446.305A MANUFACTURING PROCESSES

Chapter 4. Surfaces, Tribology, Dimensions, Inspection & Quality

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Introduction

- **Surface properties affect**
  - Friction and wear
  - Lubrication
  - Painting, coating, welding, soldering, adhesive bonding, corrosion resistance
  - Crack initiation
  - Thermal and electrical conductivity
- **Tribology**
  - Friction
  - Wear
  - Lubrication

Surface structure

- **Oxide layer (hard, brittle, abrasive)**
  - Iron: FeO, Fe_3O_4, Fe_2O_3
  - Aluminum: Al_2O_3
  - Copper: Cu_2O, CuO
  - Stainless steel: CrO
- **Beilby layer: melting & surface flow-> rapid quenching**
- **Work-hardened layer: residual stress**

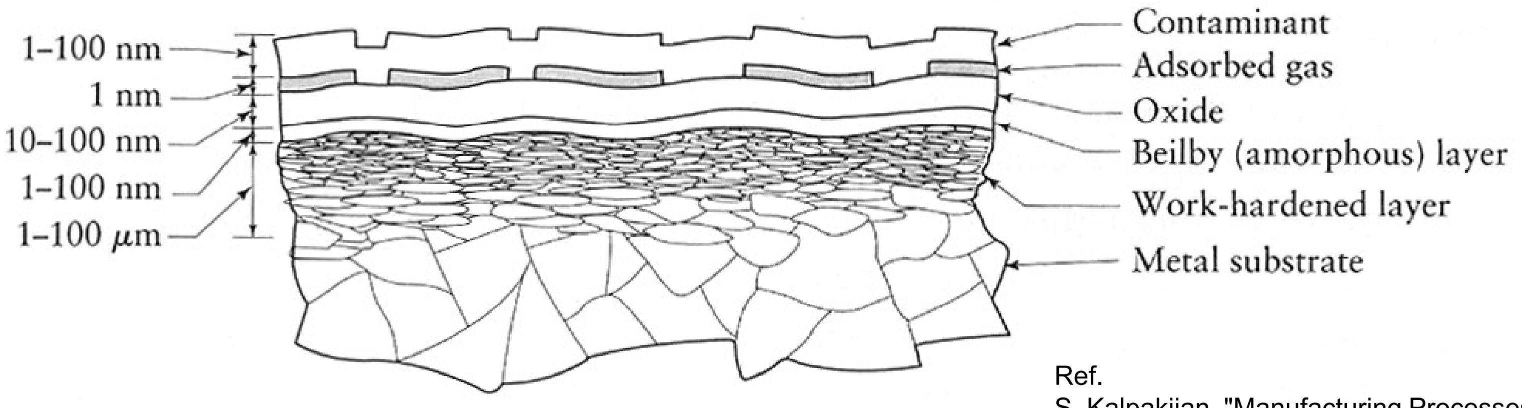
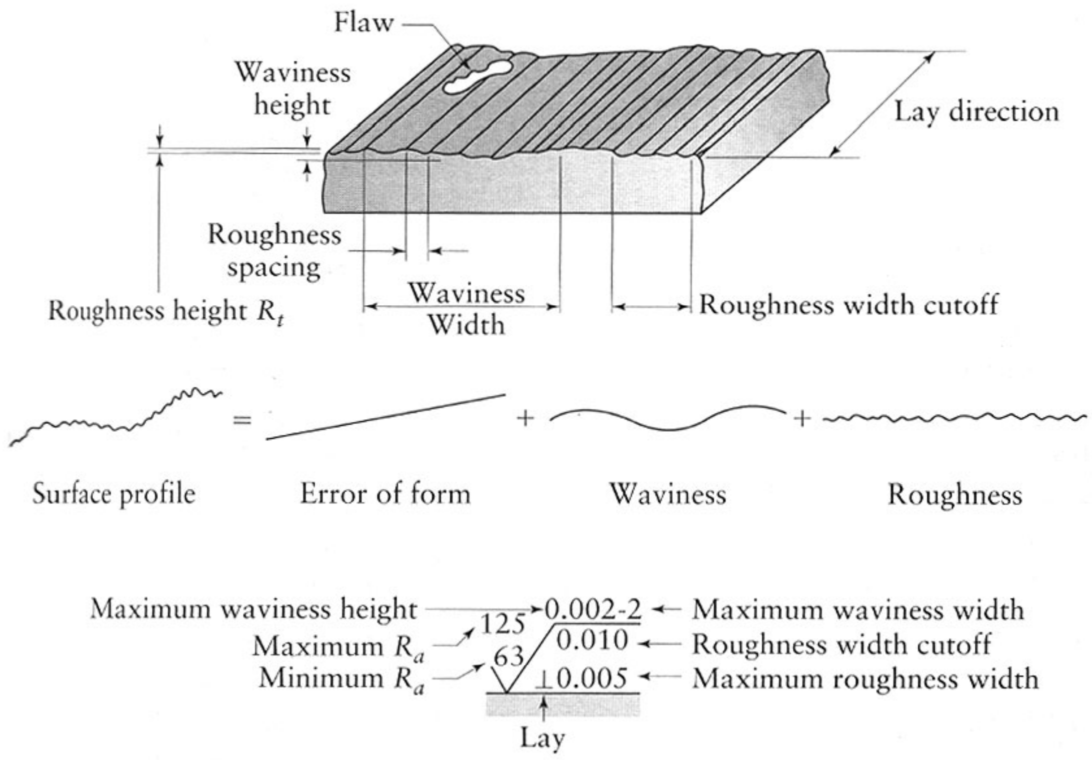


