Chapter 40

Product Design and Process Selection in a Competitive Environment

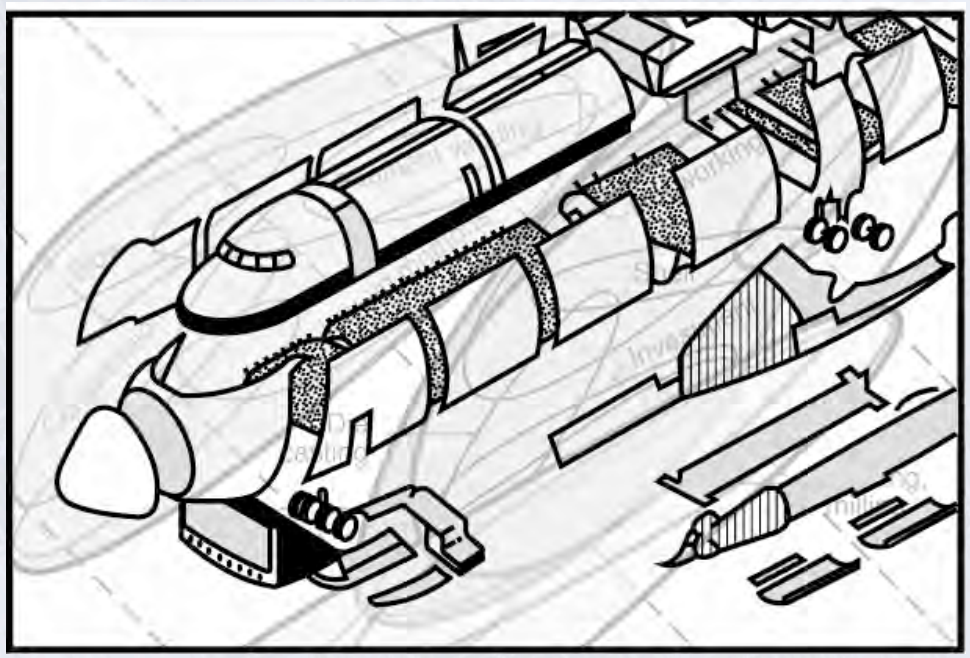

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TABLE 40.1

References to Various Topics in This Book

Design Considerations in Processing

Metal casting	Section 12.2
Forging	Section 14.6
Sheet-metal forming	Section 16.13
Powder metallurgy	Section 17.6
Ceramics shaping	Section 18.5
Polymers processing	Section 19.15
Machining	Various sections in Chapters 23 and 24
Abrasive processes	Section 26.5
Advanced machining	Various sections in Chapter 27
Joining processes	Various sections in Chapters 30 through 32

Material Properties

Tables 2.1, 2.2, 2.3, and Figs. 2.4, 2.6, 2.8, 2.14, 2.15, 2.16, and 2.28
Tables 3.1, 3.2, 3.3, and Figs. 3.1 and 3.2
Tables 5.2, 5.4 and 5.6
Tables 6.2 through 6.10
Tables 7.1 through 7.3
Tables 8.2 and 8.3
Table 9.2 and Figs. 9.3, 9.5, and 9.7
Table 10.1
Tables 12.3, 12.4, and 12.5, and Fig. 12.4
Tables 16.3 and 16.4
Tables 17.3, 17.4, 17.5, and Fig. 17.10
Table 20.2
Tables 22.1, 22.2, 22.5 and
Figs. 22.1 and 22.9
Table 26.1
Table 32.3

Manufacturing Characteristics of Materials

Table I.3
Table 5.6
Table 10.1
Tables 12.2 and 12.6
Table 14.3
Tables 16.2 and 16.3 and Fig. 16.34
Section 21.7
Figs. 22.2
Section 30.9.2

Capabilities of Manufacturing Processes

Tables 11.1 and 11.2
Table III.1
Table 14.1
Table 16.1
Section 17.7 and Fig. 17.14
Table 18.1
Tables 19.1 and 19.2
Table 20.1
Tables 23.1, 23.6, 23.8, and 23.10
Tables 26.3 and 26.4
Table 27.1
Tables 28.1 and 28.2
Table 29.1
Table VI.1
Table 30.1
Table 32.4
Table 34.1
Tables 40.2 and 40.3

