Design for Manufacture and Cost Analysis

24-370 - Spring 2011

Professor Steve Collins

Reminders and Announcements

- HW7 due Today (or Friday)
- HW8 assigned today, due Wednesday
  - Optional bonus homework
- Project 3 due May 5th
  - Design II students may turn in on May 7th
- Faculty Course Evaluations now open
- Project 2 reports graded
  - Individual feedback by email
  - Grippers in B2 SH (except 10, 11, 15, 16)
  - Reimbursement forms

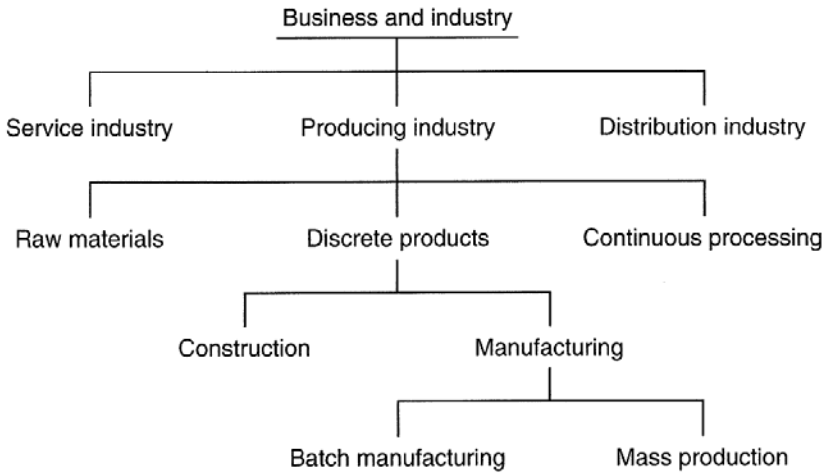
Manufacturing and Cost

- Review of Dieter and Schmidt
  - (Figures & Charts are from Ch. 13 & 16
- Exercise using IPD worksheet
- Exercise using custompart.net

Manufacturing

- What is manufacturing?
  - Converting design into product
- Manufacturing and design
  - Serial ordering is inefficient, interplay necessary
- Multilevel process
  - Process, tool, work, plant , administration
- Area of active improvement
  - Utilization: Small-lot 5%, Automated: 90%
  - Shrinking but vital portion of economy

Manufacturing and Cost



Categorization of Man. Processes

- Primary
  - Form general shape
- Secondary
  - Modify and add features
- Finishing
  - Polish, coat or paint
- Assembly

Primary Manufacturing Processes

- Create general shape
- Casting processes
  - Molten liquid (metal) solidifies in mold cavity
- Polymer molding
  - Viscous polymer compressed/injected into mold
- Deformation processes
  - Material (metal) forged, rolled, extruded, bent
- Powder processing
  - Particles (metal, ceramic, polymer) sintered

Secondary Manufacturing Processes

- Modify shape to add features
- Material removal (machining)
  - Controlled fracture: turning, milling, grinding
- Joining processes
  - Welding, soldering, riveting, bonding
- Heat treatment
  - Material properties: hardening, carburizing

Manufacturing Systems

- Different styles:
  - Job shop: small quantities, ever-changing
  - Batch: intermittent runs of similar parts
  - Assembly line: creation of sets of parts
  - Continuous flow: very specialized
- Typically mechanized
  - Machines do primary work, not people
- Varying degrees of automation
  - Machines manage process, not people

Manufacturing Selection

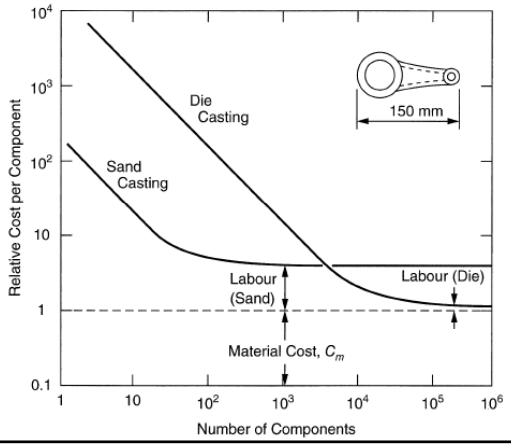
- Steps in selecting a manufacturing process
  - Identify constraints
  - Identify objectives
  - Screen possibilities
  - Compare estimated costs
- Important factors:
  - Quantity
  - Complexity
  - Material
  - Quality requirements
  - Cost and timing constraints

Quantity and cost

- Two types of manufacturing costs
  - Fixed: overhead for entire process independent qty
  - Variable: per-part costs, dependent on qty
- Examples of fixed costs
  - Cost of making molds, purchasing machines
  - Renting warehouse space
- Examples of variable costs
  - Cost of material, electricity, renting machines
  - Labor costs
- Total cost = Fixed + Variable · Qty