FIGURE 4.1 Schematic illustration of the cross-section of the surface structure of metals. The thickness of the individual layers depends on processing conditions and the environment. *Source*: After E. Rabinowicz and B. Bhushan.

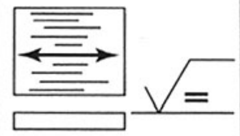
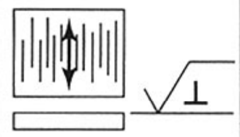
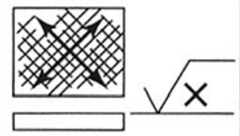
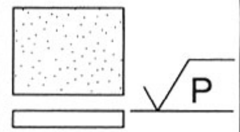
Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Surface texture

- **Flaw (흠)/ defect (결함), lay (가공무늬), roughness (거칠기), waviness (파상도)**



(a)

Lay symbol	Interpretation	Examples
=	Lay parallel to the line representing the surface to which the symbol is applied	
⊥	Lay perpendicular to the line representing the surface to which the symbol is applied	
X	Lay angular in both directions to the line representing the surface to which the symbol is applied	
P	Pitted, protuberant, porous, or particulate nondirectional lay	

(b)

FIGURE 4.2 (a) Standard terminology and symbols used to describe surface finish. The quantities are given in μ in. (b) Common surface-lay symbols.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Surface roughness

