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Indian Institute of Technology Jodhpur

Proposed Curriculum

Ph.D. (METALLURGICAL AND MATERIALS ENGINEERING)

Cat.	***Course Number***	***Course Title***	***L-T-P***	***Credits***	***Cat.***	***Course Number***	***Course Title***	***L-T-P***	***Credits***
I Semester					**II Semester**				
E		*Elective 1**	3-0-0	3	E		*Elective 5**	3-0-0	3
E		*Elective 2*	3-0-0	3	E		*Elective 6*	3-0-3	3
E		*Elective 3*	3-0-0	3	E		*Elective 7*	3-0-0	3
E		*Elective 4*	3-0-0	3	E		*Elective 8*	3-0-0	3
							Seminar	0-2-0	2
			Total					*Total*	
III Semester					**IV Semester**				
TH	MT799	Ph.D. Thesis			TH	MT799	Ph.D. Thesis		
			Total					*Total*	
V Semester					**VI Semester**				
TH	MT799	Ph.D. Thesis			TH	MT799	Ph.D. Thesis		
			Total					*Total*	
VII Semester					**VIII Semester**				
TH	MT799	Ph.D. Thesis			TH	MT799	Ph.D. Thesis		
			Total					*Total*	

**** Electives 1 and 5 to be taken from M.Tech. elective courses only. No 5XX courses can be taken.***

ELECTIVES

Course Number	***Course Title***	***L-T-P***	***Credits***	***Course Number***	***Course Title***	***L-T-P***	***Credits***
MT7XX	*Interfacial Phenomena*	3-0-0	3	MT6XX	*Electronic, Optical and Magnetic Properties of Materials*	3-0-0	3
MT6XX	*Fatigue and Fracture*	3-0-0	3				
MT7XX	*Quantitative Metallography*	3-0-0	3	MT6XX	*Thin Film Technology*	3-0-0	3
MT7XX	*Particulate Matter Technology*	3-0-0	3	MT7XX	*Theory and Design of Alloys*	3-0-0	3
MT6XX	*Transport Phenomena*	3-0-0	3	MT6XX	*Diffusion in Solids*	3-0-0	3

DISTRIBUTION OF CREDITS (Ph.D.)

S. No.	***Category***	***Category Title***	**Students with**	***Total Courses***	***Total Credits***
1.	E	*ELECTIVES*	M. Tech., M.E., M.Sc. Degree in MT	4	12
			M. Tech., M.E., M.Sc. Degree in other Engineering disciplines	4	12
			M. Sc. Degree in Science disciplines	10	30
			Bachelor Degree	10	30
2.	H	*THESIS*	-	-	-

DETAILED SYLLABUS FOR THE PROPOSED COURSES

Title	**Interfacial Phenomena**	Number	MT7XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Introduce various kinds of interfaces and their role in development of material properties

Learning Outcomes

The students are expected to have the ability to:

1. Design the microstructure in order to meet the properties desired in the materials

Contents

1. *Grain boundary (GB) structure:* Atomistic models and their comparison, extrinsic versus intrinsic GB structure, interaction between dislocations and GB structure, design of GBs
2. *GB energy:* Relation between GB structure and GB energy, variation in energy of different types of grain boundaries
3. *GB phenomena:* GB diffusion, GB sliding, GB migration, GB segregation, *Environmental effect on GBs (corrosion)*
4. *Importance of GBs in physical and mechanical properties:* GB strengthening, superplasticity and effect of high temperature deformation
5. *Role of interface in thin films:* Interface engineering, electronic interface state, accelerated reactions, thin film magnetism

Textbooks

1. Priester, L., *Grain Boundaries and Crystalline Plasticity*, Wiley, 2013
2. Gottstein, G. and Shvindlerman, L.S., *Grain Boundary Migration in Metals: Thermodynamics, Kinetics, Applications*, Second Edition, CRC Press, 2009
3. Chadwick, G.A., *Grain Boundary Structure and Properties*, Elsevier Science Publishing Co Inc, 1976
4. Murr, L.E., *Interfacial Phenomena in Metals and Alloys*, Addison-Wesley Educational Publishers Inc., 1975
5. McLean, D., *Grain Boundaries in Metals*, Clarendon Press, 1957

Reference Books

1. Rohrer, G.S., *Grain Boundary Energy Anisotropy: a Review*, J. Mater. Sci., 2011
2. Watanabe, T., *Grain Boundary Design and Control for High Temperature Materials*, Materials Science and Engineering: A, 1993

Online Course Materials

1. Ghosh, R.N., *Principles of Physical Metallurgy*, NPTEL Course Material, Department of Metallurgical & Materials Engineering Indian Institute of Technology Kharagpur, http://nptel.ac.in/courses/113105024/15

