

# Robust Design

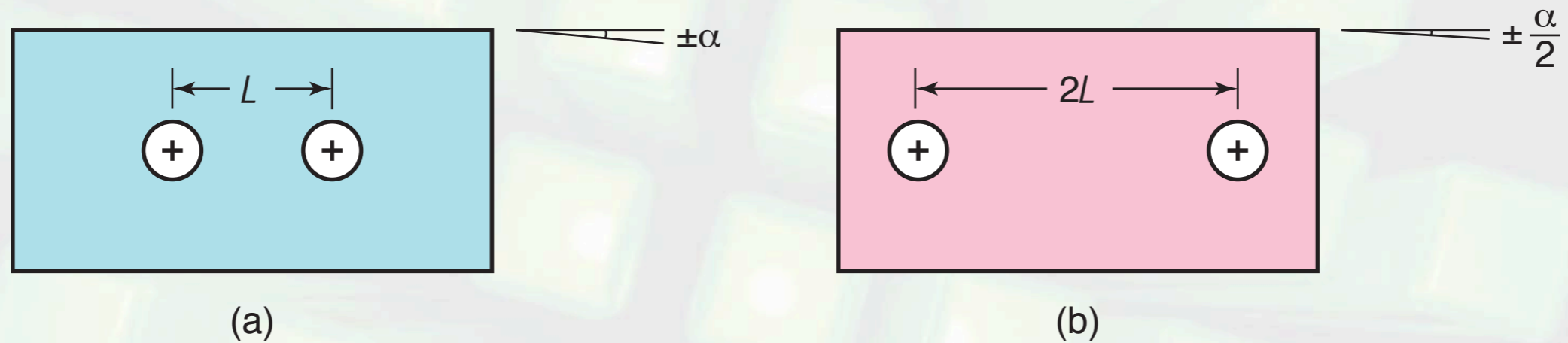
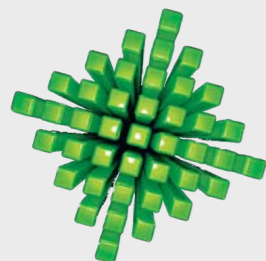


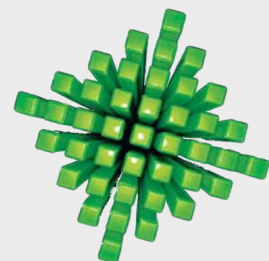
FIGURE 16.1 A simple example of robust design. (a) Location of two mounting holes on a sheet-metal bracket, where the deviation of the top and bottom surfaces of the bracket from being perfectly horizontal is  $\pm\alpha$ . (b) New location of holes in a robust design, whereby the deviation is reduced to  $\pm\alpha/2$ .



# Deming's 14 Points

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1. Create constancy of purpose toward improvement of product and service.
  2. Adopt the new philosophy.
  3. Cease dependence on mass inspection to achieve quality.
  4. End the practice of awarding business on the basis of price tag.
  5. Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease cost.
  6. Institute training for the requirements of a particular task, and document it for future training.
  7. Institute leadership, as opposed to supervision.
  8. Drive out fear so that everyone can work effectively.
  9. Break down barriers between departments.
  10. Eliminate slogans, exhortations and targets for zero defects and new levels of productivity.
  11. Eliminate quotas and management by numbers, numerical goals. Substitute leadership.
  12. Remove barriers that rob the hourly worker of pride of workmanship.
  13. Institute a vigorous program of education and self-improvement.
  14. Put everybody in the company to work to accomplish the transformation.
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TABLE 16.2 Deming's fourteen points.



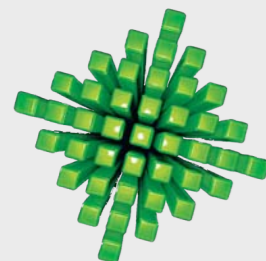
# Available Shapes of Materials

Material	Available as
Aluminum	B, F, I, P, S, T, W
Ceramics	B, p, s, T
Copper and brass	B, f, I, P, s, T, W
Elastomers	b, P, T
Glass	B, P, s, T, W
Graphite	B, P, s, T, W
Magnesium	B, I, P, S, T, w
Plastics	B, f, P, T, w
Precious metals	B, F, I, P, t, W
Steels and stainless steels	B, I, P, S, T, W
Zinc	F, I, P, W

*Note:* B=bar and rod; F=foil; I=ingots; P=plate and sheet; S = structural shapes; T=tubing; W=wire.