- **Surface profilometers (표면거칠기 측정기)**

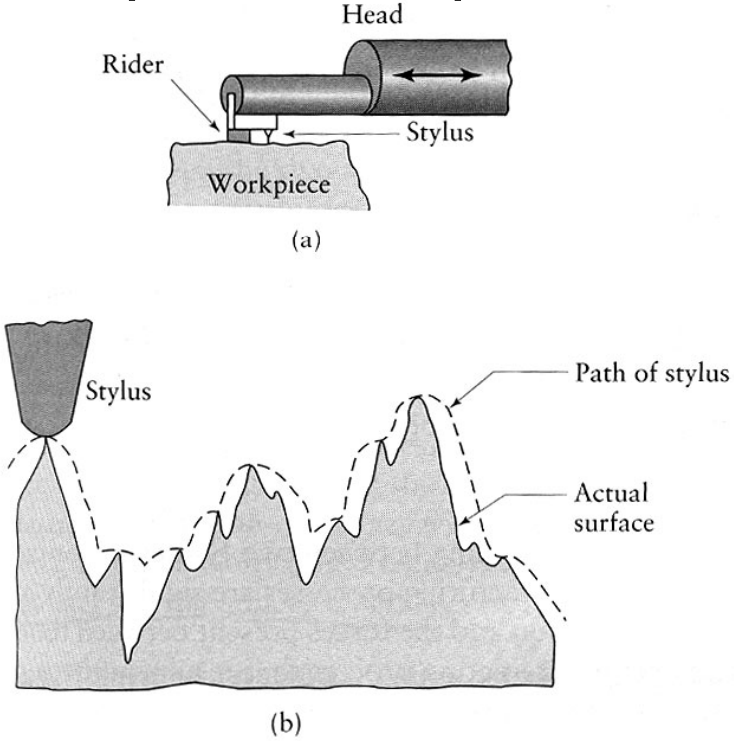
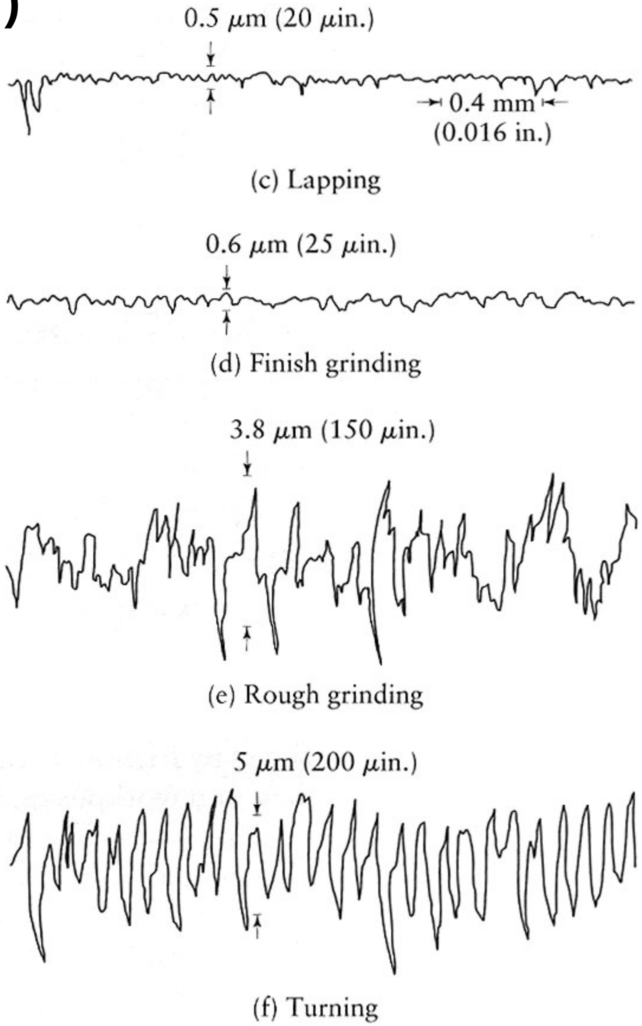


FIGURE 4.4 (a) Measuring surface roughness with a stylus. The rider supports the stylus and guards against damage. (b) Path of the stylus in measurements of surface roughness (broken line) compared with the actual roughness profile. Note that the profile of the stylus' path is smoother than the actual surface profile. *Source*: D. H. Buckley. Typical surface profiles produced by (c) lapping, (d) finish grinding, (e) rough grinding, and (f) turning processes. Note the difference between the vertical and horizontal scales. *Source*: from D. B. Dallas (ed.), *Tool and Manufacturing Engineers Handbook*, 3d ed.



Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

R_a and R_q

- **Arithmetic mean value**
  - arithmetic ave. (AA)
  - center-line ave. (CLA)
- **Root-mean-square ave. (RMS)**

$$R_a = \frac{y_a + y_b + y_c + y_d \cdots}{n} = \frac{1}{n}\sum_{i=1}^{n} y_i = \frac{1}{l}\int_0^l |y| dx$$

$$R_q = \sqrt{\frac{{y_a}^2 + {y_b}^2 + {y_c}^2 + {y_d}^2 + \cdots}{n}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} {y_i}^2} = \left[\frac{1}{l}\int_0^l y^2 dx\right]^{1/2}$$

- **Rough surface:**
  - Lower precision, short fatigue life, higher electrical & thermal contact resistance, lower corrosion resistance, better painting & coating, lower cost