Dimensional Tolerances and Surface Finish

Table 11.2
Table 23.1 and Figs. 23.13 and 23.14
Fig. 27.4

General Costs and Economics

Table I.4
Table 6.1
Section 12.6
Section 14.9
Section 16.15
Section 17.8 and Table 17.6
Section 19.16
Fig. 24.34
Section 25.8
Section 26.9 and Fig. 26.34
Section 27.10
Section 31.8
Section 32.7
Tables 40.2, 40.5, and 40.9

References to Textbook Topics

Relative Cost of Repair at Stages of Product Development and Sale

TABLE 40.2

Relative Cost of Repair at Various Stages of Product Development and Sale

Stage	Relative cost of repair
When the part is made	1
Sub-assembly of part	10
Final assembly of product	100
Product is at dealership	1000
Product is at the customer	10,000

TABLE 40.3

Average Life Expectancy for Various Products. See also Table 36.1.

Product	Years
Car battery	4
Central air-conditioning unit	15
Clothes dryer (gas)	13
Clothes washer	13
Dishwasher	10
Furnace (gas)	18
Hair dryer	5
Kitchen disposal	10
Machinery	30
Manufacturing cell	15
Passenger car	8
Personal computer	4
Refrigerator	17
Vacuum cleaner	10
Water heater (electric)	14
Water heater (gas)	12

Average Life Expectancy for Various Products

Commercially Available Shapes of Materials

TABLE 40.4

Commercially 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 = plateand sheet; S = structural shapes; T = tubing; W = wire.
Lowercase letters indicate limited availability.
Most of the metals also are available in powder form, including pre-alloyed powders.

Cost per Unit Volume for Wrought Metals and Polymers Relative to Cost of Carbon Steel

TABLE 40.5

Approximate Cost per Unit Volume for Wrought Metals and Polymers Relative to Cost of Carbon Steel

Gold	60,000	Aluminum alloys	2-3
Silver	600	High-strength low-alloy steels	1.4
Molybdenum alloys	20-250	Gray cast iron	1.2
Nickel	35	Carbon steel	1
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
Magnesium alloys	2-4		

* As molding compounds

Note: Costs vary significantly with quantity purchased, supply and demand, size and shape, and various other factors.

Approximate Ranges of Scrap Produced in Various Manufacturing Processes

TABLE 40.6

Approximate Ranges of Scrap Produced in Various Manufacturing Processes

Process	Scrap (%)	Process	Scrap (%)
Machining	10-60	Permanent-mold casting	10
Hot forging	20-25	Powder metallurgy	<5
Sheet-metal forming	10-25	Rolling	<1
Hot extrusion	15		

Example: Material Changes in Transport Aircraft

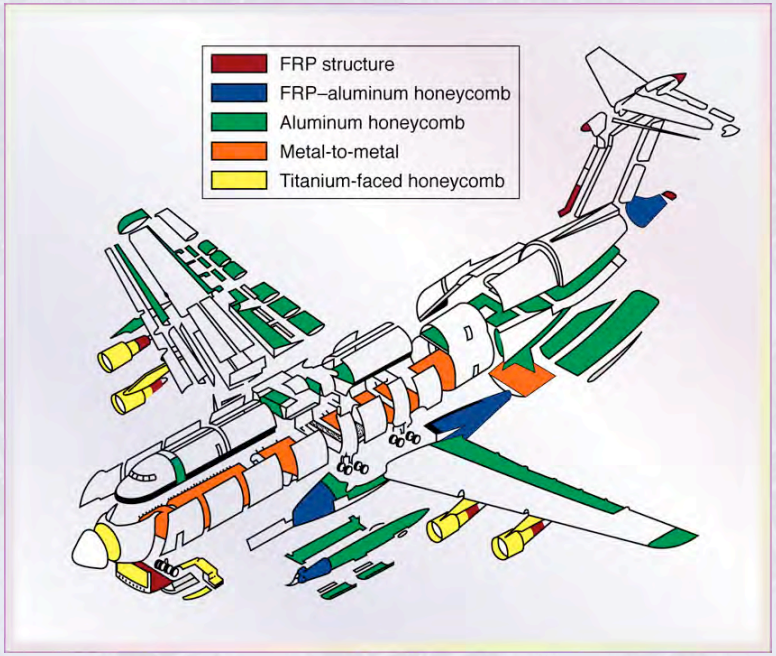


TABLE 40.7

Material Changes from C-5A to C-5B Military Cargo Aircraft

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 ramp lock hooks	D6-AC	PH13-8Mo	Corrosion prevention
Hydraulic lines	AM350 stainless steel	21-6-9 stainless steel	Improved field repair
Fuselage failsafe straps	6Al-4V titanium	7475-T61 aluminum	Titanium strap debonding

