Advanced Manufacturing Processes (AMPs)

Introduction to AMPs

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Chapter Description

- Aims
  - To provide and insight on advanced manufacturing processes
  - To provide details on why we need AMP and its characteristics
- Expected Outcomes
  - Learner will be able to know about AMPs
  - Learner will be able to identify role of AMPs in todays sceneries
- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials
- References
  - Prof N K Jain (IIT Indore, Lecture Notes)
  - Prof. V K Jain (IIT Kanpur, Lecture Notes)

Materials Used In Engineering Applications

Metal and its Alloys

Plastics and Composites

Ceramics

Engineering Materials Having Much Superior Properties

- Getting More Popularity
- Definite Advantages Over Others

- Ultra High Strength, Hardness Very High Temperature Resistance
- Difficult To Machine By Conventional Machining Methods

HOW TO MACHINE THEM ?

SOLUTION

Advanced Manufacturing/Machining Processes

Courtesy: Prof. N K Jain (IIT Indore, India)

Need of Advanced Manufacturing/Machining Processes

- **Limitations of conventional machining methods** (workpiece hardness, surface roughness, 3-d parts and complex geometries)

Increased Workpiece Hardness

Decreased Economic Cutting Speed

Lower Productivity

- Rapid Improvements In The Properties Of Materials (Workpiece Hardness, Strength, Etc.)
- Metals & Non – Metals : Stainless Steel , High Strength Temperature Resistant(hsrt) Super Alloys: Stellite, Incoloys Etc.
- Tool Material Hardness >> Workpiece Hardness
- Requires Much Superior Quality Of Tool Materials

Need Of Advanced Manufacturing/ Machining Processes ??

Product Requirements

- Complex Shapes
- Machining In Inaccessible Areas
- Low Tolerances (Say, 10 µm)
- Better Surface Integrity (No Surface Defects, Etc.)
- High Surface Finish (Nano Level Ra Value =>Nm)
- Miniaturization Of Products (Examples: Landline Phone & Mobile, Old Computers & Lap Top, Etc.)
- High Mrr

High Production Rate While Processing Difficult –To-Machine Materials

Low Cost Of Production Precision

And Ultra precision Machining (Nano-meter Machining)

↓

Requires Material Removal In The Form Of Atoms And / Or Molecules

↓

ADVANCED MACHINING PROCESSES (Amps)

Behaviour and Manufacturing Properties of Engineering Materials

Structure of Material

- Atomic Bond: Metallic, Ionic, Covalent
- Crystalline
- Amorphous

or

Non-Crystalline

- Partly Crystalline
- Polymer Chains

Physical and Chemical Properties

- Melting Point
- Density
- Specific Heat
- Thermal Conductivity
- Thermal Expansion
- Electrical Conductivity
- Magnetic Properties
- Oxidation
- Corrosion

Mechanical Properties

- Strength
- Ductility
- Elasticity
- Stiffness
- Hardness
- Toughness
- Fatigue
- Creep
- Resistance to Wear, Corrosion, Oxidation
- Hot Hardness and Strength

Property Modification

- Heat Treatment
- Annealing
- Tempering
- Normalizing
- Hardening
- Alloying
- Reinforcement s
- Composites
- Laminations
- Fillers
- Surface Treatment

Courtesy: Prof. N K Jain (IIT Indore, India)

[1] CLASSIFICATION OF VARIOUS MANUFACTURING PROCESSES

<table>
<tr><th>Basic Nature</th><th colspan="3">Traditional or Conventional Processes</th><th colspan="3">Advanced or Unconventional Processes</th></tr>
<tr><td rowspan="5">Primary Forming Processes