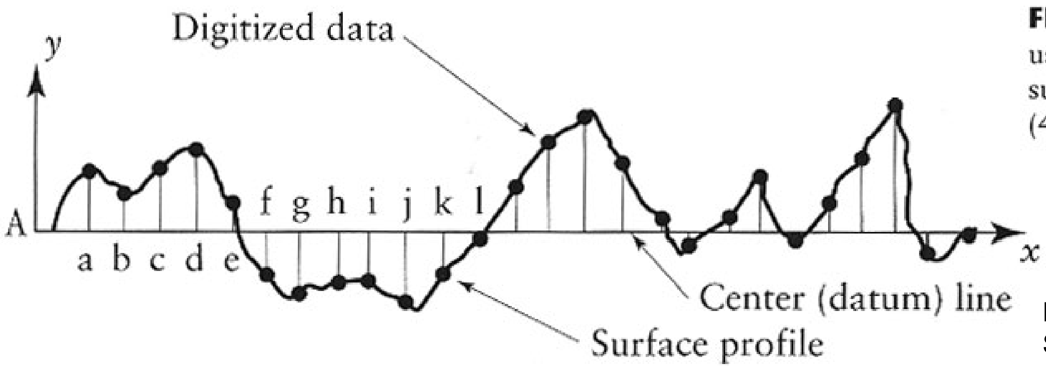
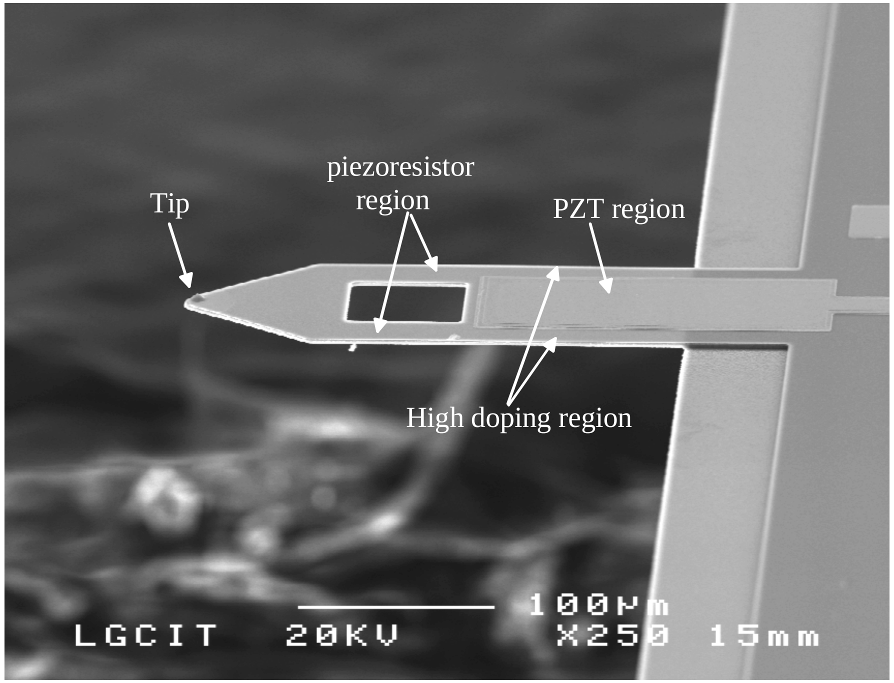
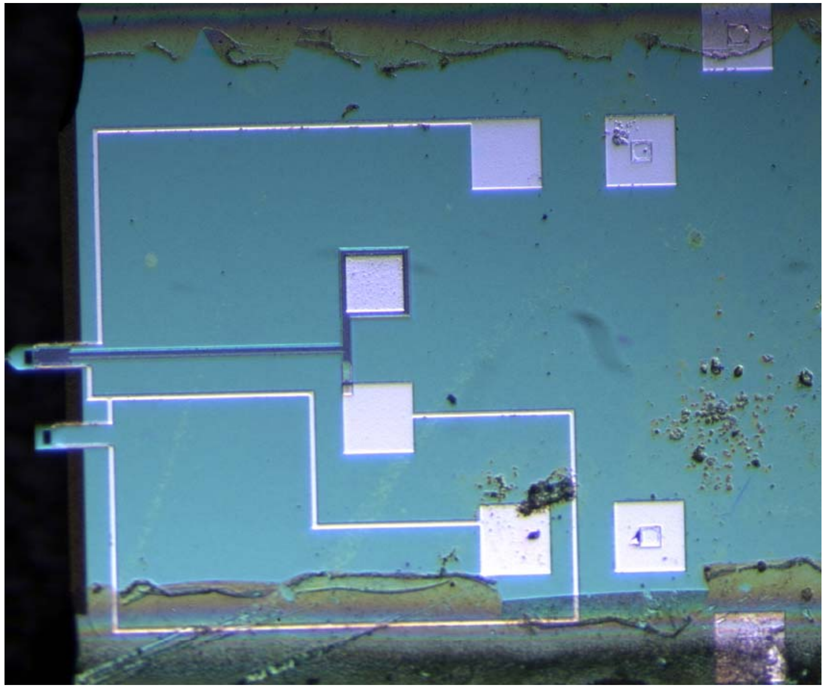


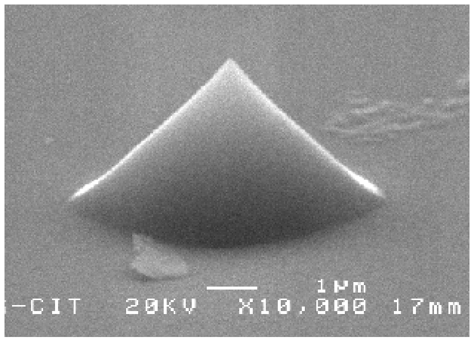
FIGURE 4.3 Coordinates used for measurement of surface roughness, using Eqs. (4.1) and (4.2).