Title	**Fatigue and Fracture**	Number	MT6XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Explain all the reasons behind failure with respect to fatigue and fracture under different conditions

Learning Outcomes

The students are expected to have the ability to:

1. Visualize, compute and asses all aspects of failure analysis in order to prevent the occurrence of untoward accidents

Contents

1. *Introduction:* fracture, fatigue, creep-fatigue interaction, nature of fracture surfaces
2. *Fracture:* Theory of linear-elastic and elastic-plastic fracture mechanics, damage mechanics, damage tolerance, dynamic fracture, fracture stress distribution at crack tip, crack initiation and propagation, fracture control, computational fracture mechanics, fracture toughness and test techniques: COD and J-integral approaches, fracture mechanics in metals, ceramics, and composites
3. *Fatigue:* Fatigue damage and design, life prediction techniques, fatigue crack initiation and propagation, residual stress effects on fatigue damage, fatigue mechanisms, short crack propagation and fretting fatigue.
4. *Fatigue Creep- fatigue interaction:* modes of high temperature fracture and fatigue fracture, micro-mechanism of damage, fracture criterion for creep fatigue, failure mapping and testing, influence of environment
5. *Analysis and Case studies:* elementary techniques for reliability analysis, components failure from different industries

Textbooks

1. Dieter, G. E., *Mechanical Metallurgy*, 3rd Edition, McGraw Hill Book Company, 1986
2. Sachs N.W., *Practical Plant Failure Analysis: A Guide to Understanding Machinery Deterioration and Improving Equipment Reliability*, Dekker Mechanical Engineering, CRC Press 2006
3. Suresh, S., *Fatigue of Materials*; 2nd Edition, Cambridge University Press, 1998
4. Carlson, R. L. and Kardomateas, G. A., *An Introduction to Fatigue in Metals and Composites*; First Edition, Chapman and Hall, London, 1995
5. Lemaitre, J., Desmorat, R., *Engineering Damage Mechanics: Ductile, Creep, Fatigue and Brittle Failures*, Springer Science & Business Media, 2006

Reference Books

1. Cooper T.D., *Prevention of Structural Failure - the Role of Quantitative Non-Destructive Evaluation*, ASM International, 1975
2. Powell G.W. and Mahmoud S.E., *Failure Analysis and Prevention*, Metals Handbook, Vol. 11, 9th edition, ASM International, 1986
3. Colangelo V.J. and Heiser F.A., *Analysis of Metallurgical Failure*, 2nd edition, Wiley-Interscience, 1987
4. Shipley R.J. and Becker W.T., *Failure Analysis and Prevention*, ASM handbook, Vol. 11, ASM International, 2002
5. Gulati R. and Smith R., *Maintenance and Reliability Best Practices*, Industrial Press, 2009.
6. Hull D. and Clyne T.W., *An Introduction to Composite Materials*, 2nd Ed., Cambridge University Press, 2013

Online Course Materials

1. Ramesh, K., *Engineering Fracture Mechanics,* NPTEL Course Material, Department of Applied Mechanics, Indian Institute of Technology Madras, http://nptel.ac.in/courses/112106065/
2. Ramesh, K., *Experimental Stress Analysis,* NPTEL Course Material, Department of Applied Mechanics, Indian Institute of Technology Madras, http://nptel.ac.in/courses/112106068/

Title	**Quantitative Metallography**	Number	MT7XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Explain the principles to accurately relate the information in two-dimensional images observed in microstructure with their three-dimensional features

Learning Outcomes

The students are expected to have the ability to:

1. Interpret the features of the images of microstructure accurately and develop interrelationships among them

Contents

1. *Introduction:* elements of microstructure, geometric properties of features
2. *Basic stereological procedures*: stereology, ground rules for applying stereology
3. *Geometry of microstructures:* characterization of microstructures- qualitative, quantitative, topographic microstructural states, quantitative fractography
4. *Classical stereological measures:* area fraction from the point count, volume fraction from the point count, feature perimeter from line intercept count, surface areas and the line intercept count
5. *Sampling:* sample design, procedure for isotropic, uniform and random sampling
6. *Data analysis:* Statistical interpretation, computer assisted methods, geometric modelling, unfolding size distributions, anisotropy and gradients, quantification of features in Transmission Electron Microscopy

Textbooks

1. Russ, J. C., Dehoff, R. T., *Practical Stereology*, 2nd edition, Springer, 2001
2. Voort, G. F. V., *Metallography: Principles and Practice*, ASM International, 1984
3. Fractography, *ASM Handbook*, Volume 12, ASM International, 1987
4. *Metallography and Microstructures*, ASM Handbook, Volume 9, ASM International, 2004