Figure 40.1 Advanced materials in the Lockheed C-5A transport aircraft. (*Note*: FRP is fiber-reinforced plastic.)

Manufacturing Capabilities for Minimum Part Dimensions

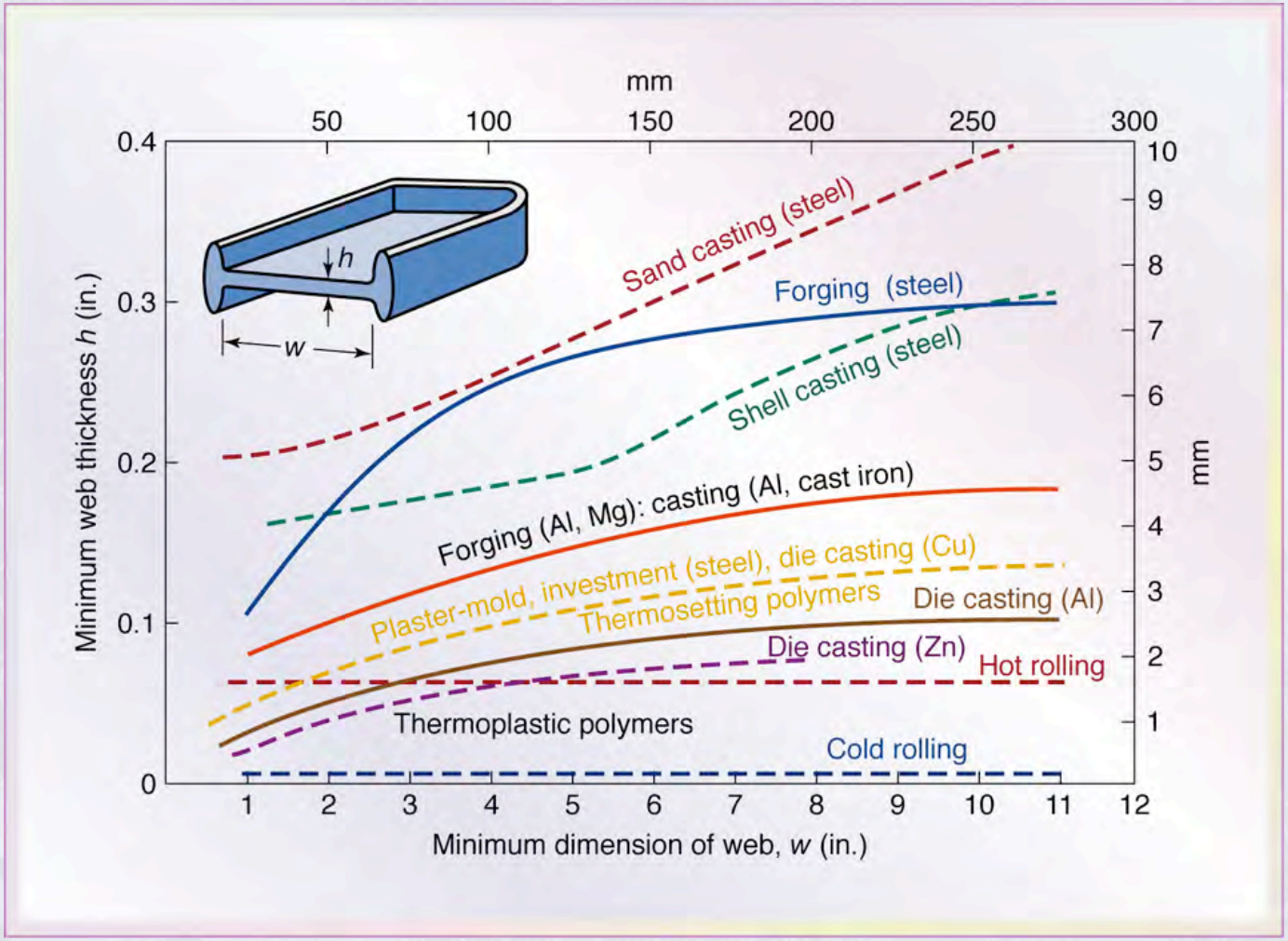
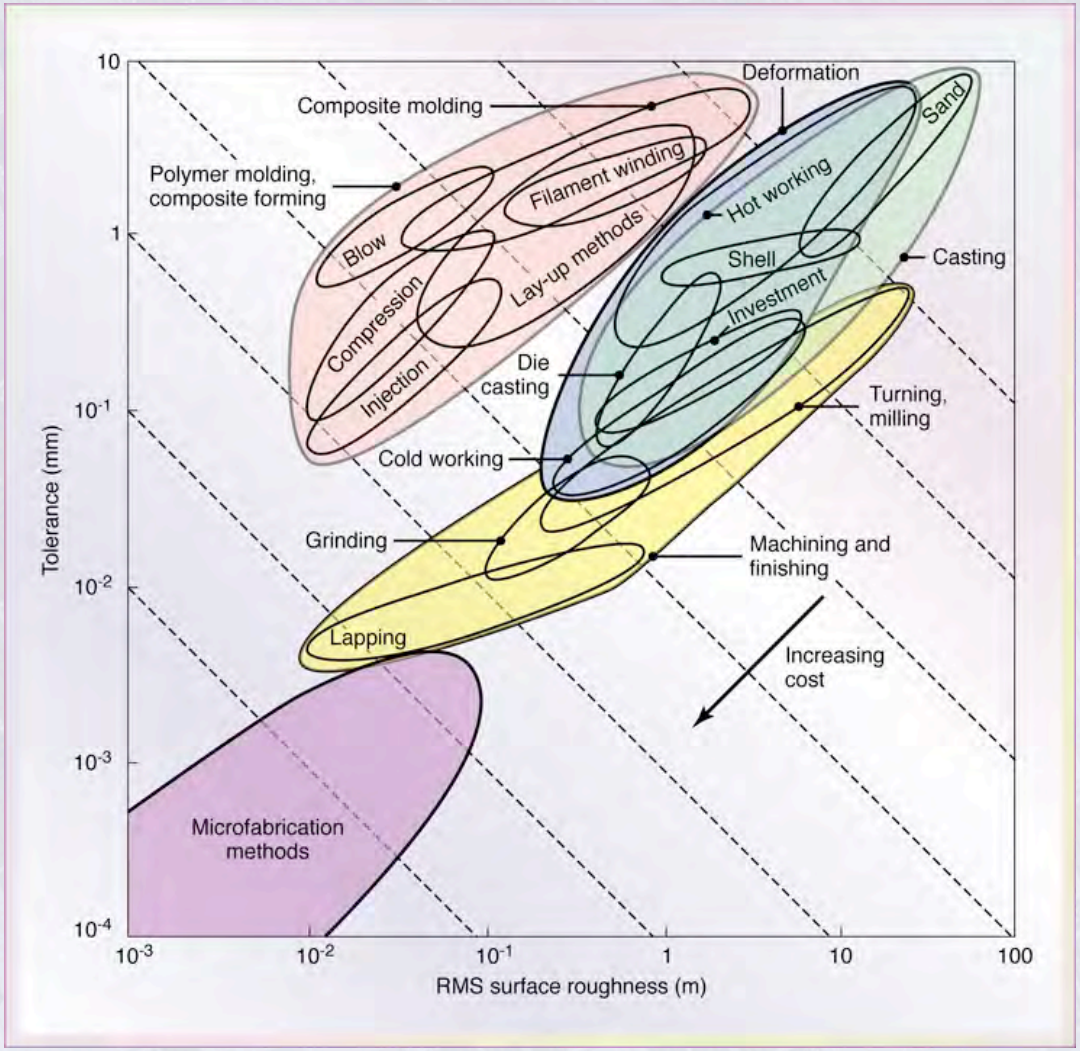


Figure 40.2 Manufacturing process capabilities for minimum part dimensions.
Source: After J. A. Schey.