[Additive Or Accretion: Create Shape From Molten, Gaseous, or Solid Particles]</td><td colspan="3">Casting and Molding Processes</td><td colspan="3">Rapid Prototyping Processes
[After 1990]</td></tr>
<tr><td colspan="2">Single-Use or Expendable Mold Casting</td><td>Multiple-Use Mold Casting</td><td>Liquid Based</td><td>Solid Based</td><td>Powder Based</td></tr>
<tr><td>Multiple-use Pattern</td><td>Single-use Pattern</td><td rowspan="3">Permanent Mold Casting: Slush casting, Corthias Casting Low-pressure Vacuum Casting Die Casting, Squeeze Casting, Centrifugal Casting, Semicentrifugal Casting Centrifuging Casting, Continuous Casting, Electromagnetic Or Levitation Casting</td><td>SLA, SLT, SGC, SOUP, SCS, etc.</td><td>FDM, LOM, MJM, SAHP, etc.</td><td>SLS, BPM, TDP, MJS, DSPC, etc.</td></tr>
<tr><td>Sand Casting, Plaster Mold Casting, Ceramic Mold Casting, Rubber Mold Casting, Graphite Mold Casting, Shell Molding,</td><td>Investment Casting, Full-mold and Lost-Foam Casting</td><td colspan="3" rowspan="2">For Fabrication of Polymers: Thermoforming, Extrusion, Blow, Compression, Injection, Reaction Injection, Transfer, Cold, Rotational, & Foam Molding, Calendering, Spinning, Dipping, etc.
For Fabrication of Ceramics: Blow Molding, Dry Pressing, Isostatic Pressing, Slip Casting, Plastic Forming Techniques
For Fabrication of Fiber Reinforced Composites: Pultrusion, Filament Winding, Vacuum-bag and Pressure-bag Molding, Resin-transfer Molding, Spray Molding, Sheet Stamping, Braiding, 3D- Knitting & Weaving.</td></tr>
<tr><td colspan="3">Powder Metallurgy Processes [Late Nineteenth Century]</td></tr>
</table>

[1] CLASSIFICATION OF VARIOUS MANUFACTURING PROCESSES (Cont…)

<table>
<tr><th>Basic Nature</th><th colspan="2">Traditional or Conventional Processes</th><th>Advanced or Unconventional Processes</th></tr>
<tr><td rowspan="2">Deforming Processes

[Formative: Shapes The Material In Solid State Using Property Of Plasticity.]</td><td colspan="2">Metal Forming Processes</td><td>Advanced Metal Forming Processes</td></tr>
<tr><td>Hot-working</td><td>Cold-working Processes</td><td rowspan="2">High Energy Rate Forming (HERF) Processes:
Electromagnetic Forming, Explosive Forming, and Electro-hydraulic Forming. Laser Bending,
3d-laser Forming,
Hot Isostatic Pressing (HIP)

For Sheet Metal Components:
Electroforming, Plasma Spray Forming</td></tr>
<tr><td>Rolling,
Forging,
Extrusion,
Hot-drawing,
Piercing</td><td>Squeezing: Cold Rolling, Cold Forging , Cold Extrusion, Swaging, Sizing, Riveting, Staking, Coining, Peening, Burnishing, Hubbing, and Thread Rolling.
Bending: Angle Bending, Roll Bending, Draw and Compression Bending, Roll-forming, Seaming, Flanging, and Straightening.
Shearing: Slitting, Blanking, Piercing, Lancing, Perforating, Notching, Nibbling, Shaving, Trimming, Cutoff, and Dinking.
Drawing: Spinning, Embossing, Stretch Forming, and Ironing
Sheet-metal Forming Operations</td></tr>
</table>

[1] CLASSIFICATION OF VARIOUS MANUFACTURING (Continued)

Basic Nature	Traditional or Conventional Processes			Advanced/Unconventional Processes			
Material Removal Processes	**Conventional Machining Processes** [19th Century Onwards]			**AMPs [After 1945]**			
	Axi-symmetric Parts	**Prismatic Parts**	**General**	**Mechanical**	**Chemical**	**Electro-chemical**	**Thermal**
Subtractive: Shape the Product by Removing the Excess Material]	Turning, Facing, Taper Turning, Threading, Drilling, Boring, Reaming, etc.	Milling, Shaping, Planning, etc.	Sawing, Broaching, Hobbing, Grinding, Honing, Lapping, etc.	**USM,** **AJM,** **WJM,** **AWJM,** **IJM,** **AFM,** **MAF,** **MRF**	**CHM,** **PCM,** **TCM**	**ECM**	**EDM** **EBM** **LBM** **IBM** **PAM**