Lowercase letters indicate limited availability. Most of the metals are also available in powder form, including prealloyed powders.

**TABLE 16.3** Commercially available forms of materials.



# Materials Selection Considerations

Gold	60,000	Carbon steel	1
Silver	600	Magnesium alloys	2-4
Molybdenum alloys	200-250	Aluminum alloys	2-3
Nickel	35	Gray cast iron	1.2
Titanium alloys	20-40	Nylons, acetals, and silicon	1.1-2
Copper alloys	5-6	Rubber*	0.2-1
Stainless steels	2-9	Other plastics and elastomers*	0.2-2
High-strength low-alloy steels	1.4		

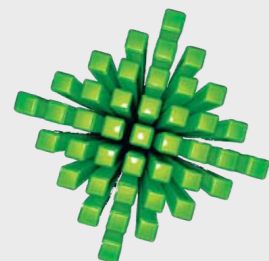
\* As molding compounds.

*Note:* Costs vary significantly with the quantity of purchase, supply and demand, size and shape, and various other factors.

**TABLE 16.4** Approximate cost per unit volume for wrought metals and plastics relative to the cost of carbon steel.

Process	Scrap (%)	Process	Scrap (%)
Machining	10-60	Permanent-mold casting	10
Closed-die forging, hot	20-25	Powder metallurgy	< 5
Sheet-metal forming	10-25	Rolling and ring rolling	< 1
Extrusion, hot	15		

**TABLE 16.5** Typical scrap produced in various manufacturing processes.



# Material Replacement

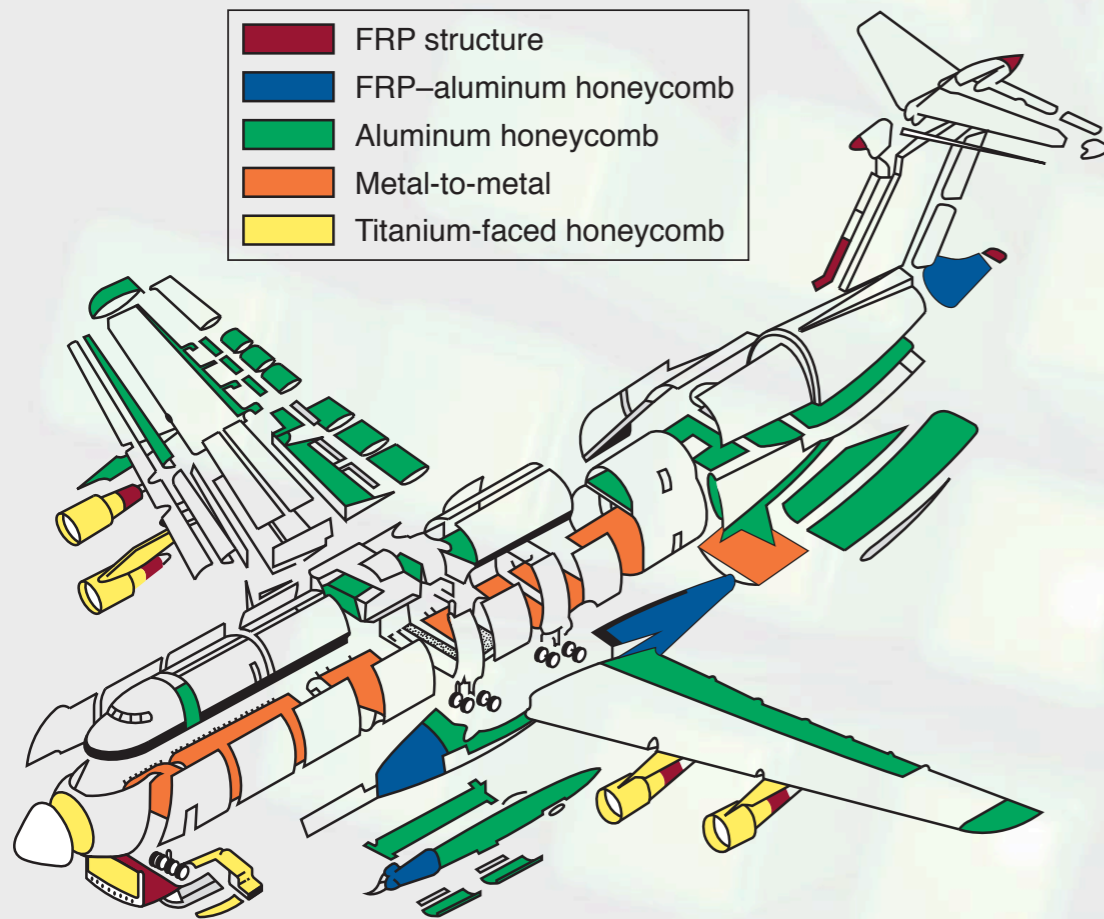
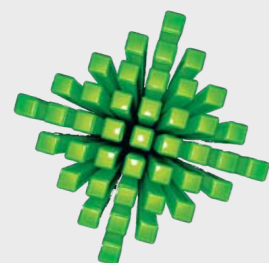