Dimensional Tolerances and Surface Finish

Figure 40.3 A plot of achievable tolerance versus surface roughness for assorted manufacturing operations. The dashed lines indicate cost factors where an increase in precision corresponding to the separations of two neighboring lines gives an increase in cost for a given process (for a factor of two). *Source*: M. F. Ashby, *Materials Selection in Design*. Butterworth-Heineman, 1999.

Dependence of Manufacturing Cost on Dimensional Tolerances

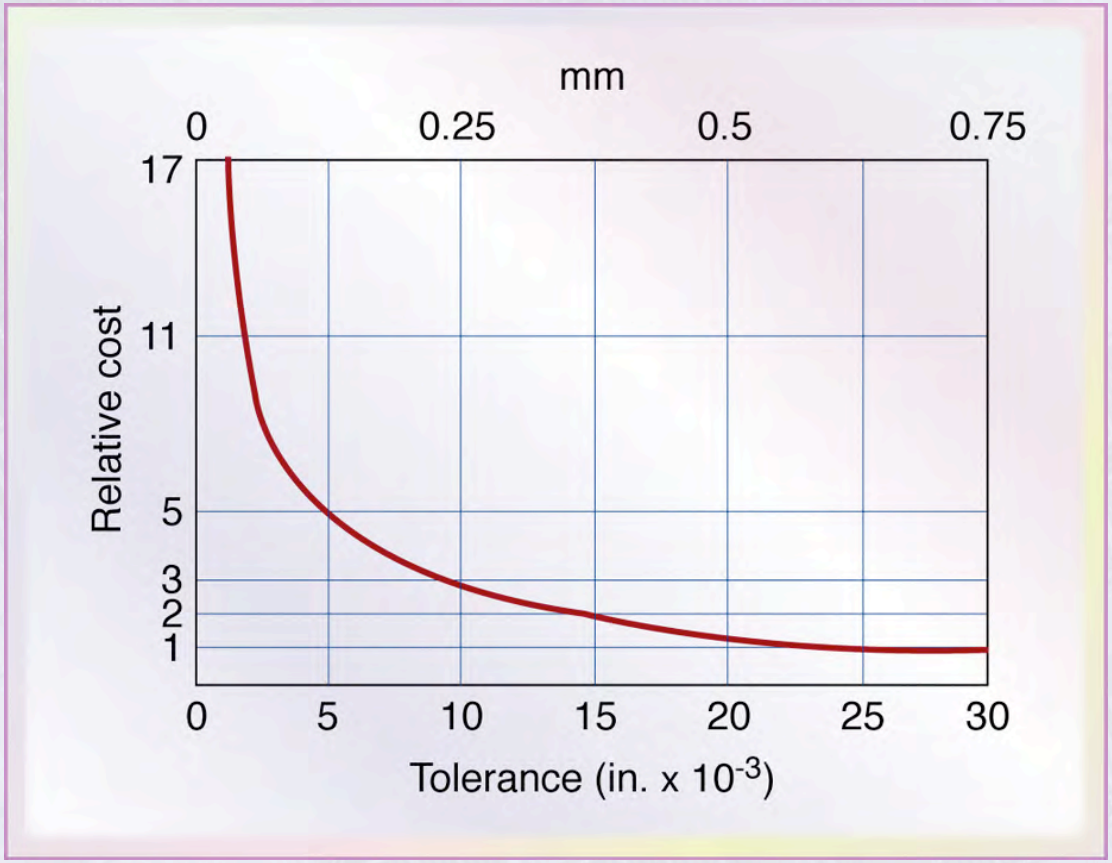


Figure 40.4 Dependence of manufacturing cost on dimensional tolerances.