[1] CLASSIFICATION OF VARIOUS MANUFACTURING (Continued)

Joining Or Consolidation Or Fabrication Processes	Joining Processes						
	Mechanical Bonding		Atomic Bonding				
	Tempor - ary	Permanent or semi-permanent	Solid state welding	Liquid state or Fusion Welding		Solid/ Liquid state	
				Electrical	Chemical		
[For assembling the various component s of a product]	Thread joints	Rivets, Stitches, Staples, Shrink-fits,	Friction, Forge, Diffusion welding, **Cold Welding:** Pressure, Explosive, Ultrasonic Welding	**Arc welding:** *Using Consumable Electrode* SMAW, GMAW, FCAW, SAW; Those using *Non- consumable Electrode:* GTAW, PAW, SW. **Resistance welding:** RSW, RSEW, RPW. **Induction welding**	**Gas welding:** OAW, and PGW, Thermit welding	Brazing, Soldering, and Adhesive bonding	**Advanced Welding Techniques:** EBW, LBW, USW **Welding of Plastics (only for Thermoplastics):** USW, LBW, Friction/spin Welding Vibration Welding Friction stir welding Hot-plate welding Hot-gas welding Implant welding Infrared welding Ultrasonic welding

[1] CLASSIFICATION OF VARIOUS MANUFACTURING (Continued)

Basic Nature	Traditional or Conventional Processes		Advanced or Unconventional Processes
Heat Treatment or Bulk Property Enhancing Processes [To modify the **bulk** properties.]	**HARDENING TECHNIQUES**	**SURFACE HARDENING** (ie Selective Heating) Processes: Flame Hardening, and Induction Hardening	Laser Beam Hardening and Electron Beam Hardening
		CASE HARDENING (ie Surface Chemistry Altering) Processes: Carburizing (pack, gas, and liquid type), Nitriding, Cyaniding or Carbonitriding.	**Additional Layer Depositing**: Ionitriding, Ion Carburizing, Ion Plating, and Ion Implantation
		CRACK REDUCTION TECHNIQUES: Austempering, Martempering / Marquenching	
	DUCTILITY, TOUGHNESS, and MACHINABILITY changing processes: Annealing (Full and Process type), Normalizing, Tempering, Spheroidizing.		
	STRENGTHENING processes: Solid Solution Strengthening, Grain Size Refinement, Strain Hardening, Precipitation or Age Hardening, Dispersion Hardening, and Phase Transformation Hardening		

[1] CLASSIFICATION OF VARIOUS MANUFACTURING (Continued)

Basic Nature	Traditional or Conventional Processes		Advanced or Unconventional Processes
Finishing And Surface Treatment Processes [To modify the **surface** properties.]	**BURR REOMVAL:** Grinding, Chamfering, Filing, Centrifugal and Spindle Finishing, Thermal-energy Deburring, Power Sanding, Power Brushing, and Mechanical Cleaning Processes as described below.		**For burr Removal:** USM, AJM, WJM, AWJM, AFM, CHM, ECDE
	MECHANICAL CLEANING and FINISHING: Abrasive Cleaning, Barrel Finishing Or Tumbling, Vibratory Finishing, Belt Sanding, Wire Brushing, Buffing, Electro-polishing.		
	CHEMICAL CLEANING: Vapor Degreasing, Acid Pickling, Alkaline, Solvent, And Ultrasonic Cleaning.		
	COATING TECHNIQUES	**COATING** (*Liquid/Gas Deposition*): Painting, Chemical Conversion Coating, Hot Dip Coating, Electro-plating, Anodizing, Electroless or Autocatalytic Plating, Mechanical Plating, Porcelain Enameling.	
		CLADDING (*Solid deposition*)	
	VAPORIZED METAL COATING	**Physical Vapor Deposition (PVD):** Vacuum Metallizing, Sputtering, Ion Plating	
		Chemical Vapor Deposition (CVD)	

Types of AMPs

- Basic AMPs: 15 (8 Mechanical + 1 Electrochemical + 1 Chemical + 5 Thermal)