FIGURE 16.2 Advanced materials used on the Lockheed C-5A transport aircraft. (FRP is fiber-reinforced plastic.)

Item	C-5A material	C-5B material	Reason for change
Wing panels	7075-T6511	7175-T73511	Durability
Main frame forgings	7075-F	7049-01	Stress-corrosion resistance
Machined frames	7075-T6	7049-T73	
Frame straps	7075-T6 plate	7050-T7651 plate	
Fuselage skin	7079-T6	7475-T61	Material availability
Fuselage under-floor end fittings	7075-T6 forging	7049-T73 forging	Stress-corrosion resistance
Wing/pylon attach fitting	4340 alloy steel	PH13-8Mo	Corrosion prevention
Aft ramps lock hooks	D6-AC	PH13-8Mo	Corrosion prevention
Hydraulic lines	AM350 stainless steel	21-6-9 stainless steel	Improved field repair
Fuselage fail-safe straps	Ti-6Al-4V	7475-T61 aluminum	Titanium strap debonding

TABLE 16.6 Changes in materials from C-5A to C-5B military cargo aircraft.



# Process Capability

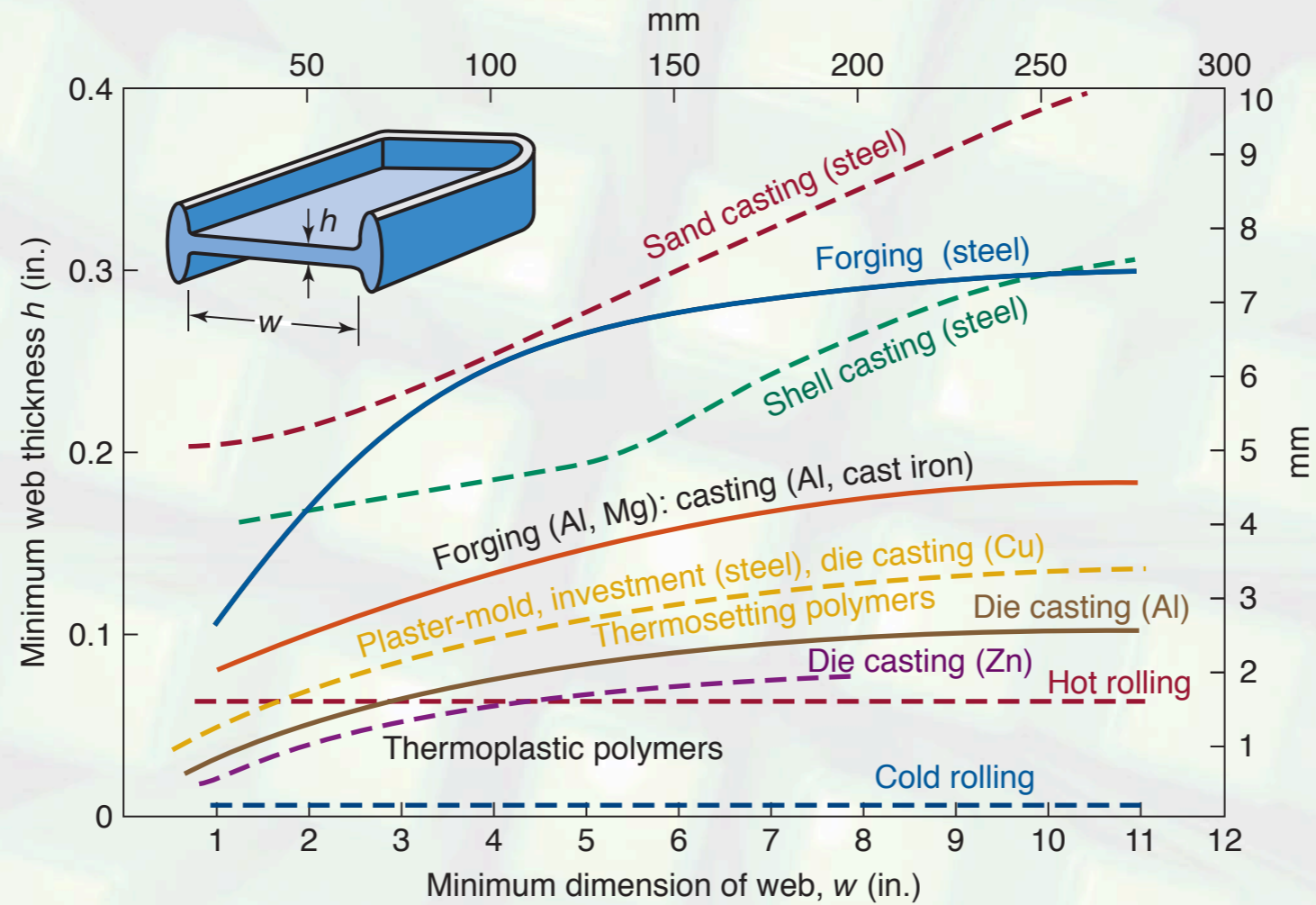
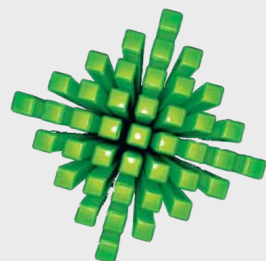