Quantity and batch size

- Volume: number of pieces
- Economic batch size: min practical volume

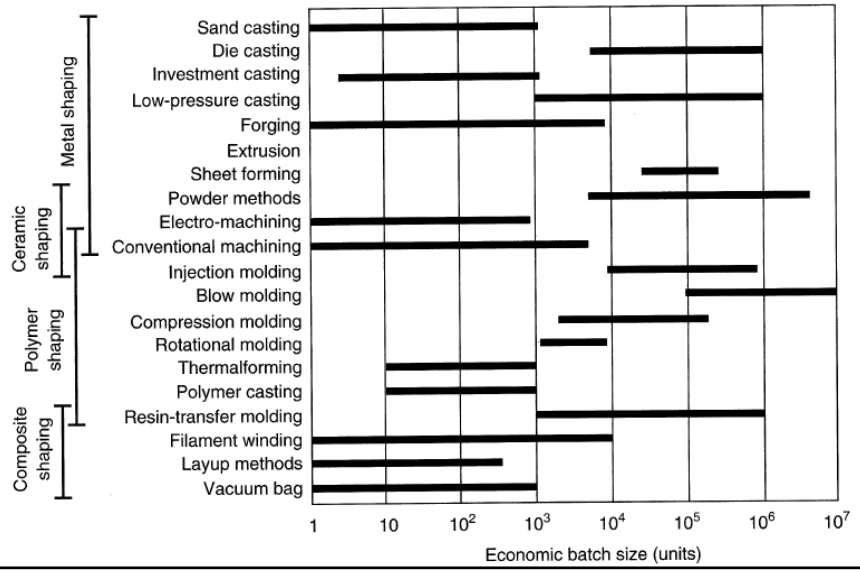


Quantity and batch size

Process	Mold cost	Labor input/unit
Injection molding	$450,000	3 min = $1
Reaction injection molding	$90,000	6 min = $2
Compression molding	$55,000	6 min = $2
Contact molding	$20,000	1 h = $20

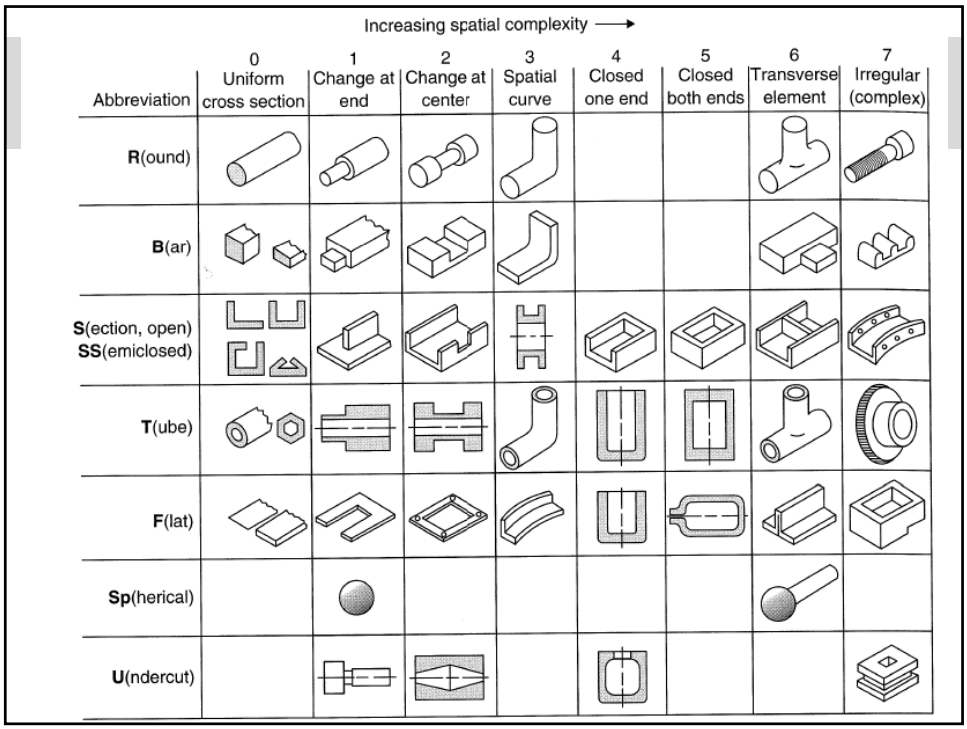
	Cost per part			
Process	1000 parts	10,000 parts	100,000 parts	1,000,000 parts
Injection molding	$451	$46	$5.50	$1.45
Reaction injection molding	$92	$11	$2.90	$2.09
Compression molding	$57	$7.50	$2.55	$2.06
Contact molding	$40	$22	$20.20	$20.02