Title	**Particulate Matter Technology**	Number	MT7XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech. (MT) and Ph.D. (MT) Program	Type	Compulsory
Prerequisite	None		

Objectives

The Instructor will:

1. Explain the origin and application of particulate matter technology

Learning Outcomes

The students are expected to have the ability to:

1. Select an appropriate process for separation of particulate materials and also optimise the properties for technological impact

Contents

1. *Particle size:* definitions, determination, size reduction methods. Grinding. Liquid-Solid separation, Separation methods, thickeners, cyclones, filters, froth flotation
2. *Sedimentation, filtration, fluidization and flotation*
3. *Thermodynamic stability diagrams:* Roasting. Structure and properties of slags.
4. *Liquid metallic solutions:* change of standard states, activity interaction parameters. Leaching, solvent extraction, ion exchange, precipitation. Electro-winning. Material and heat balance
5. *Applications in extraction of copper and aluminium*
6. *Nano-sized Particles:* Top-down and bottom-up approaches, introduction to nanotechnology and understanding its properties and characterization

Textbooks

1. Geankoplis C.J., *Transport Processes and Separation Process Principles*, 4th Ed., Prentice Hall, 2003
2. Brown G.G., and Associates, *Unit Operations*, BS Publishers, 1995
3. Kelly, E.G., and Spottiswood, D.J., *Introduction to Mineral Processing*, John Wiley, New York, 1982
4. Rosenquist, T., *Principles of Extractive Metallurgy*, McGraw-Hill, New York, 1974

Reference Books

1. Fuerstenau, M.C., and Han, K.N., *Principles of Mineral Processing, Society for Mining, Metallurgy and Exploration (SME)*, Colorado, 2003
2. Yang W.C., *Handbook of Fluidization and Fluid Particle systems*, Marcel Dekker Inc., 2003
3. Ray, H.S., Sridhar, R. and Abraham, K.P., *Extraction of Nonferrous Metals*, Affiliated East-West Press, New Delhi, 1985

Online Course Materials

1. Nagarajan. R., *Particle Characterization,* NPTEL Course Material, Department of Chemical Engineering, Indian Institute of Technology Madras, http://nptel.ac.in/courses/103106103/

Title	**Transport Phenomena**	Number	MT6XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Explain heat, mass and momentum transfer in various metallurgical processes

Learning Outcomes

The students are expected to have the ability to:

1. Relate the subject with industrial practice
2. Implement the understanding towards the optimization of ongoing metallurgical processes

Contents

1. *Introduction to Metallurgical Systems*: Concept of unit operations in chemical metallurgy, engineering fundamentals of unit processes
2. *Momentum Transfer:* Differential and overall balances and their applications in flow through pipes, inclined planes, packed beds and flow measuring devices such as orifice meter, Venturi meter, flow nozzles, pitot tube, rotameter, concept and working principle of supersonic nozzles; momentum transfer in turbulent flow situation
3. *Heat Transfer:* Conduction- Steady state heat conduction problems in slabs, hollow cylinders, spheres, composite walls, composite pipes etc, unsteady heat transfer in metallic specimens (lumped system) Convection- free and forced convection, heat transfer coefficient, dimensional analysis problems. Radiation- emissivity, absorptivity, Planck's distribution law, Wein's displacement law, Stefan - Boltzmann law, radiative heat transfer between two black bodies and concept of view factor
4. *Mass Transfer:* Fundamentals of diffusion; rate laws, Uphill diffusion and Kirkendal's effect, steady and unsteady diffusion, Numerical problems on diffusion mass transfer, Fundamentals of convective mass transfer; free and forced convective mass transfer, Convective mass transfer, rate laws and mass transfer coefficient, Problems on Convective mass transport, Application of mass transfer in: case hardening, doping of semiconductors, homogenization, oxidation, absorption/desorption of gases in liquid metals
5. *Case studies on components from different industries*

Textbooks

1. Bird, R.B., Stewart, E.S., Lightfoot, E.N., *Transport Phenomena*, 2nd Edition, John Wiley, 2006
2. Geiger, G.H., Poirier, D.R., *Transport Phenomena in Metallurgy*, Addison-Wesley, 1973
3. Kou, S., *Transport Phenomena in Materials Processing*, John Wiley, 1996