FIGURE 16.3 Minimum part dimensions obtainable by various manufacturing processes.  
Source: After J.A. Schey.



# Ashby Chart for Process Selection

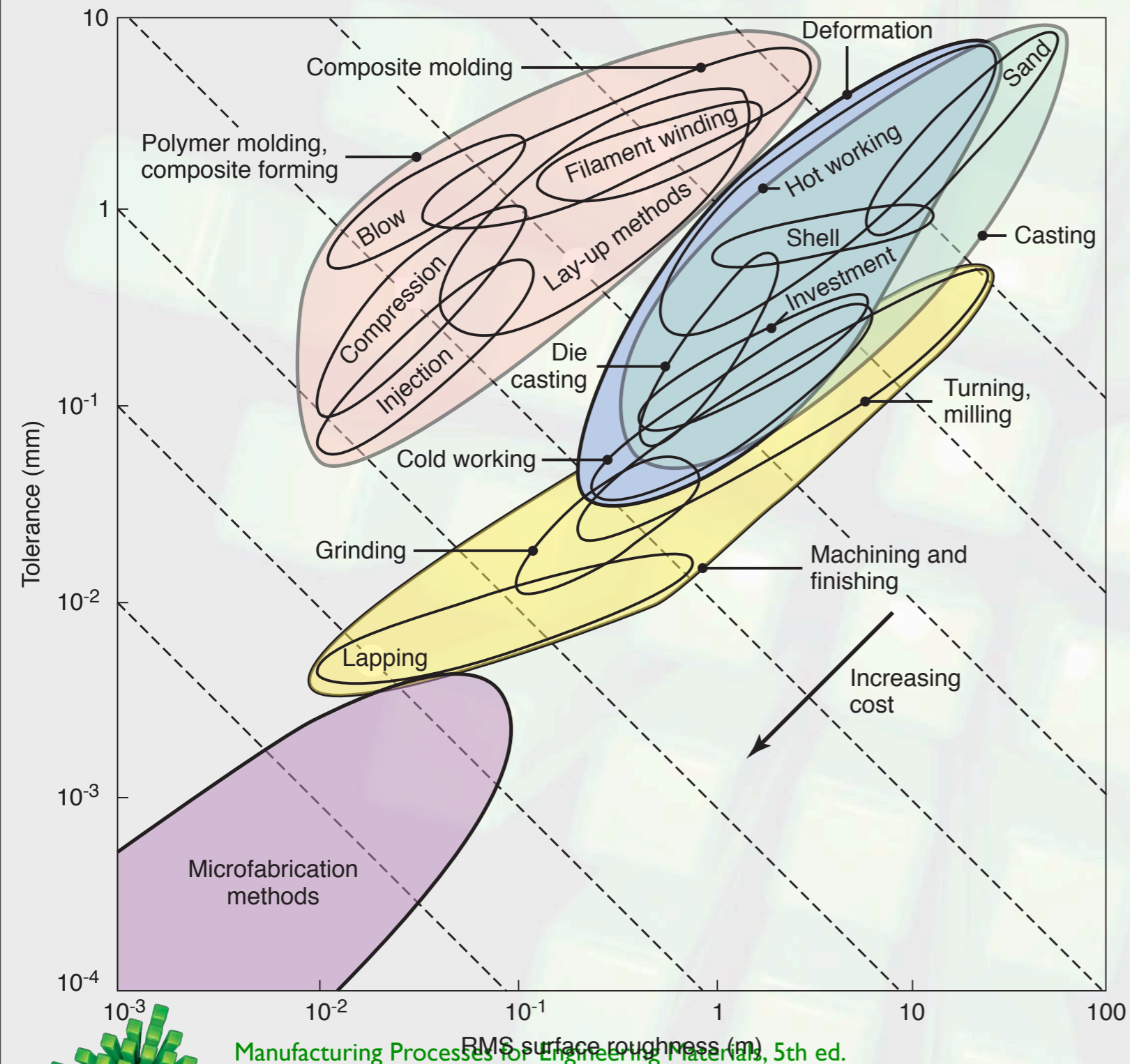
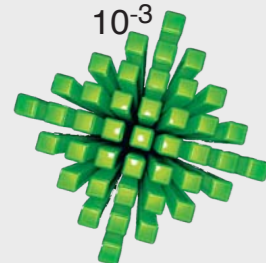