Economic batch size vs. Process



Shape and Feature Complexity

- What is complexity?
  - Information content
    - Number of dimensions, relative tolerances
  - Type of shape
- Implications for manufacturing?
  - Some processes incapable of forming some shapes
  - Some uneconomical for some complexities



Ability of Manufacturing Processes to Produce Shapes in Fig. 13.6

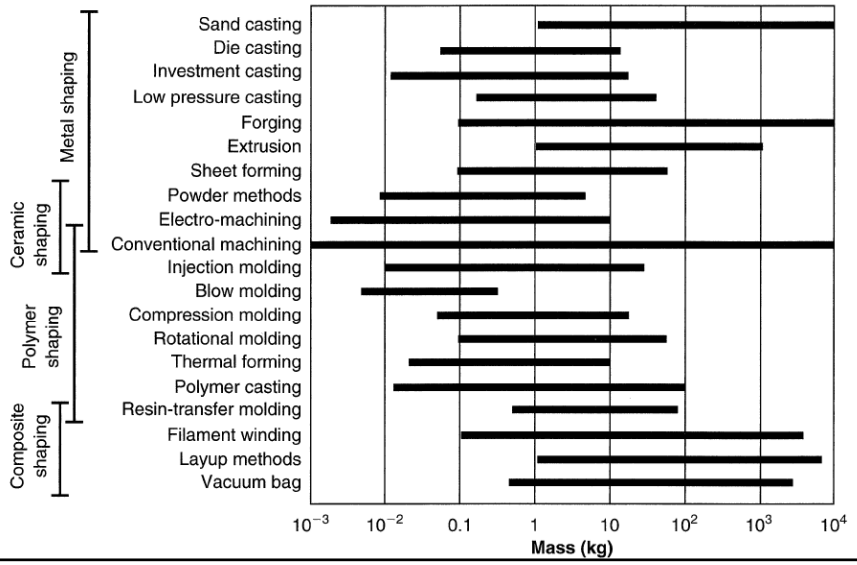
Process	Capability for producing shapes
Casting processes	
Sand casting	Can make all shapes
Plaster casting	Can make all shapes
Investment casting	Can make all shapes
Permanent mold	Can make all shapes except T3, T5; F5; U1, U5, U7
Die casting	Same as permanent mold casting
Deformation processes	
Open-die forging	Best for R0 to R3; all B shapes; T1; F0; Sp6
Hot impression die forging	Best for all R, B, and S shapes; T1, T2; Sp
Hot extrusion	All 0 shapes
Cold forging/ cold extrusion	Same as hot die forging or extrusion
Shape drawing	All 0 shapes
Shape rolling	All 0 shapes
Sheet-metal working processes	
Blanking	F0 to F2; T7
Bending	R3; B3; S0, S2, S7; T3; F3, F6,
Stretching	F4; S7
Deep drawing	T4; F4, F7
Spinning	T1, T2, T4, T6; F4, F5
Polymer processes	
Extrusion	All 0 shapes
Injection molding	Can make all shapes with proper coring
Compression molding	All shapes except T3, T5, T6, F5, U4
Sheet thermoforming	T4, F4, F7, S5
Powder metallurgy processes	
Cold press and sinter	All shapes except S3, T2, T3, T5, T6, F3, F5, all U shapes
Hot isostatic pressing	All shapes except T5 and F5
Powder injection molding	All shapes except T5, F5, U1, U4
PM forging	Same shape restrictions as cold press and sinter
Machining processes	
Lathe turning	R0, R1, R2, R7; T0, T1, T2; Sp1, Sp6; U1, U2
Drilling	T0, T6
Milling	All B, S, SS shapes; F0 to F4; F6, F7, U7
Grinding	Same as turning and milling
Honing, lapping	R0 to R2; B0 to B2; B7; T0 to T2, T4 to T7; F0 to F2; Sp