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

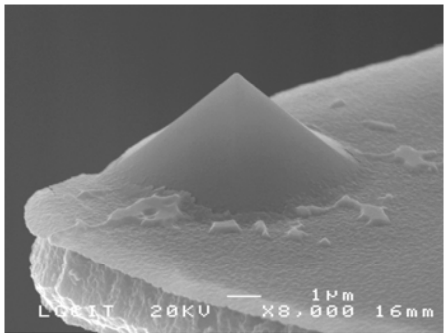
Atomic Force Microscope (AFM) Tip







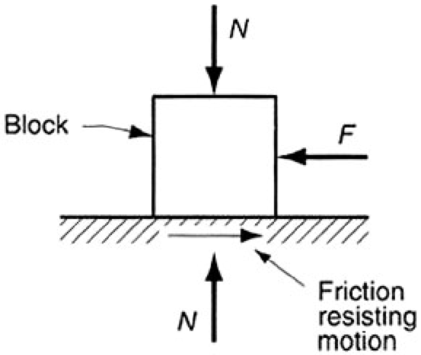
Before PZT process



After PZT process

Friction

- **Adhesion theory of friction (응착이론)**
  - Intimate contact of asperities creates an adhesive bond



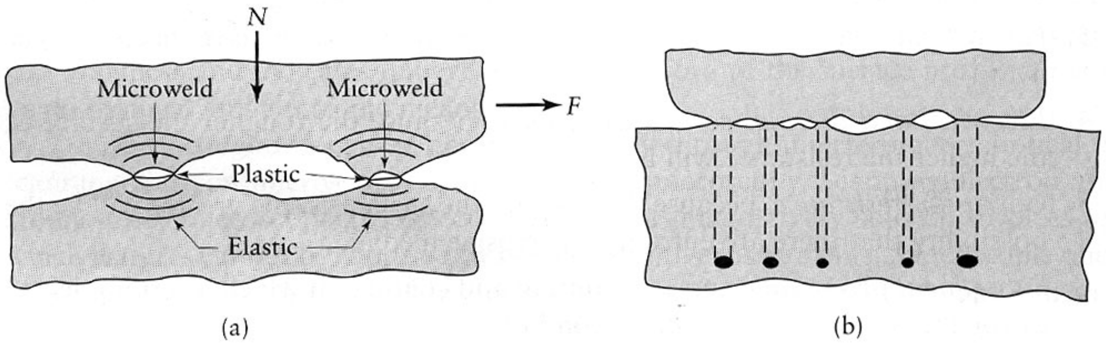
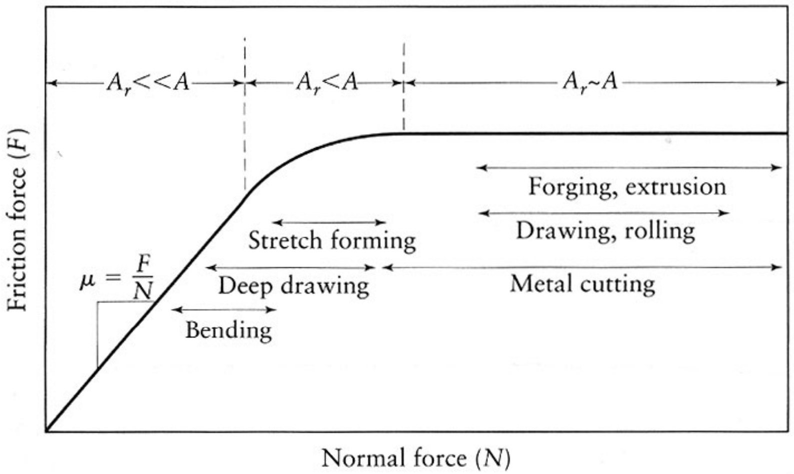


FIGURE 4.5 (a) Schematic illustration of the interface of two contacting surfaces, showing the real areas of contact. (b) Sketch illustrating the proportion of the apparent area to the real area of contact. The ratio of the areas can be as high as four to five orders of magnitude.