- Derived AMP: Modification of Basic AMP to Meet Specific Objectives

Derived AMPs from ECM	Electro Stream Drilling (ESD)
	Shaped Tube Electro Machining (STEM)
	Electrolytic Jet Drilling (EJD)
Derived AMP from CHM	Photo Chemical Machining (PCM)
Derived AMP from EDM	Wire Electro Discharge Machining (WEDM)
Derived AMP from AFM	*Centrifugal Force Assisted Abrasive Flow Machining (CFA-AFM)*

Derived Version of HMP have also Reported TW-ECSM

- Hybrid Machining Processes (HMPs)

Hybrid Machining Processes (HMPs)

[1] Concept of HMP

Combining Either Two or More than Two AMPs

or

AMP + Conventional Machining Process

[2] When to Conceptualize and Develop an HMP ?

- ❖ To Simultaneously Exploit the Potentials and Capabilities of the Constituent Processes; and / or
- ❖ To Minimize the Adverse Effects Induced When a Constituent Process is Used Independently

- ➢ Generally, Development of an HMP is either Material or Shape Application Specific

Courtesy: Prof. N K Jain (IIT Indore, India)

HMPs are Gaining Considerable Attraction

- Meet Some of the Ultraprecision Machining Requirements
- Meet High Productivity Requirements for the Components Made of Advanced DTM Materials
- Meet the Challenging Stringent Design Requirements
- Meet Extreme Surface Quality and Tolerance Requirement

Types of HMPs [Can be Classified Into Two Major Categories (Kozak & Rajurkar, 2001)]

- Processes in which Constituent Processes are Directly Involved in Material Removal;
- Processes in which only ONE of the Participating Processes Directly Removes the Material while others Only ASSIST in Removal By Changing the Conditions of Machining in a Positive Manner
- Most of the HMPs are in their Inception and Development Phase
- Sustained Research is Required to Transform HMPs into a Matured Manufacturing Technology and for Their Successful Commercialization and Industrial Applications

Process	Combining Energy Sources	Mechanism of Material Removal	Tool	Transfer Media
Conventional Machining + Electrochemical AMP				
ECH	Electrochemical + Mechanical	Electrochemical Dissolution and Abrasion	Abrasive Sticks	Electrolyte
ECG	Electrochemical + Mechanical	Electrochemical Dissolution and Abrasion	Abrasive Wheel	Electrolyte
ECAG	Electrochemical + Mechanical	Electrochemical Dissolution and Abrasion	Metal Bonded Abrasive Wheel	Electrolyte
Conventional Machining + Thermal AMP				
AEDM	Mechanical + Thermal	Melting, Evaporation and Abrasion	Loose Abrasive Particles	Dielectric
EDAG	Mechanical + Thermal	Melting, Evaporation and Abrasion	Metal Bonded Abrasive Wheel	Dielectric
EDDG	Mechanical + Thermal	Melting, Evaporation and Abrasion	Diamond wheel	Dielectric
LAT	Mechanical + Thermal	Shearing and Heating	Turning Tool	Air
PAT	Mechanical + Thermal	Shearing and Heating	Turning Tool	Air
LAE	Chemical + Thermal	Chemical Dissolution and Heating	Mask	Etchant
Conventional Machining + Mechanical AMP				
RUM	Mechanical + Ultrasonic Vibration	Abrasion	Sonotrode having Diamond Abrasives	Coolant
UAT	Mechanical + Ultrasonic Vibration	Shearing	Turning Tool	Air

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Examples of HMPs [Conventional Machining + AMP]

Process	Combining Energy Sources	Mechanism of Material Removal	Tool	Transfer Media
		Electrochemical + Thermal		
ECSM or ECAM	Electrochemical + Thermal	Melting and/Or Evaporation	Electrode	Electrolyte
LAECM	Electrochemical + Thermal	Electrochemical Dissolution and Heating	Electrode	Electrolyte
		Electrochemical + Mechanical		
USECM	Electrochemical + Ultrasonic Vibration	Electrochemical Dissolution	Sonotrode	Electrolyte
ECMAF	Electrochemical + Mechanical	Electrochemical Dissolution + Abrasion	Abrasives	Electrolyte
		Mechanical + Thermal		
USEDM	Thermal + Ultrasonic Vibration	Melting and Evaporation	Sonotrode	Dielectric
USLBM	Thermal + Ultrasonic Vibration	Melting and Evaporation	Laser Beam	Air
		Two Mechanical AMPs		
MRAFF	Two Mechanical AMPs	Shearing	Abrasives	MR Fluid
		More than Two AMPs		
BEDMM	Electrochemical + Mechanical + Thermal	Electrochemical, Melting and Mechanical Rupture	Rotating Metal Brush	Water Glass Solution In Water