Based on data from J.A. Schey, *Introduction to Manufacturing Processes.*

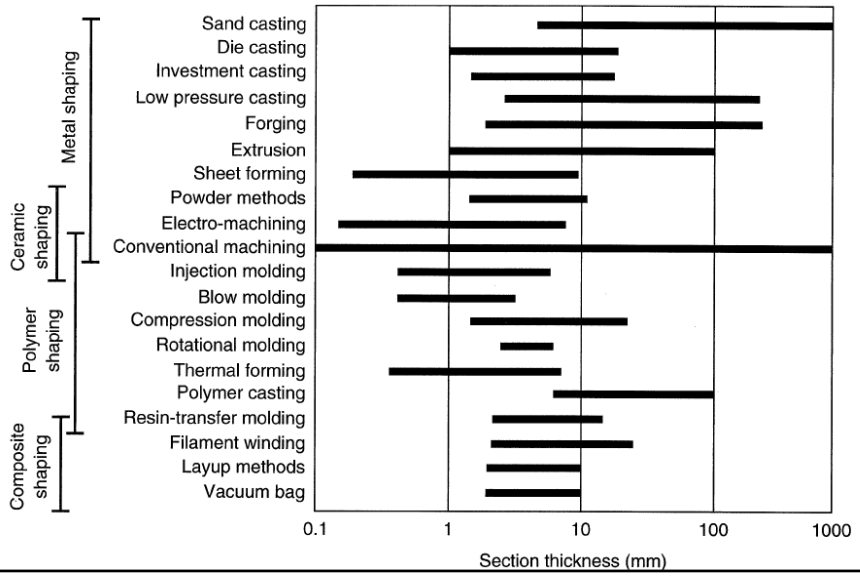
Size of parts

- What size aspects are important?
  - Overall envelope: workspace
  - Part area: pressure
  - Minimum thickness: material flow
  - Maximum thickness: cooling time
- Implications for manufacturing?
  - Some processes uneconomical for some sizes

Part mass vs. Process



Part thickness vs. Process



Material

- Processes depend on material properties, e.g.
  - Viscosity: low for casting, high for blow molding
  - Melting point: mold limits
  - Thermal capacity: cooling time
  - Hardness, brittleness: minimum bending radius

