	1993
4.	Kou S., Welding metallurgy, 2nd edition, Wiley Publications	2003
5.	Baldev Raj, V Shankar, A K Bhaduri, "Welding for engineers", Narosa publishing house, India	2006
6.	K Esterling, "Introduction to Physical Metallurgy of Welding", BH	1991
7.	Gene Mathers, "Welding of Aluminium and alloys", Wood Head Pub. UK.	2002

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-623 **Course Title**: Inspection and Testing for Quality Assurance
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge of joint inspection and testing, types of discontinuities and their prevention, different destructive and non-destructive techniques for weld joints, codes for welding inspections, Welding Procedure and Performance Qualifications.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Introduction:** Types and purposes of weld joint testing, important terms in joining, symbols for welding and testing	4
2.	**Discontinuities in Weld Joints:** Classification of discontinuities in weldments, occurrence, causes and prevention of discontinuities, location, orientation and extent of discontinuities, method for testing weld and base metal imperfections	4
3.	**Destructive Testing (DT):** Chemical tests, metallographic tests, hardness tests, mechanical test for groove and fillet welds of full section, reduced section and all-weld-metal tensile tests, root, face and side bend tests, fillet weld break tests, fillet weld shear strength test	8
4.	**Non-Destructive Testing (NDT):** Visual inspection, dye-penetrant test, magnetic particle testing; Ultrasonic testing- principle of ultrasonic testing, types of ultrasonic probes, standard blocks for calibration; Radiographic inspection – principle of radiography, X-ray tubes, Gamma-ray sources, interpretation of radiographs, defect discernibility, Eddy current inspection; Proof test, leak tests: NDT, AWS (American Welding Society) standards, safety in NDT	12
5.	**Inspection of Weld Joints:** Duties and requirement of an inspector before, during and after welding, codes governing welding inspection, ASME (American Society of Mechanical Engineers) Codes	6
6.	**Welding Procedure and Performance Qualifications:** Standard procedure for specification and qualification of welding procedure, operator qualification, standard method of recording of qualification tests, welding procedure specification (WPS), procedure qualification record (PQR) and Welding performance qualification (WPQ).	8
Total		**42**

11. List of Experiments

1. Visual inspection for weld quality
2. Dye-penetrant inspection of surface defects in welded joints
3. Magnetic particle inspection surface defects in welded joints
4. Ultrasonic inspection for assessing sub-surface defects
5. Radiographic inspection of weld joints

12. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	"Welding Inspection Handbook", 4rd Ed., American Welding Society	2015
2.	"Welding Hand Book", Vol. 5, 9th Ed., American Welding Society	2003
3.	"ASME Code Section IX ", ASME	1998
4.	"Structural Welding Code – Steel", AWS D1.1:2000 AWS	2000
5.	"Specifications for Welding Procedure & Performance Qualification", ANSI /AWS B2.1:1998, 1998	1998
6.		
7.	Jeffus, L., "Welding: Principles and Applications", 8th Ed., Delmar Cengage Learning	2016

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-624 **Course Title**: Design and Analysis of Joints
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To provide basic knowledge to design weld joints, different types of weld joints and connections, design of joints for static and dynamic loading, applications of various joints in industries, heat flow and residual stress related to joining.

10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Introduction:** Introduction to design, engineering properties of steels, weldability of structural steels, carbon equivalent, tensile, impact, fatigue and creep properties of welded joints, theories of failures.	6
2.	**Basic terms:** Type of welds and weld joints, description of welds terminology, welding symbols, edge preparation, sizing of welds in structure, type of connections in welded structures, combined groove and fillet weld connections.	6
3.	**Design for Static Loading:** Weld calculations for lap, butt and fillet welds, analysis of connections for direct tension, compression and shear loading conditions, resistance to moment by combined tension and compression.	6
4.	**Design for Fatigue loading:** Introduction, mechanism of fatigue fracture, residual fatigue strength, factors affecting fatigue life, design of welded joints for fatigue loading, fatigue behaviour of hollow section joints, methods for improving the fatigue strength of welded joints, reliability analysis and safety factors applied to fatigue design with reference to fracture toughness.	8
5.	**Industrial Applications of Weld Design:** Design of tubular structure, circular and rectangular hollow sections under static loading; design of weld joint for pressure vessel and automobile applications; design of brazed and soldered joints.	8
6.	**Heat flow in Welding:** Heat flow in welding, effect of welding parameters on heat distribution, calculation of peak temperature, weld thermal cycle, cooling rate and solidification time, effect of heat flow on joint performance, residual stresses in weld, stress corrosion	8
Total		**42**