- **Friction coefficient (마찰계수)**

FIGURE 4.6 Schematic illustration of the relation between friction force F and normal force N. Note that as the real area of contact approaches the apparent area, the friction force reaches a maximum and stabilizes. Most machine components operate in the first region. The second and third regions are encountered in metalworking operations, because of the high contact pressures involved between sliding surfaces, i.e., die and workpiece.



$$\mu = \frac{F}{N} = \frac{\tau A_r}{\sigma A_r} = \frac{\tau}{\sigma}$$

$$\mu = \frac{\tau}{hardness}$$

$$friction(shear)\ \ factor,\ m = \frac{\tau_i}{k}$$

$$k(shear\ \ yield\ \ stress) = Y/2$$

$$\mu = \frac{\tau}{hardness} = \frac{Y/\sqrt{3}}{3Y} \cong 0.2$$

$$\mu = \frac{\tau}{\sigma} = \frac{Y/\sqrt{3}}{Y} = 0.577$$

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Measuring Friction

- **Ring compression test**

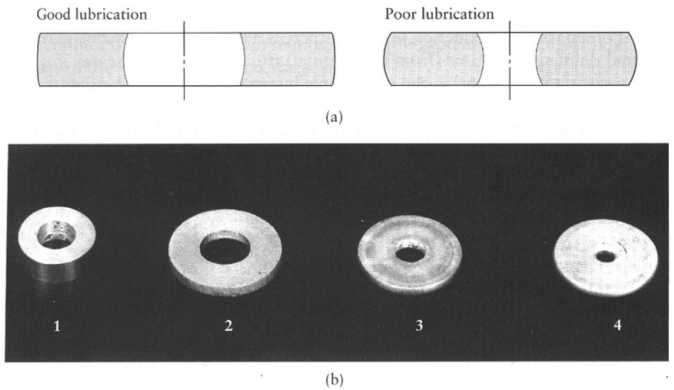


FIGURE 4.7 (a) The effects of lubrication on barreling in the ring compression test: (a) With good lubrication, both the inner and outer diameters increase as the specimen is compressed; and with poor or no lubrication, friction is high, and the inner diameter decreases. The direction of barreling depends on the relative motion of the cylindrical surfaces with respect to the flat dies. (b) Test results: (1) original specimen, and (2–4) the specimen under increasing friction. *Source*: A. T. Male and M. G. Cockcroft.