Material vs. Manufacturing process

MATERIAL / QUANTITY	IRONS	STEEL (carbon)	STEEL (tool, alloy)	STAINLESS STEEL	COPPER & ALLOYS	ALUMINIUM & ALLOYS	MAGNESIUM & ALLOYS	ZINC & ALLOYS	TIN & ALLOYS	LEAD & ALLOYS	NICKEL & ALLOYS	TITANIUM & ALLOYS	THERMOPLASTICS	THERMOSETS	FR COMPOSITES	CERAMICS	REFRACTORY METALS	PRECIOUS METALS
VERY LOW 1 TO 100	[1.5] [1.6] [1.7] [4.M]	[1.6] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.1] [1.6] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6] [5.7]	[1.6] [1.7] [3.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.5] [1.7] [3.6] [4.M] [5.1]	[1.5] [1.7] [3.7] [3.10] [4.M] [5.5]	[1.6] [1.7] [3.10] [4.M] [5.1] [5.5]	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [3.10] [4.M] [5.5]	[1.5] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.1] [1.6] [3.7] [3.10] [4.M] [5.1] [5.5] [5.6] [5.7]	[2.5] [2.7]	[2.5] [3.7]	[2.2] [2.6] [3.7]	[1.5] [5.1] [3.5] [5.5] [5.6] [5.7]	[1.1] [5.7]	[5.5]
LOW 100 TO 1,000	[1.2] [1.5] [1.6] [1.7] [4.M] [5.3] [5.4]	[1.2] [1.6] [1.7] [1.10] [4.M] [5.1] [5.3] [5.4] [5.5]	[1.1] [1.2] [1.7] [4.M] [5.1] [5.3] [5.4] [5.5] [5.6] [5.7]	[1.2] [1.7] [3.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5]	[1.2] [1.3] [1.5] [1.7] [1.8] [3.2] [3.6] [4.M] [5.1] [5.3] [5.4]	[1.2] [1.5] [1.7] [1.8] [3.7] [3.10] [4.M] [5.3] [5.4] [5.5]	[1.6] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.8] [3.10] [4.M] [5.5]	[1.2] [1.5] [1.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5] [5.6]	[1.1] [1.6] [3.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5] [5.6] [5.7]	[2.3] [2.5] [2.7]	[2.2] [2.3]	[2.2] [2.3] [2.5] [2.6] [3.7]	[1.1] [1.5] [5.1] [5.3] [5.5] [5.6] [5.7]	[5.7]	[5.5]
LOW TO MEDIUM 1,000 TO 10,000	[1.2] [1.3] [1.5] [1.6] [1.7] [3.11] [4.A] [5.2]	[1.2] [1.3] [1.5] [1.7] [3.1] [3.10] [3.11] [4.A] [5.2] [5.3] [5.4] [5.5]	[1.2] [1.5] [1.7] [3.1] [3.4] [3.11] [4.A] [5.2] [5.3] [5.4] [5.5]	[1.2] [1.5] [1.7] [3.1] [3.2] [3.7] [3.10] [3.11] [4.A] [5.2] [5.3] [5.4] [6.0]	[1.2] [1.3] [1.5] [1.6] [3.1] [3.2] [3.10] [3.11] [4.A] [5.2] [5.3] [5.4]	[1.2] [1.3] [1.5] [3.7] [3.10] [3.11] [4.A] [5.3] [5.4] [5.5]	[1.3] [1.5] [1.6] [3.1] [3.3] [3.4] [3.10] [4.A] [5.5]	[1.3] [1.8] [3.3] [3.10] [4.A] [5.5]	[1.3] [1.5] [3.2] [3.10]	[1.3] [1.5] [3.3] [3.10]	[1.2] [1.3] [1.5] [1.7] [3.1] [3.2] [3.11] [4.A] [5.1] [5.3] [5.4] [5.5] [3.10]	[3.1] [3.7] [3.10] [3.11] [4.A] [5.2] [5.3] [5.4] [5.5]	[2.3] [2.5] [2.6] [2.7]	[2.2] [2.3] [2.4]	[2.1] [2.2] [2.3]	[5.2] [5.3] [5.4] [5.5]		[5.5]
MEDIUM TO HIGH 10,000 TO 100,000	[1.2] [1.3] [3.11] [4.A]	[1.0] [2.1] [3.3] [3.4] [3.5] [3.11] [3.12] [4.A] [5.2] [5.5]	[3.1] [3.4] [3.5] [3.11] [3.12] [4.A] [5.2]	[1.0] [3.1] [3.3] [3.5] [3.11] [3.12] [4.A]	[1.2] [1.4] [1.6] [3.1] [3.3] [3.4] [3.5] [3.11] [3.12] [4.A]	[1.2] [1.3] [1.4] [1.6] [3.1] [3.3] [3.4] [3.5] [3.11] [3.12] [4.A] [5.5]	[1.3] [1.4] [3.1] [3.3] [3.4] [3.5] [3.12] 4.A]	[1.3] [1.4] [3.3] [3.4] [3.5] [3.12] [4.A]	[1.3] [1.4] [3.3] [3.4] [3.12]	[1.5] [1.4] [3.5] [3.4] [3.6] [3.12] [4.A]	[3.1] [3.5] [3.5] [3.4] [3.11] [3.12] [4.A] [5.2] [5.5]	[3.1] [3.4] [3.11] [3.12] [4.A] [5.2] [5.5]	[2.1] [2.3] [2.6] [2.7] [2.8]	[2.1] [2.5] [2.9]	[2.1] [2.3]	[3.11]	[3.12]	[3.5]
HIGH 100,000+	[1.2] [1.3] [3.11] [4.A]	[1.9] [3.1] [3.2] [3.3] [3.4] [3.5] [3.12] [4.A]	[4.A]	[1.9] [3.2] [3.5] [4.A]	[1.2] [1.M] [3.1] [3.2] [3.3] [3.4] [3.5] [3.7] [3.8] [3.11] [3.12] [4.A]	[1.2] [1.3] [1.4] [1.6] [3.1] [3.2] [3.3] [3.4] [3.5] [3.6] [3.12] [4.A]	[1.3] [1.4] [3.1] [3.3] [3.4] [3.6] [3.12] [4.A]	[1.4] [3.2] [3.3] [3.4] [3.5] 4.A]	[1.4] [3.3] [3.4] [4.A]	[1.4] [3.2] [3.5] [3.4] [4.A]	[3.2] [3.3] [4.A]	[4.A]	[2.1] [2.6] [2.8]	[2.1] [2.3] [2.4] [2.5]		[3.7] [3.11]		[3.5]
ALL QUANTITIES	[1.1]	[1.1] [1.5] [3.0] [3.0] [3.5]	[1.6] [3.6]	[1.1] [1.6] [3.6] [3.6] [3.9]	[1.1] [1.6] [3.6] [3.8] [3.9] [5.5]	[1.1] [1.6] [3.4] [3.5] [3.6]	[1.1] [3.5] [3.6] [3.8]	[3.6] [3.8] [3.9]		[3.5]	[1.1] [1.6] [3.4] [3.5] [3.6]	[3.6] [3.9]				[5.5]	[1.5]	[1.6]

KEY TO MANUFACTURING PROCESS PRIMA SELECTION MATRIX:

CASTING PROCESSES
- [1.1] SAND CASTING
- [1.2] SHELL MOULDING
- [1.3] GRAVITY DIE CASTING
- [1.4] PRESSURE DIE CASTING
- [1.5] CENTRIFUGAL CASTING
- [1.6] INVESTMENT CASTING
- [1.7] CERAMIC MOULD CASTING
- [1.8] PLASTER MOULD CASTING
- [1.9] SQUEEZE CASTING