11. List of Experiments

1. Study the effect of type of weld on tensile properties of weld joint
2. Development of weld thermal cycle during arc welding
3. Measurement of residual stress in welded joints
4. Measurement of hardness, toughness and fracture toughness of welded joints
5. Study stress corrosion cracking behaviour of stainless steel joints

12. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Fuchs, H. O. and Stephen, R I., "Metal Fatigue in Engineering", John Wiley & Sons.	2000
2.	Gray, T. G. F. and Spence, J., "Rational Welding Design", Butterworths.	1992
3.	"Welding Hand Book", Vol. 2 & 3, 9th Ed., American Welding Society.	2001
4.	Dieter, G., "Mechanical Metallurgy", McGraw Hill.	1988
5.	Messler, R.W. Jr., "Principles of Welding", John Wiley & Sons.	1999

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-625 **Course Title**: Safety Analysis of Metallic Joints
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge fundamental of failure, fracture mechanics, stress localization for safety and reliability analysis of the weld joints.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Fundamentals:** Definition of safety and definition of safety concept; basic mechanism of failure of components; brittle and ductile fracture; collapse fatigue fracture mechanism and representations at sub-microscopic and macroscopic levels through Mohr's circle; specific problems of safety related to weldments; definition and safety relevance of weld imperfections.	9
2.	**Conventional Methods for Safety Analysis:** Concepts of strength and toughness of engineering materials; determination and consequences of stress and strain state; material - stress and strain state embitterment, their reasons and consequences; effects of notches, stress state in notched component, safety analysis and assessment of notched components using notch theory; semi quantitative fracture analysis diagrams; limitations of conventional methods.	9
3.	**Fracture Mechanics:** Concepts of stress-strain state of cracked components; Introduction and basic principles of fracture mechanics; Linear Elastic Fracture Mechanics (LEFM); stress intensity factor; determination of fracture toughness.	8
4.	**Methods for Safety Analysis:** Limitations of LEFM; Modified LEFM, General yielding criterion; Plastic Limit Load Calculations (PLLC); Principles of Two Criteria Approach (TCA); Failure assessment diagram (CEGB Report R-6); Mechanism of cyclic crack growth; Paris law; Modifications of Paris law; Effects of temperature and environment; Elastic plastic fracture mechanics (EPFM); Stable crack growth; COD concept (CTOD BS: 5762); R-curve technique; Instability diagram.	8
5.	**Application of Safety Concepts to Welded Structures:** Material imperfections and stress states in weldments; Quality - degradation in welded structures; CODE requirements; Case studies as examples of failures; Design and service requirements for engineering structures fabricated by welding i.e. welded structures.	8
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Anderson T. L., "Fracture Mechanics: Fundamentals and Applications", 3rd Edition, Taylor & Francis Group.	2000
2.	Latzko D.G.H, "Post Yield Fracture Mechanics", 2nd Edition, Elsevier Applied Science Publication.	1984
3.	Broek D., "Elementary Engineering Fracture Mechanics", Martinus Nijhoff.	1982
4.	Farahmand Bahram.,"Fracture Mechanics of Metals, Composites, Welds and Bolted Joints", Hardcover, Kluwer Academic Publishers.	2000
5.	Maddox S.J., "Fatigue of Welded Structures", 2nd Edition, Woodhead Publishing.	1991
6.	Gurney T.R.,"Fatigue of Welded Structures", Cambridge University Press.	1979

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-627 **Course Title**: Hybrid Joining Technologies
2. **Contact Hours:** **L:** 2 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 2 **Practical:** 0
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 3 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To introduce need and basis hybridization of joining techniques and develop understanding on common hybrid joining technologies used primarily in automotive sector.

10. Details of the Course

S.No.	Contents	Contact hours
1.	**Introduction**: Requirement of hybrid joining, fundamental principles, types of hybrid joining technologies, and applications	2
2.	**Hybrid adhesive bonding with mechanical joining:** Adhesive bonding in conjunction with mechanical point joints, adhesive bonding and clinching, adhesive bonding and self-piercing riveting, adhesive bonding and blind riveting, adhesive bonding combined with other mechanical fasteners, adhesive injection fasteners, hem flange bonding	6
3.	**Hybrid adhesive bonding with solid state joining techniques:** Adhesive bonding and magnetic pulse welding, adhesive bonding and friction stir spot welding, adhesive bonding and ultrasonic welding	6
4.	**Hybrid adhesive bonding with fusion welding:** Adhesive bonding combined with resistance spot welding process, adhesive bonding combined with laser welding process, adhesive bonding combined with TIG/MIG welding process	6
5.	**Hybrid fusion welding techniques:** Laser – arc welding processes, Laser - MIG welding, Laser - TIG welding, Laser - plasma arc welding, Laser – MIG tandem welding process, MIG plasma welding	6
6.	**Advances in hybrid joining:** Research trends in hybridization of joining technologies, development in hybrid joining technologies for unique industrial applications	2
Total		**28**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Flemming Ove Olsen, “Hybrid laser-arc welding”, Woodhead Publishing, Cambridge UK	2009
2.	Sergio T. Amancio Filho, Lucian-Attila Blaga, "Joining of polymer-	2018