$$volume = \frac{\pi}{4}(30^2 - 15^2)10 = \frac{\pi}{4}(39^2 - ID^2)5$$

$$change\ \ in\ \ ID = \frac{15-13}{15} \times 100 = 13\%(decrease)$$

$$\mu = 0.09 \quad and \quad m = 0.4$$

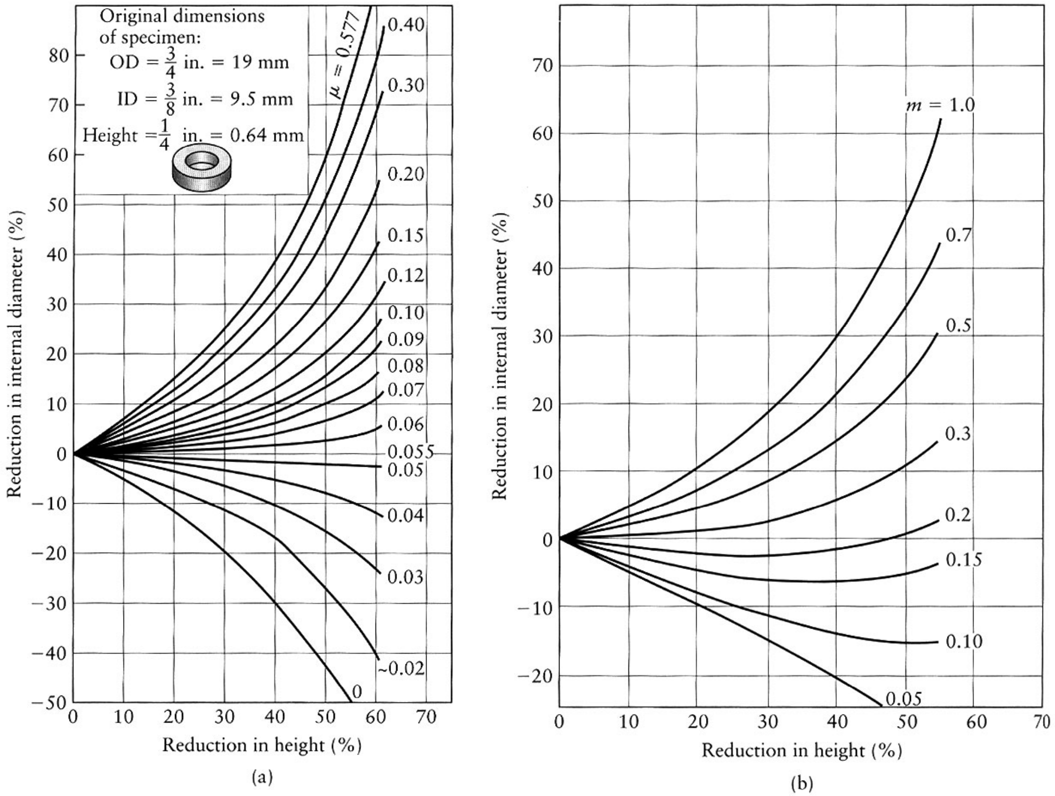


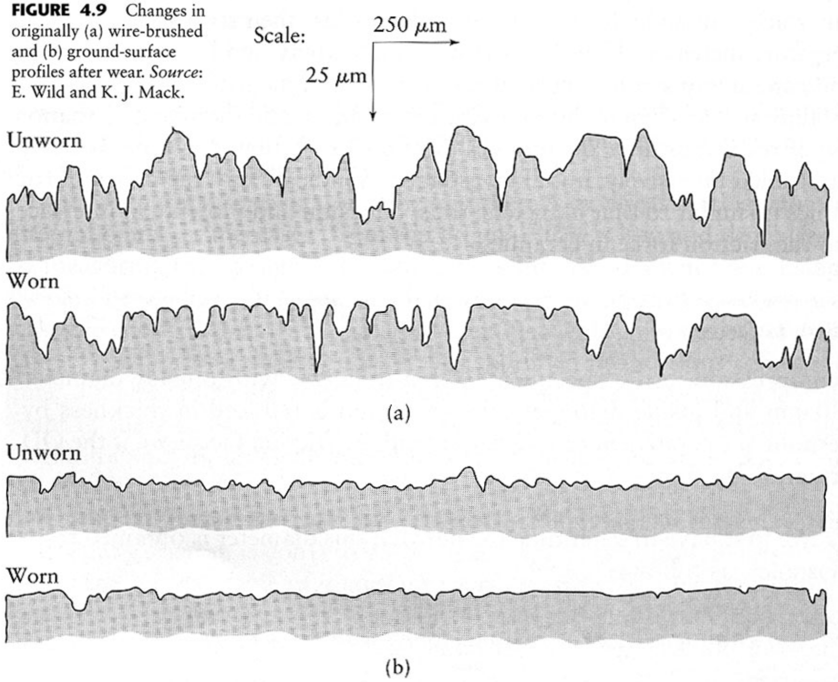
FIGURE 4.8 Charts to determine friction in ring compression tests: (a) coefficient of friction, μ; (b) friction factor, m. Friction is determined from these charts from the percent reduction in height and by measuring the percent change in the internal diameter of the specimen after compression.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Wear (1)

- **Progressive loss of material from a surface**

FIGURE 4.9 Changes in originally (a) wire-brushed and (b) ground-surface profiles after wear. *Source:* E. Wild and K. J. Mack.



$V = 0.001 in^3$

$k = 10^{-3}$ (from table 4.2)

$W = 200 lb$

$p = 120 kg/mm^2 = 170{,}700 lb/in^2$

$$L = \frac{3Vp}{kW} = \frac{(3)(0.001)(170{,}700)}{(10^{-3})(200)} = 2560 in = 213 ft$$

- **Adhesive wear (응착마멸)**

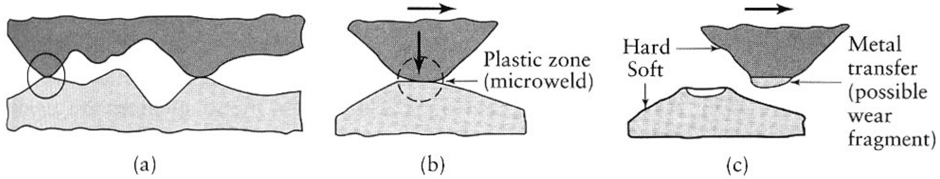


FIGURE 4.10 Schematic illustration of (a) two asperities contacting, (b) adhesion between two asperities, and (c) the formation of a wear particle.