PLASTIC & COMPOSITE PROCESSING
- [2.1] INJECTION MOULDING
- [2.2] REACTION INJECTION MOULDING
- [2.3] COMPRESSION MOULDING
- [2.4] TRANSFER MOULDING
- [2.5] VACUUM MOULDING
- [2.6] BLOW MOULDING
- [2.7] ROTATIONAL MOULDING
- [2.8] CONTACT MOULDING
- [2.9] CONTINUOUS EXTRUSION (PLASTICS)

FORMING PROCESSES
- [3.1] CLOSED DIE FORGING
- [3.2] ROLLING
- [3.3] DRAWING
- [3.4] COLD FORMING
- [3.5] COLD HEADING
- [3.6] SWAGING
- [3.7] SUPERPLASTIC FORMING
- [3.8] SHEET-METAL SHEARING
- [3.9] SHEET-METAL FORMING
- [3.10] SPINNING
- [3.11] POWDER METALLURGY
- [3.12] CONTINUOUS EXTRUSION

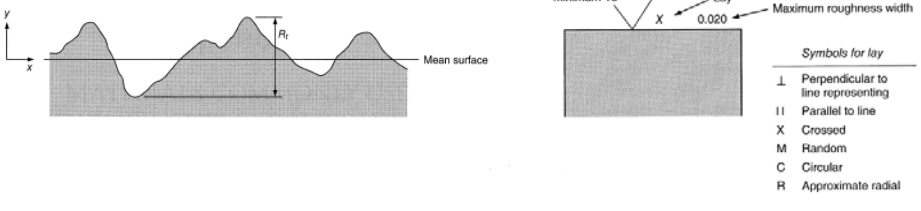
MACHINING PROCESSES
- [4.A] AUTOMATIC MACHINING
- [4.M] MANUAL MACHINING

(THE ABOVE HEADINGS COVER A BROAD RANGE OF MACHINING PROCESSES AND LEVELS OF CONTROL TECHNOLOGY. FOR MORE DETAIL, THE READER IS REFERRED TO THE INDIVIDUAL PROCESSES.)

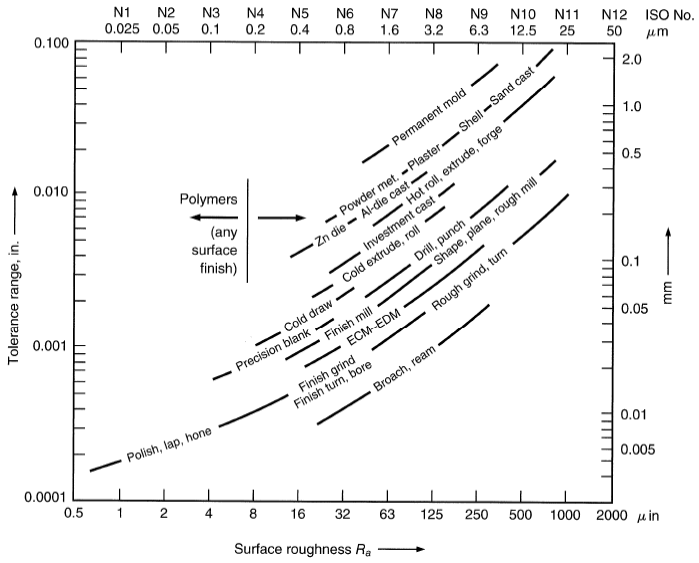
NTM PROCESSES
- [5.1] ELECTRICAL DISCHARGE MACHINING (EDM)
- [5.2] ELECTROCHEMICAL MACHINING (ECM)
- [5.3] ELECTRON BEAM MACHINING (EBM)
- [5.4] LASER BEAM MACHINING (LBM)
- [5.5] CHEMICAL MACHINING (CM)
- [5.6] ULTRASONIC MACHINING (USM)
- [5.7] ABRASIVE JET MACHINING (AJM)

Required Quality

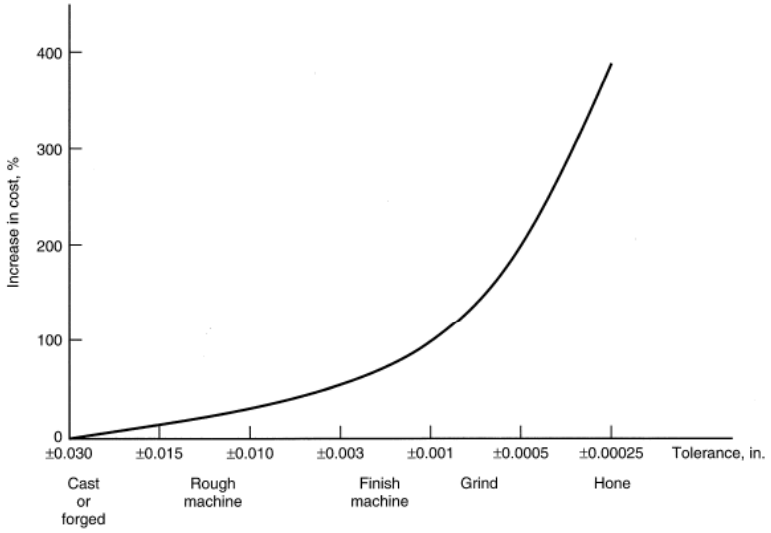
- Freedom from defects
  - Voids, cracks, chemical consistency
- Surface finish
  - Roughness, lay, waviness, integrity
- Dimensional accuracy