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Examples of HMPs [Two or More AMPs]

Typical Examples of Parts Developed by AMPs

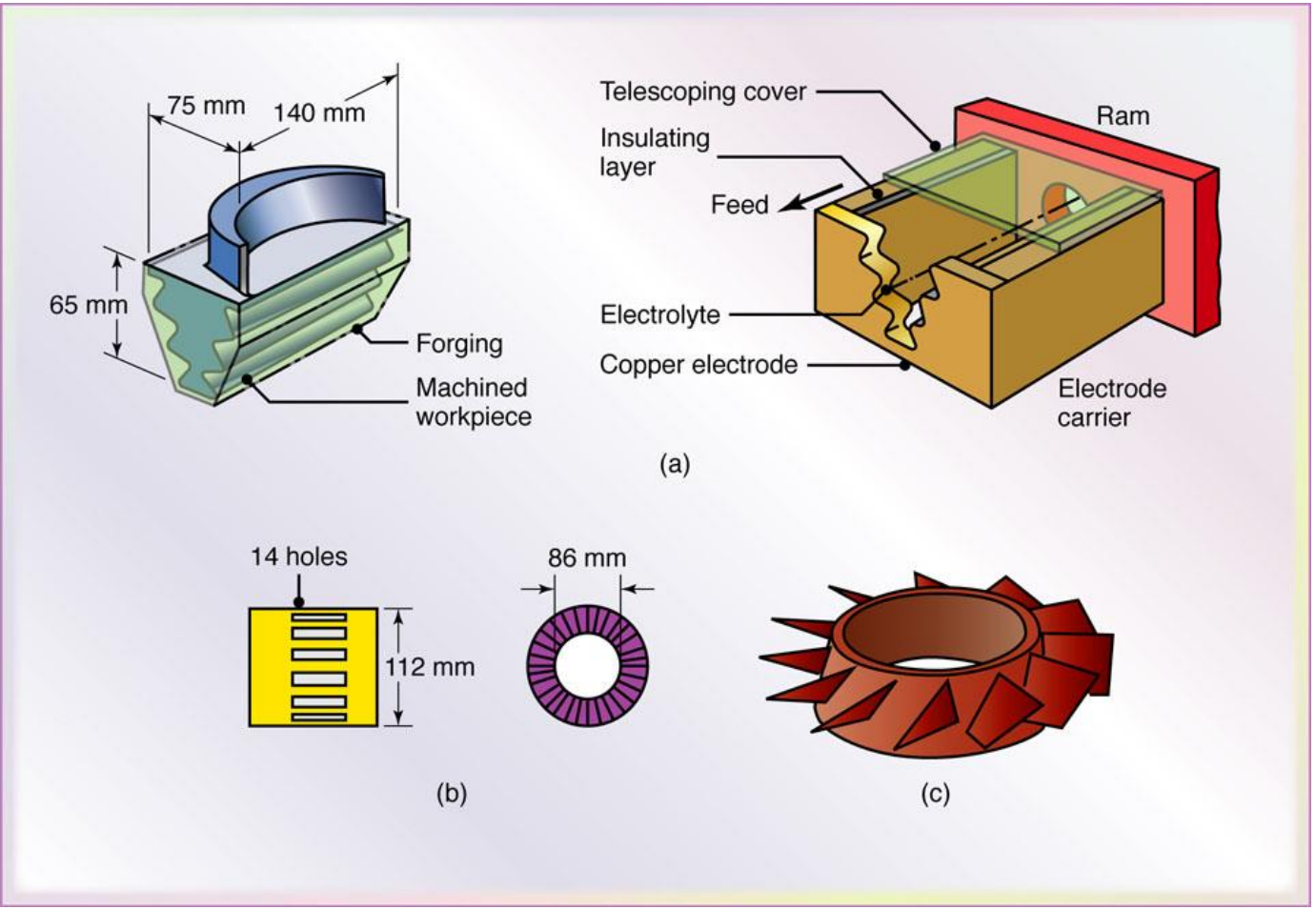
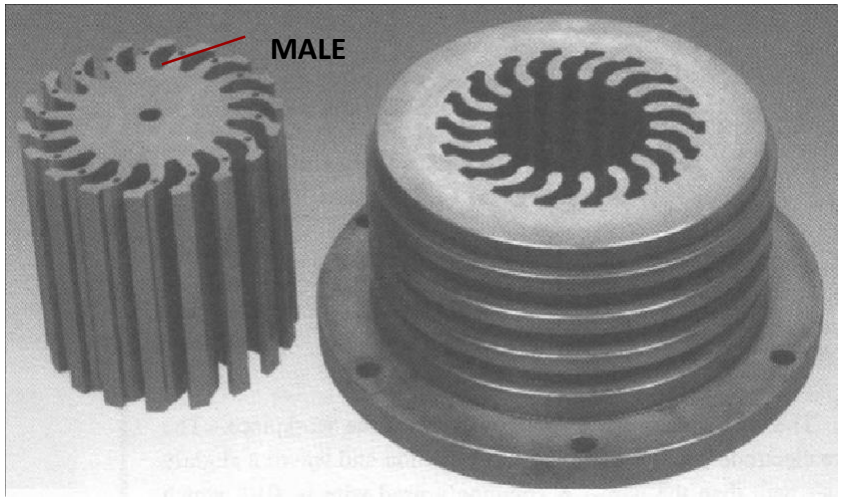
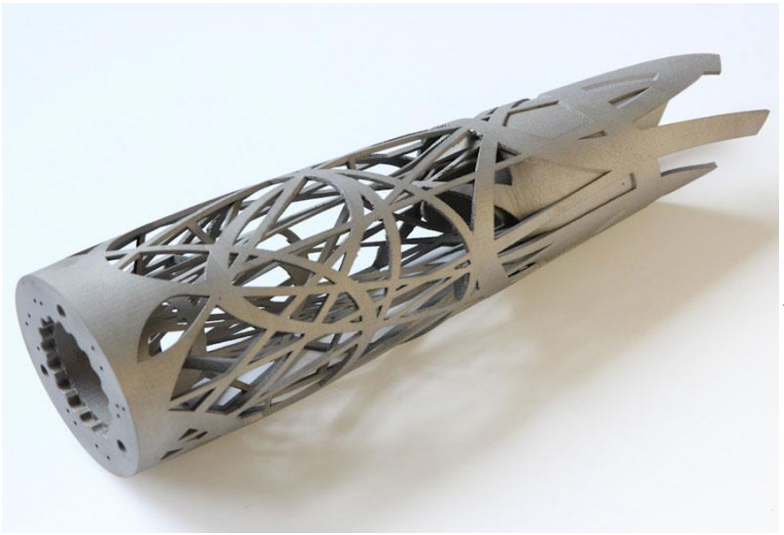


Figure:1 Typical parts made by electrochemical machining. (a) Turbine blade made of nickel alloy of 360 HB. Note the shape of the electrode on the right. (b) Thin slots on a 4340-steel roller-bearing cage. (c) Integral airfoils on a compressor disk.



PRECISION WIRE EDM



Design Made using 3D Printing

Important Characteristics of AMPs

Process performance is independent of Workpiece Material properties such as hardness. Toughness, ductility, brittleness etc.

Process Performance highly depends upon the thermal, electrical, magnetic and chemical properties of the workpiece material

Usually AMPs Possesses lower material removal rate as compared to conventional processes but in turns AMPs provide high quality parts

Initial investment cost of setting an AMP is high due to costly machine tools and high operating costs

Process utilizes different types of source energy i.e. Mechanical, Thermal, Electrical and Chemical in its direct form

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