Production Time as a Function of Surface Finish

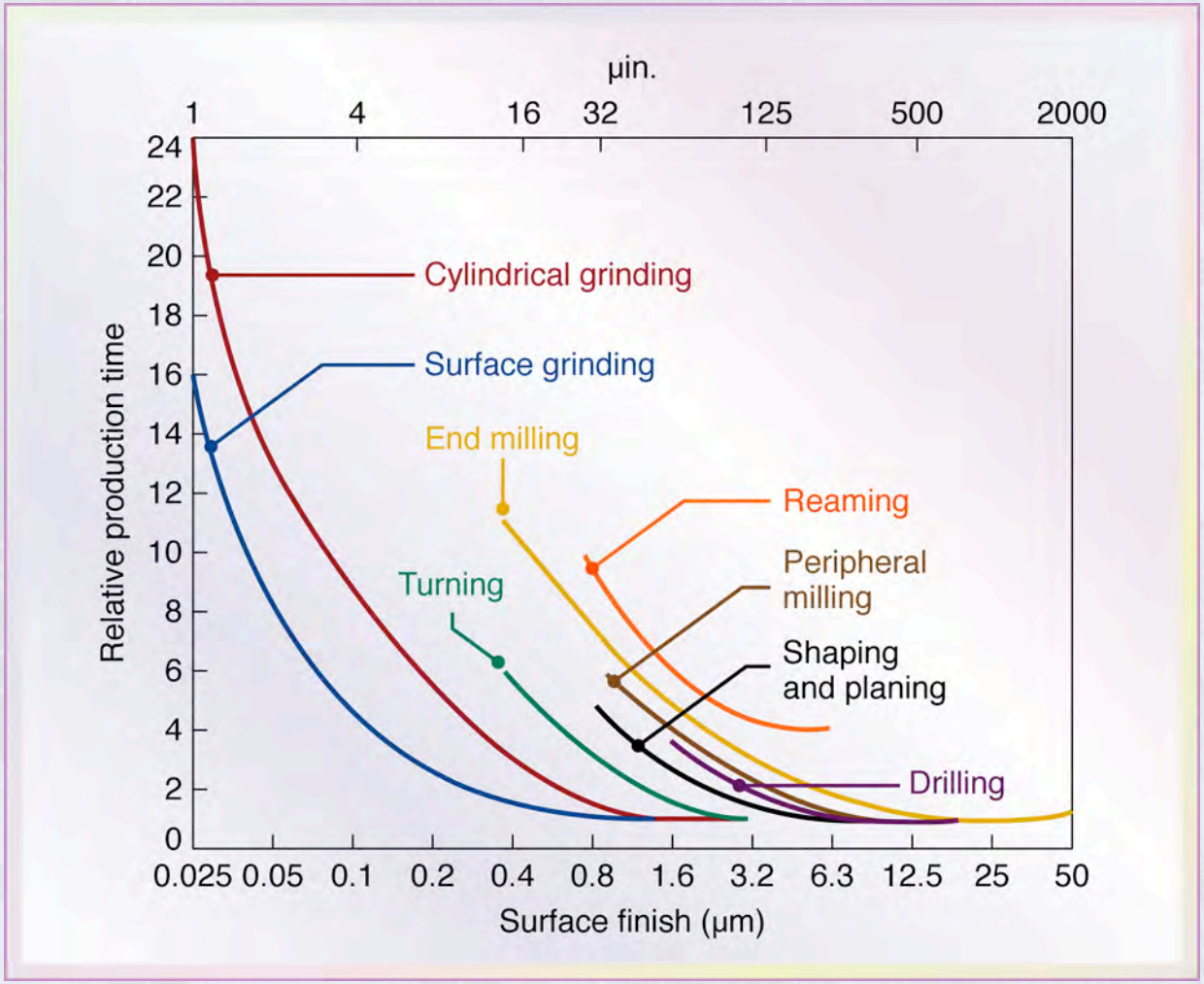


Figure 40.5 Relative production time as a function of surface finish produced by various manufacturing processes. (See also Fig. 26.34.)

General Characteristics of Manufacturing Processes for Various Metals and Alloys

TABLE 40.8

General Characteristics of Manufacturing Processes for Various Metals and Alloys

	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	A
Machining	A	A	A	—	A	A	A	B	A	B
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	A
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.