Quality vs. Manufacturing Process



Cost vs. Quality



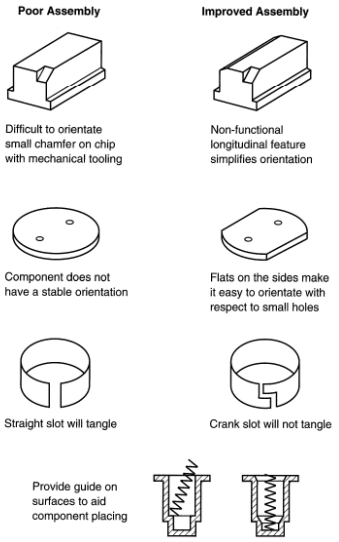
Design for Manufacture (DFM) Guidelines

- Minimize number of parts
- Standardize components
- Commonize components
- Standardize features
- Keep functional and simple
- Multifunctional parts
- Ease of fabrication (near net shape, fixturing)
- Loose tolerances
- Minimize secondary operations
- Utilize process characteristics (Judo)

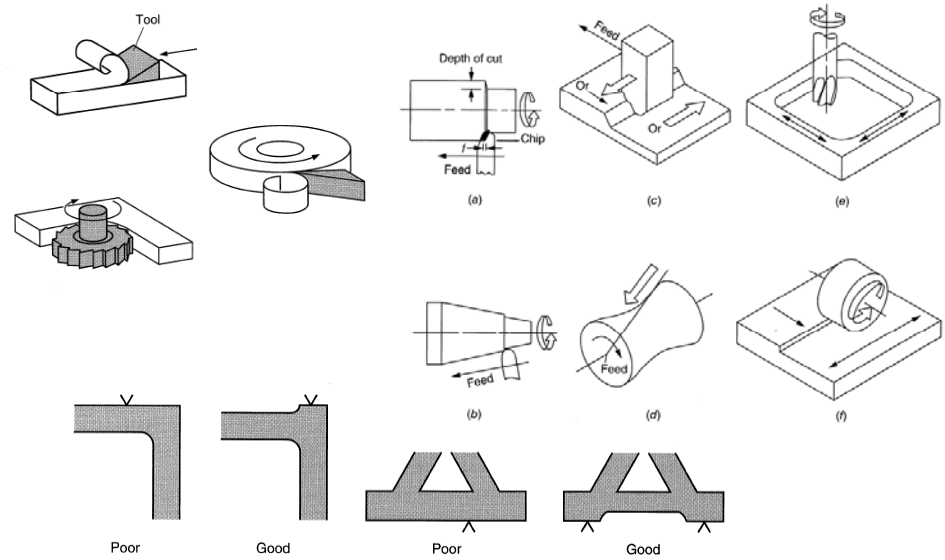
Design for Assembly (DFA) Guidelines

- Minimize number of parts
  - Unique: motion, material, assembly, maintenance
- Minimize assembly surfaces
- Sub-assemblies
- Mistake-proofing
- Handling: Avoid fasteners, Minimize handling
- Insertion: Minimize direction, Provide access