	metal hybrid structures: principles and applications", John Wiley & Sons, USA	
3.	Mahadzir Ishak, "Joining Technologies", Intech Open, Croatia	2016
4.	F.M.De. Wit, J.A. Poulis, "Joining technologies for automotive components", Advanced materials in automotive engineering, Woodhead Publishing, (:315-29), Cambridge UK	2012
5.	Horst E. Friedrich, Barry L. Mordike, "Magnesium technology", Springer-Verlag Berlin Heidelberg	2006
6.	L.F. da Silva, A. Pirondi, A. Öchsner, "Hybrid adhesive joints", Springer Science & Business Media, Heidelberg New York	2011
7.	H. Fricke, T. Vallée, "Hybrid joining techniques", Advanced Joining Processes, (pp. 353-381), Elsevier, United States	2021
8.	R.W. Messler, "Joining of materials and structures: from pragmatic process to enabling technology", Elsevier Butterworth-Heinemann; Oxford UK	2004
9.	"Welding Handbook" Vol. 3, 9th Edition", American Welding Society	2001
10.	Rubino F et al., "Ultrasonic welding of magnesium alloys: a review", Materials and Manufacturing Processes; 35(10):1051-68, Italy	2020
11.	Dawei Z et al., "Review on joining process of carbon fiber-reinforced polymer and metal: methods and joining process", Rare Metal Materials and Engineering; 47(12):3686-96, China	2018
12.	Graham DP et al., "The development and scalability of a high strength, damage tolerant, hybrid joining scheme for composite–metal structures", Composites Part A: Applied Science and Manufacturing; 64:11-24, Bristol UK	2014

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-628 **Course Title**: FEM for manufacturing processes
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge of FEM and its application in various manufacturing processes.
10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Introduction to finite element methods:** Fundamentals of finite element (FE) method, elastic stress analysis, weighted residue technique, material non-linearity, heat conduction, fluid flow, structure of a FE model, steps of a FE model, FE solver, X-FEM and interface tracking methods, Finite Element Modelling of Machining, model formulation, mesh, elements, boundary, contact, material Modelling, friction modelling, adaptive meshing, FEM software	10
2.	**FEM in Metal Cutting:** Performance of machining FEM models**, h**igh speed machining modelling, 3D machining modelling, FEM modelling of micromachining**,** Modelling of Grinding, Non-Conventional Machining, Soft Computing in Machining, Molecular Dynamics	8
3.	**FEM in casting and welding:** Heat source model in conduction mode welding processes, FE formulation, incorporation of temperature dependent properties, incorporation of latent heat of melting and solidifications, FE-based fluid flow model in fusion welding processes, FE-based elastic-plastic stress model of welding processes, yield criteria, hardening rule, flow rule, models, FE formulation, prediction of residual stress and distortion, incorporation of phase transformation effect, demonstration of thermo-mechanical model development using commercial software	10
4.	**Finite Element Modelling of Forming and Rolling Processes:** Background on the FEM, flow formulation of the cold rolling processes, updated Lagrangian formulation of cold rolling processes, formulation for hot rolling processes, heat transfer equations, material behaviour	7
5.	**Combining the Finite Element Method and Artificial Intelligence in Manufacturing Modelling and Optimization:** A brief overview on AI techniques, AI techniques for modelling, AI techniques for optimizing, Approaches for combining the FEM and AI in machining, Neural network-based modelling, Genetic algorithm-based optimization	7
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Angelos P. Markopoulos, Finite Element Method in Machining Processes, Springer	2013
2.	J. Paulo Davim, Finite Element Method in Manufacturing Processes, WILEY	Jan 2011
3.	Edward R. Champion, Finite Element Analysis in Manufacturing Engineering, McGraw-Hill	1992
4.	J N Reddy: An Introduction to the Finite Element Method, 3rd Eds., Tata McGraw Hill	2006
5.	S Kalpakjian and S R Schmid: Manufacturing Engineering and Technology, 7th Ed., Pearson	2018
6.	O P Gupta, Finite and Boundary Element Methods in Engineering, 1st Edition, Oxford & IBH Publishing.	1999
7.	O C Zienkiewicz, The Finite Element Method, 4th Edition, Tata McGraw Hill	1991
8.	J. A. Goldak and A. Mehdi, Computational Welding Mechanics, Springer, NY	2005
9.	M-K Besharati-Givi and P. Asadi: Advances in Friction-Stir Welding and Processing, Woodhead Publishing Limited	2014
10.	J. Norrish: Advanced Welding Processes, Woodhead publishing	2006
11.	C Lakshmana Rao and Abhijit P Deshpande: Modelling of Engineering Materials, Ane Books Pvt. Ltd., New Delhi, India	2010
12.	S. Bag and A. De: Computational models for GTA and laser welding processes, Lap-Lambert Academic Publishing Co. Ltd., Germany, ISBN 978-3-659-42994-1	2013