FIGURE 16.4 A plot of achievable dimensional tolerance versus surface roughness for various manufacturing operations; the dashed lines indicate cost factors. An increase in precision corresponding to the separation of two neighboring lines corresponds to a two-fold increase in cost. Source: M.F. Ashby, *Materials Selection in Design*, 3d ed., Butterworth-Heinemann, 2005.



# Production Time vs. Surface Finish

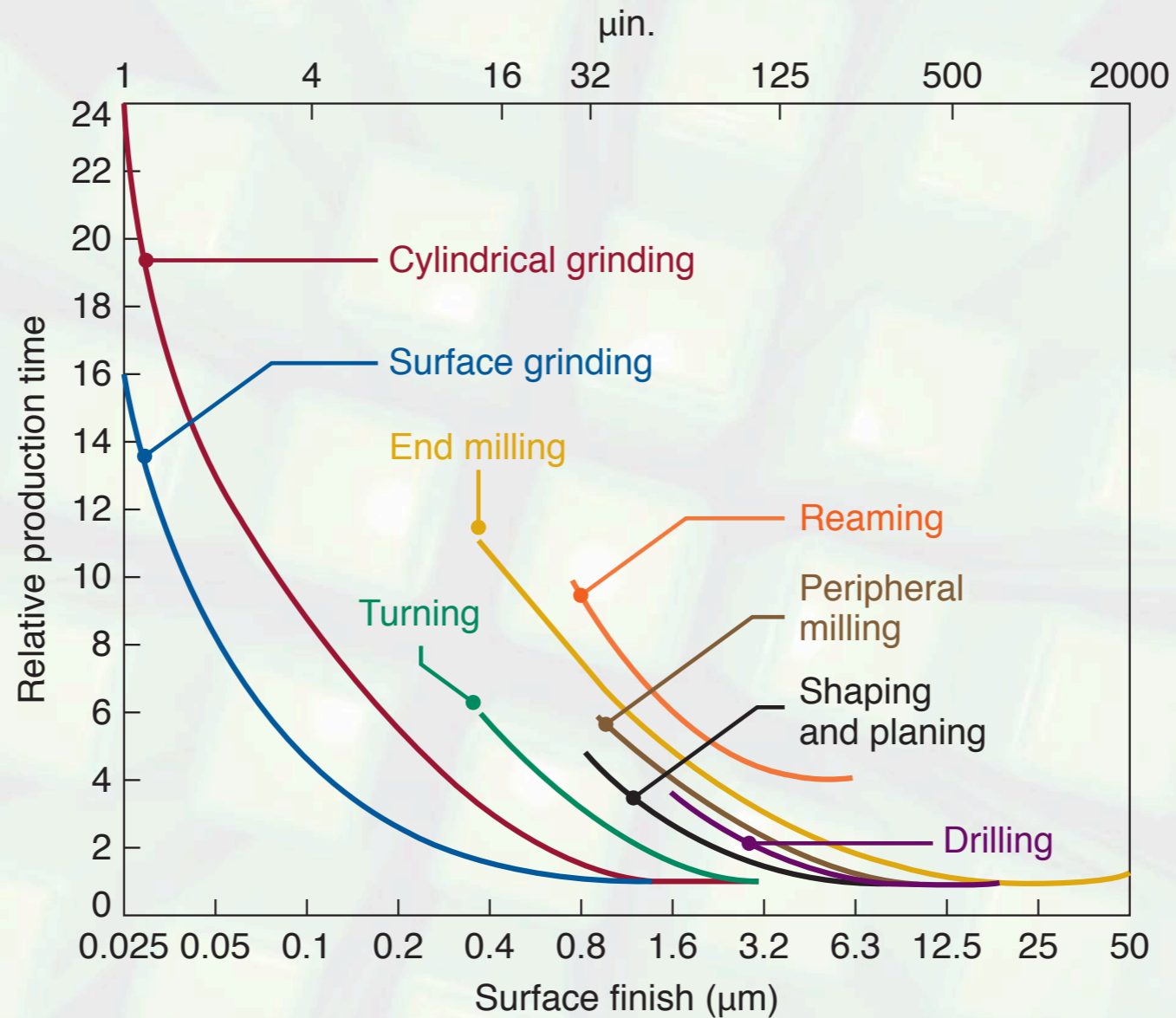
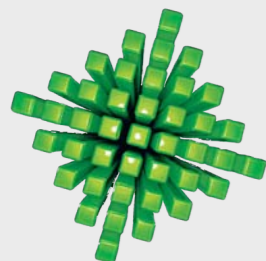


FIGURE 16.5 Relationship between relative manufacturing cost and dimensional tolerance. Note how rapidly cost increases as tolerance decreases.



# Cost vs. Tolerance

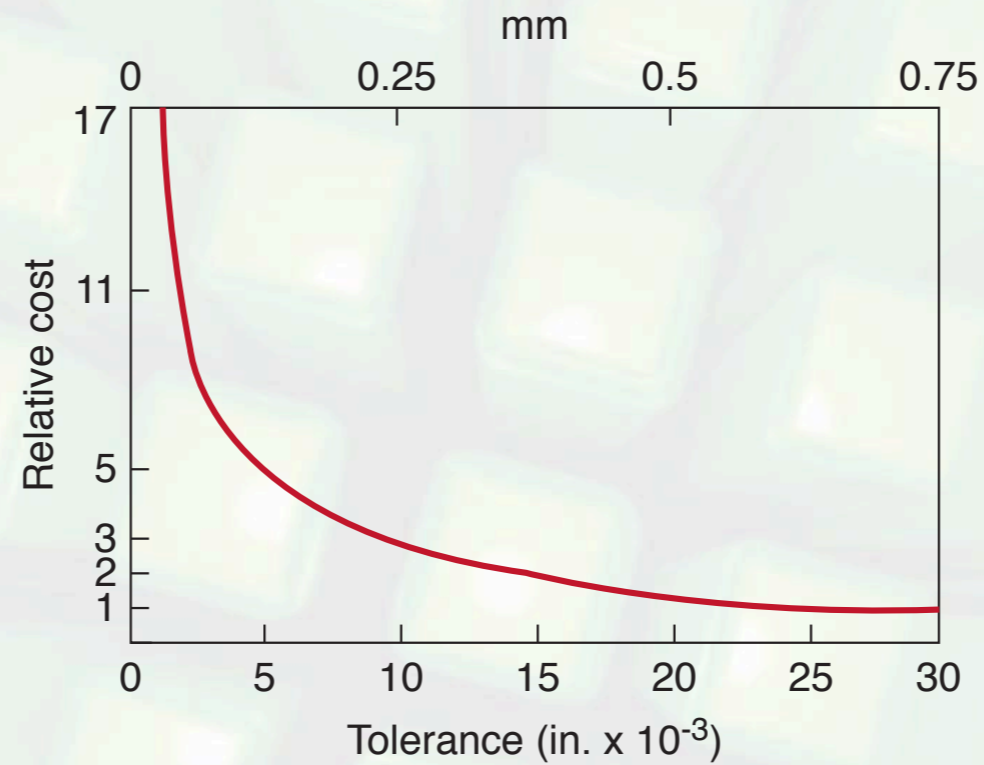
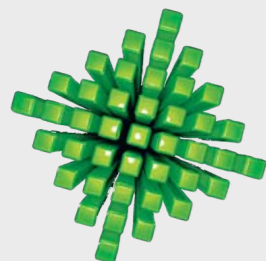