Methods of Making a Part

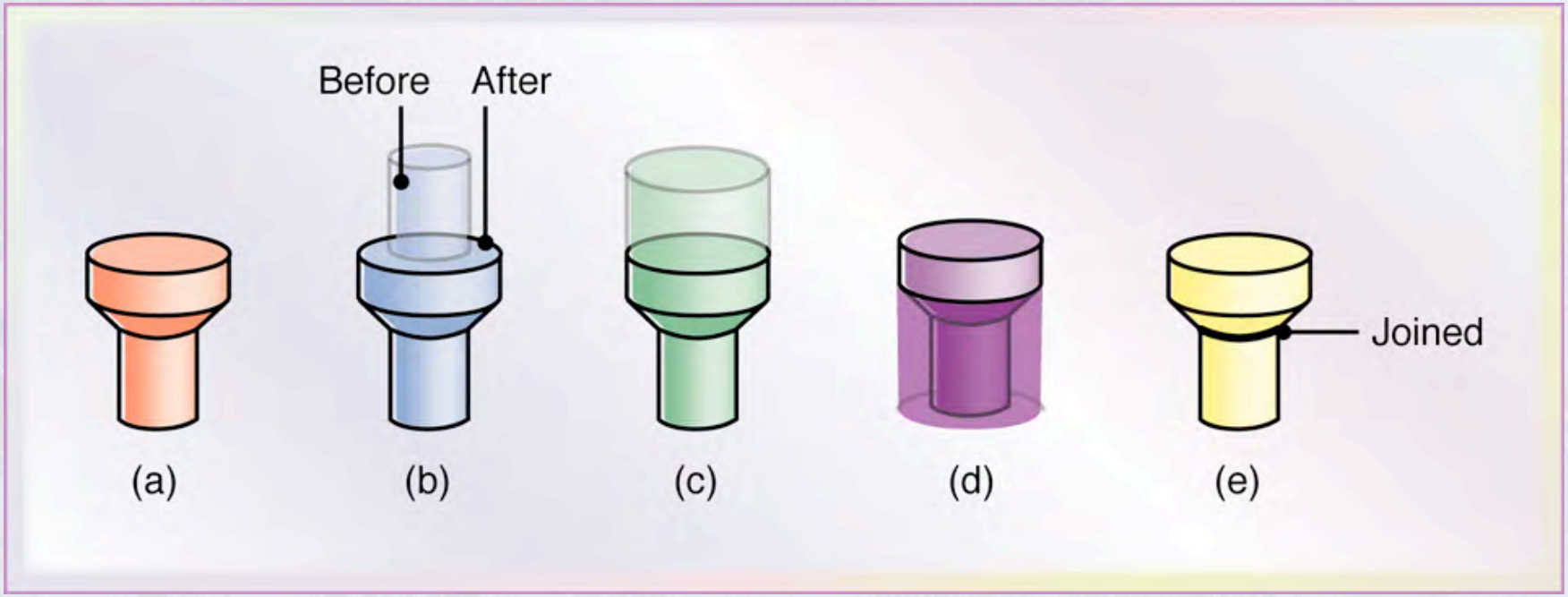


Figure 40.6 Various methods of making a simple part: (a) casting or powder metallurgy, (b) forging or upsetting, (c) extrusion, (d) machining, and (e) joining two pieces