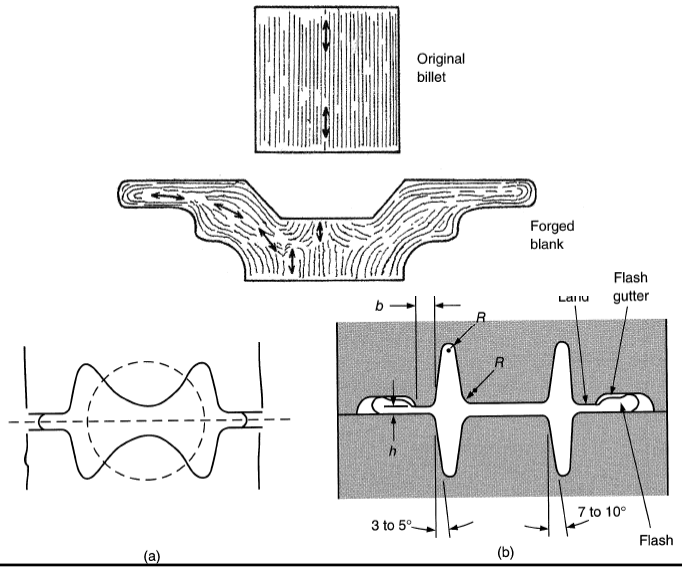
Design for Assembly Examples



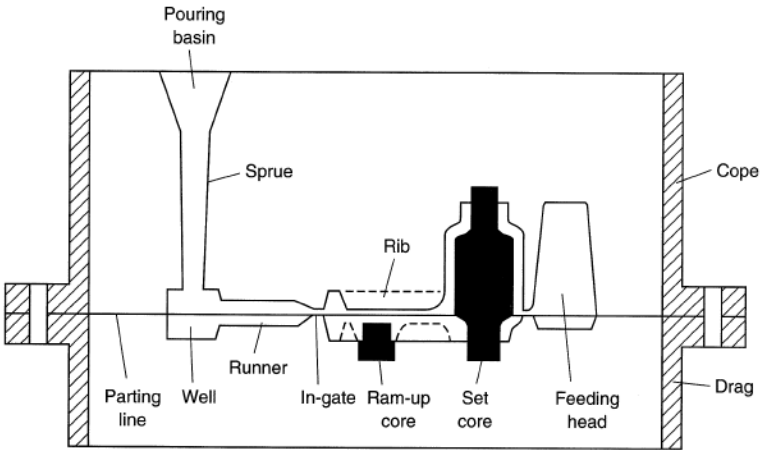
Design for Manufacture Examples: Machining



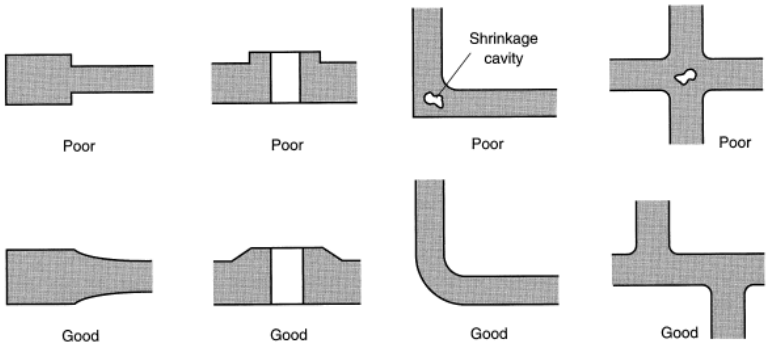
Design for Manufacture Example: Forging



Design for Manufacture Examples: Casting

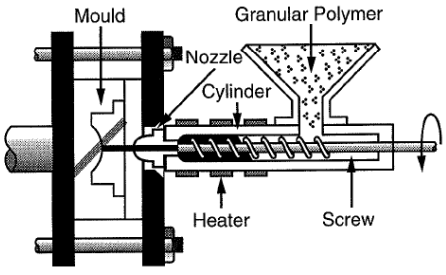


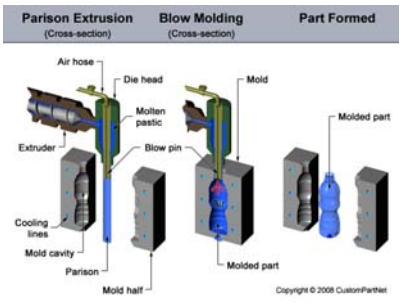
Design for Manufacture Examples: Casting



Other Processes We Will Discuss

- Injection molding
- Blow molding
- Composite processing
- Examples to follow





Manufacturing, Cost and Environment

- Cost can be primary constraint
  - Design to cost, Should-cost
- Environmental impact also important
  - Life Cycle Analysis - next week
- How to develop manufacturing cost intuition?
  - Exercises :D
  - Two tools: worksheet and online estimator

Example 1: Shaft

- What type of material and manufacturing?
  - Steel
  - Bulk: extrusion
  - Secondary: perhaps machining or grinding
- Modifications to design?
- Worksheet cost model
  - Extrusion costs
  - Cutoff costs
  - Grinding costs

Example 2: Motor cap

- See SW model, explanation
- What type of material and manufacturing?
  - Plastic
  - Primary: injection molding
- Modifications to the design?
- Worksheet cost model
  - Tooling costs
  - Variable costs
- Compare to online cost estimate

Example 3: Bearing cap

- See SW model, explanation
- What type of material and manufacturing?
  - Aluminum
  - Primary: sand casting, die casting
- Modifications to the design?
- Worksheet cost model
  - Tooling costs
  - Variable costs
- Compare to online cost estimate