FIGURE 16.6 Relative production time as a function of surface finish obtained by various manufacturing processes. See also Fig. 9.41. Source: *American Machinist*.

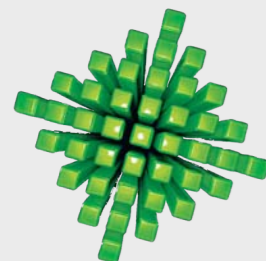


# Material Applications

	Carbon steels	Alloy steels	Stainless steels	Tool and die steels	Aluminum alloys	Magnesium alloys	Copper alloys	Nickel alloys	Titanium alloys	Refractory alloys
Casting										
Sand	A	A	A	B	A	A	A	A	B	A
Plaster	-	-	-	-	A	A	A	-	-	-
Ceramic	A	A	A	A	B	B	A	A	B	A
Investment	A	A	A	-	A	B	A	A	A	A
Permanent	B	B	-	-	A	A	A	-	-	-
Die	-	-	-	-	A	A	A	-	-	-
Forging, hot	A	A	A	A	A	A	A	A	A	A
Extrusion										
Hot	A	A	A	B	A	A	A	A	A	A
Cold	A	B	A	-	A	-	A	B	-	-
Impact	-	-	-	-	A	A	A	-	-	-
Rolling	A	A	A	-	A	A	A	A	A	B
Powder metals	A	A	A	A	A	A	A	A	A	A
Sheet-metal forming	A	A	A	-	A	A	A	A	A	B
Machining	A	A	A	A	-	A	A	A	B	A
Chemical	A	B	A	B	A	A	A	B	B	B
ECM	-	A	B	A	-	-	B	A	A	A
EDM	-	B	B	A	B	-	B	B	B	B
Grinding	A	A	A	A	A	A	A	A	A	A
Welding	A	A	A	-	A	A	A	A	A	A

*Note:* (A) Generally processed by this method; (B) can be processed by this method, but may present some difficulties; (-) usually not processed by this method. Product quality and productivity depend greatly on the techniques and equipment used, operator skill, and proper control of processing variables.

**TABLE 16.7** General applications of manufacturing processes for various metals and alloys.



# Machinery Prices

Type of machinery	Price range (\$000)	Type of machinery	Price range (\$000)
Broaching	10-300	Machining center	50-1000
Drilling	10-100	Mechanical press	20-250
Electrical discharge	30-150	Milling	10-250
Electromagnetic	50-150	Ring rolling	>500
Extruder	30-80	Robot	20-200
Fused deposition modeling	40-200	Roll forming	5-100
Gear shaping	100-200	Rubber forming	50-500
Grinding		Stereolithography	80-500
Cylindrical	40-150	Stretch forming	400 - > 1000
Surface	20-100	Transfer line	100 - > 1000
Headers	100-150	Welding	
Injection molding	30-200	Electron beam	75-1000
Jig boring	50-150	Gas tungsten arc	1-5
Horizontal boring mill	100-400	Laser beam	60-1000
Flexible manufacturing system	> 1000	Resistance, spot	20-50
Lathe	10-100	Ultrasonic	50-200
Automatic	30-250		
Vertical turret	100-400		

*Note:* Prices vary significantly, depending on size, capacity, options, and level of automation and computer controls.

**TABLE 16.8** Approximate ranges of machinery base prices.