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-629 **Course Title**: Reverse Engineering and Rapid Tooling
2. **Contact Hours:** **L:** 2 **T:** 0 **P:** 2/2
3. **Examination Duration (Hrs.):** **Theory:** 2 **Practical:** 0
4. **Relative Weightage:** **CWS:** 15-30 **PRS:** 20 **MTE:** 15-25 **ETE:** 30-40 **PRE:** 0
5. **Credits:** 3 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** MIN-601
9. **Objective:** To familiarise students with the principles of reverse engineering and rapid tooling.

10. Details of the Course

S.No.	Contents	Contact hours
1.	**Introduction to reverse engineering**: Historical background, Use in modern industry, Applications and generic process of RE, Tools and techniques in RE, object scanning, contact scanners, noncontact scanners, destructive methods, coordinate measuring machine	6
2.	**Processing of point cloud data**: Data processing, curve generation, surface generation, solid generation, removal of noise, .STL file generation, model verification.	10
3.	**Introduction to Rapid tooling:** Definition and classification of rapid tooling, direct and indirect rapid tooling techniques like soft tooling and hard tooling techniques, its working principle and applications. Case studies related to indirect rapid tooling.	12
Total		**28**

11. List of Experiments:

1. Reverse engineering using CMM.
2. Reverse engineering using 3D scanner.
3. Indirect rapid tooling using casting.
4. Term project based on RE and RT.

12. Suggested Books

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Katheryn, A. Ingle, “Reverse Engineering”, McGraw-Hill.	1994
2.	Aiken Peter, “Data Reverse Engineering”, McGraw-Hill.	1996
3.	Linda Wills,“Reverse Engineering” ,Kluiver Academic Publishers.	1996
4.	Donald R. Honsa , “Co-ordinate Measurement and reverse engineering”, American Gear Manufacturers Association	1996

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-630 **Course Title**: Residual Stress and Distortion
2. **Contact Hours:** **L:** 2 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 2 **Practical:** 0
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 3 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To impart knowledge on importance, causes and mechanisms of residual stress and distortion, factors affecting residual stresses, effect of residual stress and its control, methods of residual stress and distortion measurements.

10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Residual stresses:** Causes of residual stress, types of residual stresses, mechanisms of residual stress formation, residual stress in weld joint, casting, and formed components, distribution of residual stress, effect of residual stress,	4
2.	**Residual stress in weld joints:** Effect of welding procedure and weld thermal cycle, base metal characteristics on residuals stresses, heat flow in welding, heat distribution, peak temperatures, cooling rate, influence of residual stresses in static and dynamic loading, distortion in weldments, effect of specimen size and weight on residual stress, residual stress in similar & dissimilar metal weld joints.	6
3.	**Residual stress measurement methods:** Deep-hole drilling, incremental center-hole drilling, ring core, Sachs boring, slitting, ultrasound and X-ray diffraction.	4
4.	**Control of residual stress:** Developing suitable welding procedure, weld joint design, selection of suitable filler/electrode/interlayer, stress-relieving treatment, heat treatment, overloading, mechanical vibrations etc.	4
5.	**Distortion:** Types of distortion-longitudinal, transverse, angular, bowing, causes of distortion heat input, restraint, inherent stresses in parent metal, control of distortion-joint design, assembly procedure-pre-setting method: restrained method, welding procedure, welding process, type and size of electrode welding rod and wire, number of passes, and welding position, welding parameters, welding sequence and techniques, other techniques for distortion control.	6
6.	**Correction of distortion:** Manual, use of press, local heating - hot shrinkage, use of heat strip, use of heat triangle, Concept of residual stresses, distortion in cutting, factors causing distortion, distortion control techniques in cutting	4
Total		**28**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Welding Technology for Engineers, Eds. Baldev Raj, V. Shankar,A.K. Bhaduri, Narora Publishing House, 3rd Reprint	2009
2.	V. M. Radhakrishnan, "Welding Technology and Design", Revised Second Ed., New Age International Publishers.	
3.	A Guide to Designing Welds, J.G. Hicks, Wood-head Publishing Ltd.	2001
4.	The Science and Practice of Welding, Vol-1 : Welding Science and Technology	1996
5.	Messler R.W., "Principles of Welding", John Wiley & Sons	1999
6.	Welding Handbook 9th edition, Vol- 1: Residual stress and distortion	2001