Reference Books

1. Backhurst, J.R., Harker, J. H., Richardson, J.F., Coulson J.M., *Chemical Engineering Volume 1: Fluid Flow, Heat Transfer and Mass Transfer*, 6 th Ed., Butterworth-Heinemann, 1999
2. Mohanty, A.K., *Rate Processes in Metallurgy*, Prentice-Hall, 2000
3. Gaskell, D., *An Introduction to Transport Phenomena in Materials Engineering*, 2nd Edition, Momentum Press, 2012

Online Course Materials

1. Powell, A., IV. *3.185 Transport Phenomena in Materials Engineering.* Fall 2003. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

Title	**Electronic, Optical and Magnetic Properties of Materials**	Number	MT6XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Introduce the origin of electronic, optical and magnetic properties of materials from their electronic and molecular structure

Learning Outcomes

The students are expected to have the ability to:

1. Select appropriate materials for optimum properties aiming for engineering applications

Contents

1. *Electronic Properties:* Localized vs. delocalized states: From the free electron to the atom, Electronic states in crystals: DOS, bandgaps, interpretation of band diagrams, Fermions, symmetrisation and Pauli's exclusion principle: Electrons in bands and the classification of solids, "Free electron gas" description of carriers, The chemical potential: Fermi level, statistics of electron distribution, Electronic structure of semiconductors: Intrinsic and extrinsic, Semiconductor devices: p-n junctions under illumination and applied voltage
2. *Optical Properties:* Maxwell's equations: Electromagnetic waves in materials, Indices of refraction: Reflection and transmission, light scattering, polarization, optical fibres, LEDs, Periodic optical materials: Photonic bands and band gaps and dispersion relation
3. *Magnetic Properties:* Magnetization of matter, magnetic materials classification– diamagnetism, para-magnetism, ferromagnetism, anti-ferromagnetism, ferrimagnetism, saturation magnetization and Curie temperature, magnetic domains, soft and hard magnetic materials; Superconductivity - Zero resistance and the Meissner effect, critical current density

Textbooks

1. White, M.A., *Physical Properties of Materials*, 2nd Ed., CRC Press, 2011
2. Hummel R.E., *Electronic Properties of Materials*, 4th Ed., Springer, 2011
3. Kasap S.O., *Principles of Electronic Materials and Devices*, 3rd Ed., McGraw-Hill, 2009
4. Saleh, Bahaa E. A., and Malvin Carl Teich. *Fundamentals of Photonics*. 2nd ed. Wiley-Interscience, 2007

Reference Books

1. Streetman B. and Banerjee S., *Solid State Electronic Devices*, 6th ed., Prentice Hall, 2005
2. Griffiths, D. J., *Introduction to Quantum Mechanics*. 2nd ed. Pearson Prentice Hall, 2004
3. O'Handley, R. C., *Modern Magnetic Materials: Principles and Applications*. Wiley-Interscience, 1999
4. Kwok, H.L., *Electronic Materials*, PWS Publications, 1997
5. Pierret, R. F., *Semiconductor Fundamentals: Volume I*. 2nd ed. Prentice Hall, 1988

Online Course Materials

1. Parasuraman, S., *Electronic Materials,* NPTEL Course Material, Devices and Fabrication Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, http://nptel.ac.in/courses/113106062/
2. Ghosh, S., *Electronic Properties of Solids,* NPTEL Course Material, Department of Physics, Indian Institute of Technology Guwahati, http://nptel.ac.in/syllabus/115103033/
3. Polina Anikeeva, Geoffrey Beach, and Niels Holten-Andersen. *3.024 Electronic, Optical and Magnetic Properties of Materials.* Spring 2013. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

Title	**Thin Film Technology**	Number	MT6XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Develop a comprehensive explanation of thin film deposition principles and techniques

Learning Outcomes

The students are expected to have the ability to:

1. Select an appropriate deposition method and material while being able to analyse them for engineering applications

Contents

1. *The physics of gases and vacuum systems:* gas kinetics, Maxwell-Boltzmann distribution, molecular impingement flux, Knudsen equation, mean free path, transport properties
2. *Evaporation:* thermodynamics of evaporation, evaporation rate, alloys, compounds, sources, deposition monitoring techniques
3. *Deposition:* adsorption, surface diffusion, nucleation, structure development, interfaces, stress, adhesion
4. *Epitaxy:* symmetry, applications, disruption, growth monitoring, composition control, lattice mismatch, surface morphology
5. *Film analysis:* structure-thickness, topography, inhomogeneity, crystallography, bonding, point defects, composition, and optical, electrical and mechanical behaviour of thin films
6. *Vacuum technology:* different pumps, leakage and contamination detection, gauge readings, construction of vacuum systems
7. *Deposition techniques:* evaporation techniques (filaments, baskets, and boats), E-beam techniques, sputtering techniques and operating a vacuum coating system, chemical vapor deposition: gas supply and convection, reaction equilibrium and surface processes, diffusion limited deposition and reactor models
8. *Thickness measurement techniques:* point-source load calculations from nomograph, crystal thickness monitoring
9. *Thin film technology applications:* optical windows, integrated circuits, micro-electro-opto-mechanical systems and photovoltaics