Two Methods of Making Dish-Shaped Sheet-Metal Part

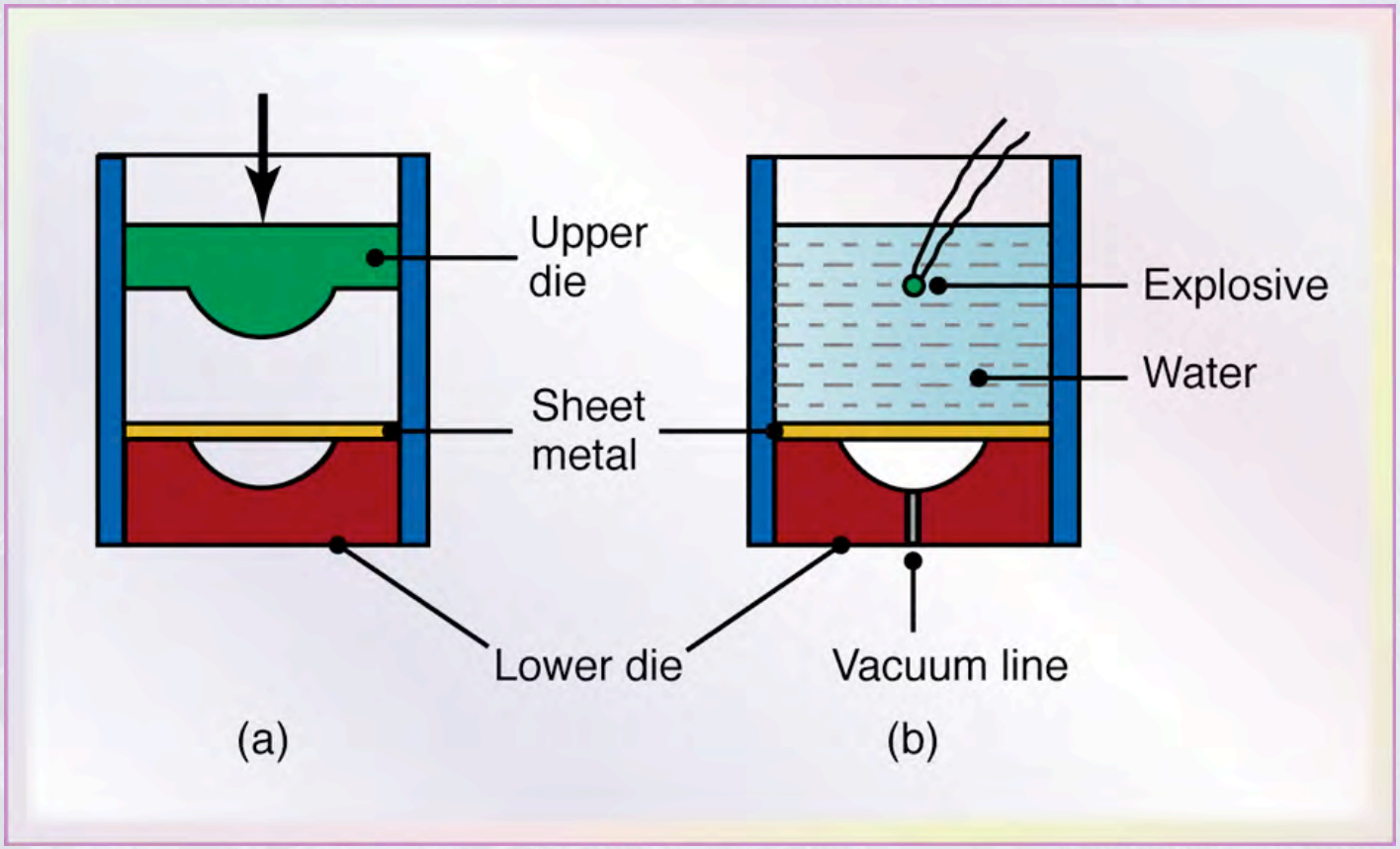


Figure 40.7 Two methods of making a dish-shaped sheet-metal part: (a) pressworking using a male and female die, (b) explosive forming using one die only.

TABLE 40.9

Relative Costs for Machinery and Equipment (Costs vary greatly, depending on size, capacity, options, and level of automation and computer controls. See also the sections on economics in various chapters.)

Automatic screw machine	M-H
Boring mill, horizontal	M-H
Broaching	M-H
Deep drawing	M-H
Die casting	M-H
Drilling	L-M
Electrical-discharge machining	L-M
Electron-beam welding	M-H
Extruder, polymer	L-M
Extrusion press	M-H
Flexible manufacturing cell and system	H-VH
Forging	M-H
Fused deposition modeling	L
Gas tungsten-arc welding	L
Gear shaping	L-H
Grinding	L-H
Headers	L-M
Honing, lapping	L-M
Injection molding	M-H
Laser-beam welding	M-H
Lathes	L-M
Machining center	L-M
Mechanical press	L-M
Milling	L-M
Powder-injection molding	M-H
Powder metallurgy	L-M
Powder metallurgy, HIP	M-H
Resistance spot welding	L-M
Ring rolling	M-H
Robots	L-M
Roll forming	L-M
Rubber forming	L-M
Sand casting	L-M
Spinning	L-M
Stereolithography	L-M
Stamping	L-M
Stretch forming	M-H
Transfer lines	H-VH
Ultrasonic welding	L-M

Note: L, low; M, medium; H, high; VH, very high.

Relative Costs for Machinery and Equipment