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mechanical & Industrial Engineering

1. **Subject Code:** MIN-631 **Course Title**: Dissimilar Metal Joining
2. **Contact Hours:** **L:** 3 **T:** 1 **P:** 0
3. **Examination Duration (Hrs.):** **Theory:** 3 **Practical:** 0
4. **Relative Weightage:** **CWS:** 20-35 **PRS:** 0 **MTE:** 20-30 **ETE:** 40-50 **PRE:** 0
5. **Credits:** 4 **6. Semester:** Spring **7. Subject Area:** PEC
8. **Pre-requisite:** Nil
9. **Objective:** To provide knowledge of issues encountered during dissimilar metal joining, approaches to overcome problems related to dissimilar metal joining, methods suitable for dissimilar metal joining.

10. **Details of the Course**

S.No.	Contents	Contact hours
1.	**Introduction:** Basic terminology, fundamental causes of issues in dissimilar metal joining, common challenges in dissimilar metal joining, applications of dissimilar metal joining, base metal properties and their influence on dissimilar metal joining, fundamental approaches to address issues of dissimilar metal joining, dilution, selection of filler/interlayer material, fillers metals and interlayers, Schaeffler diagram, joint design, identification of weak zone in dissimilar metal joints, preheat and post weld heat treatment	12
2.	**Fusion Arc Welding Processes:** Asymmetric weld and embrittlement of fusion weld joints of dissimilar metals, cracking, residual stress and distortion issues in fusion weld of dissimilar metals, brazing, and braze welding using unique approaches for dissimilar joining by activate flux, hot-wire and pulse GTAW, pulse-GMAW, narrow gap welding, spot welding, case studies related to dissimilar metal joining of stainless steel-low alloy steel, aluminium-steel, copper to steel, nickel-steel	10
3.	**Radiation welding:** Typical problems of dissimilar joining by radiation based processes (LBW/EBW)**,** unique approaches of dissimilar metal joining by laser and electron bean welding, melt in and keyhole modes of joining, typical case studies of dissimilar joining of iron-copper, stainless steel-low carbon steel, low carbon steel-Ni & Cu alloy by LBW and EBW.	6
4.	**Solid state joining :** Issues and requirement of dissimilar metal joining by solid state joining processes, unique approaches of dissimilar metal joining by friction stir welding, diffusion bonding, ultrasonic welding, explosive bonding, and roll cladding, mechanical fastening, adhesive joining, application of interlayer typical case studies of solid state joining of Al-steel, Al-Cu, Al-Mg, metal-polymer, copper-steels, titanium-steels	10
5.	**Quality assessment of dissimilar metal joint**: Inspection, characterization and their interpretation of results related to mechanical testing, non-destructive testing of dissimilar joints, case studies	4
Total		**42**

11. Suggested Books:

S.No.	Name of Authors/Book/Publisher	Year of Publication / Reprint
1.	Kazakov, "Diffusion Bonding of Materials" Mir Publishers, Moscow	2013
2.	Pierpaolo Carlone.,"Dissimilar Metal Welding" MDPI, Switzerland	2019
3.	William M. Steen, "Laser Material Processing", springer.UK.	2010
4.	Mohammad Kazem., "Advances in friction Stir Welding and Processing", Wood head, UK.	2014
5.	W.H.Kearns "Metals and their Weldability", welding Handbook, AWS	1984
6.	Baldev Raj, V Shankar, A K Bhaduri, "Welding Technology for Engineers", Narosa publishing house, India	2006
7.	"Welding Handbook" Vol. 3, 9th Edition", American Welding	2002
8.	"Metals Handbook", Vol. 6, ASM International Publication	1993