Reference Books

1. Soriaga, M.P., Stickney, J., Bottomley, L.A., and Kim Y.G, *Thin Films: Preparation, Characterization, Applications*, Springer Science 2011
2. Ohring, M., *The Materials Science of Thin Films*, 2nd Edition, Academic press, 2002
3. Smith, D.L., *Thin-Film Deposition: Principles and Practice*, McGraw-Hill, 1995
4. Hummel, R. E. and Guenther, K.H., *Handbook of Optical Properties: Thin Films for Optical Coatings*, Volume 1, CRC Press, 1995
5. Chopra, K.L., *Thin Film Phenomena*, Robert E. Krieger publishing, 1969

Online Course Materials

1. Schmidt, M., Ruff, S., and Handley, R., *6.152J Micro/Nano Processing Technology.* Fall 2005. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA
2. Pandya, D.K., *Physics of Thin Films and Nanostructure Fabrication*, NPTEL Course Material, Indian Institute of Technology Delhi, http://www.nptel.ac.in/syllabus/115102019/

Title	**Theory and Design of Alloys**	Number	MT7XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Explain the fundamentals of alloys and designing the compositions to meet the requirements of specific applications

Learning Outcomes

The students are expected to have the ability to:

1. Understand the various alloy systems having varying properties at atomic and electronic levels
2. Modify conventional alloy compositions for enhanced properties

Contents

1. *Structure and stability of alloys:* solid solubility, energy of solid solutions, phase stability, electronic theories
2. *Solid solutions:* size factor, electronegativity, intermediate phases with wide solid solubility, lattice spacing in solid solutions, order
3. *Role of defects:* vacancies, stacking faults
4. *Theories of substitutional and interstitial solid solutions, intermetallic compounds, bonding theory for metals and alloys*
5. *Theory and design of specific alloys:* Ti-alloys, super alloys, special steels, shape memory alloys, high temperature metals and alloys
6. *Alloy design maps:* microstructure control, Blackmann diagrams, Darken-Gurry maps, d-orbital energy level-bond order maps

Reference Books

1. Pettifor, D. G., Cottrell, A. H., *Electron Theory in Alloy Design*, Institute of Materials, 1992
2. Cahn, R. W., Haasen, P., *Physical Metallurgy*, volume 1, 4th edition, North-Holland, 1996
3. Smallman, R. E., Ngan, A.H.W., *Physical Metallurgy and Advanced Materials*, 7th Edition, Butterworth-Heinemann, 2007
4. Tien, J., *Alloy and Microstructural Design*, Academic Press, 1976
5. Reed, R. C., *The Superalloys - Fundamentals and Applications*, Cambridge University Press, 2006

Title	**Diffusion in Solids**	Number	MT6XX
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	Ph.D. (MT) Program	Type	Elective
Prerequisite	None		

Objectives

The Instructor will:

1. Explain the mechanism of diffusion and their relevance to various metallurgical processes

Learning Outcomes

The students are expected to have the ability to:

1. Relate the role of diffusion in different metallurgical phenomena controlling the properties of materials

Contents

1. *Introduction:* theory of diffusion, diffusion in various geometries, mechanisms for diffusion
2. *Laws of diffusion:* Fick's first law, Fick's second law, methods for analysing diffusion
3. *Diffusion in metals:* self-diffusion, interstitial solutes, dilute substitutional alloys, binary intermetallics, quasicrystalline alloys
4. *Diffusion in semiconductors:* self-diffusion, foreign atom diffusion, interstitial-substitutional diffusion
5. *Diffusion in other materials:* ionic crystals, fast ion conductors, metallic glasses, oxide glasses, ceramics and polymers
6. *Role of diffusion and case studies:* grain growth, high temperature corrosion and creep

Textbooks

1. Shewmon, P. G., *Diffusion in Solids*, 2nd Edition, Wiley-TMS, 1991
2. Helmut, M., *Diffusion in Solids: Fundamentals, Methods, Materials, Diffusion-Controlled Processes*, Springer, 2007

Online Course Materials

1. Paul, A., *Diffusion in Solids*, NPTEL Course Material, Indian Institute of Science Bangalore, http://nptel.ac.in/courses/113108052/
2. Allen, S., and Eagar, T., *3.205 Thermodynamics and Kinetics of Materials.* Fall 2006. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA

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