- **Archard wear law** $V = k\dfrac{LW}{3p}$

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Wear (2)

- **Abrasive wear**

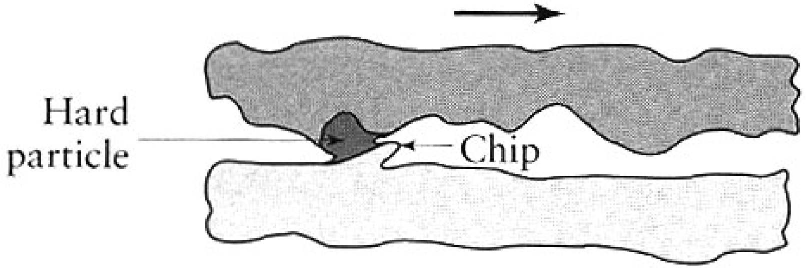
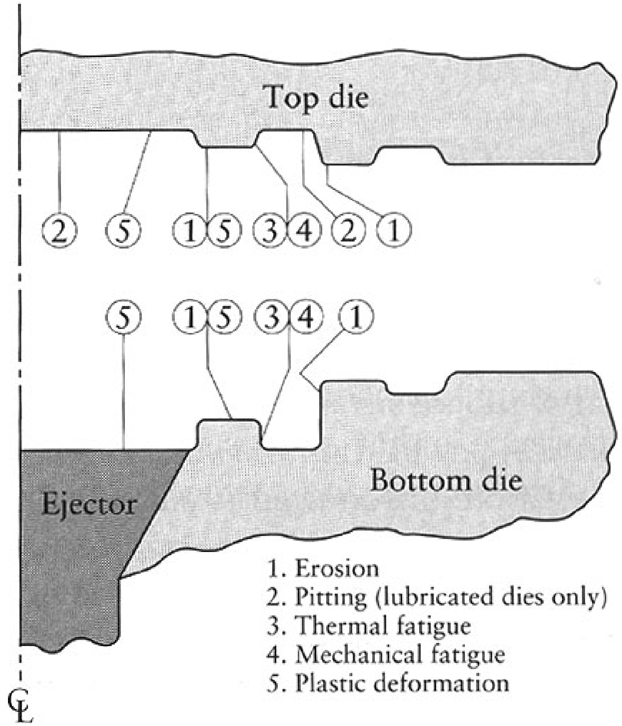


FIGURE 4.11 Schematic illustration of abrasive wear in sliding. Longitudinal scratches on a surface usually indicate abrasive wear.

- **Corrosive wear**
- **Fatigue wear**

FIGURE 4.12 Types of wear observed in a single die used for hot forging. *Source*: T. A. Dean.



Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Lubrication

- **4 regimes of lubrication**

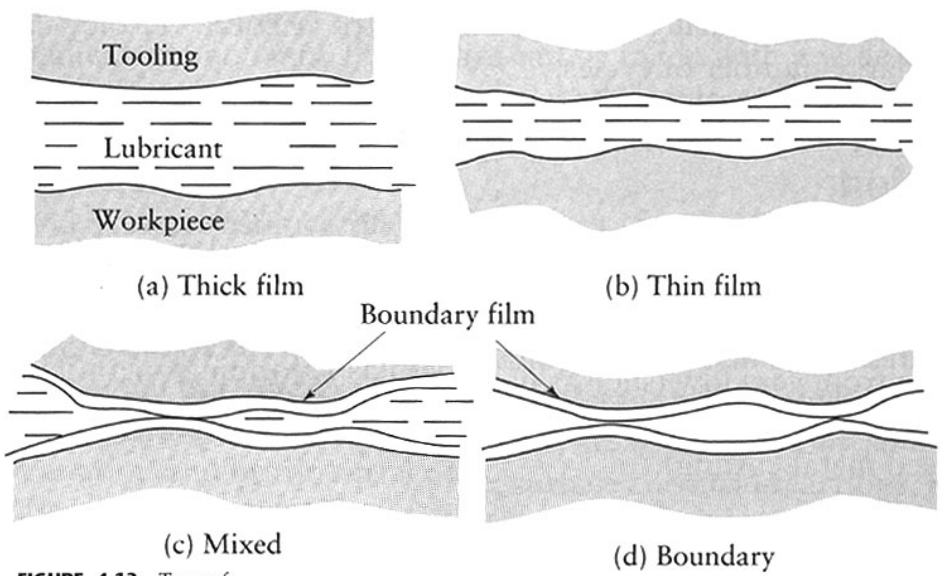


FIGURE 4.13 Types of lubrication generally occurring in metalworking operations. *Source*: After W. R. D. Wilson.

- **Geometric defects**

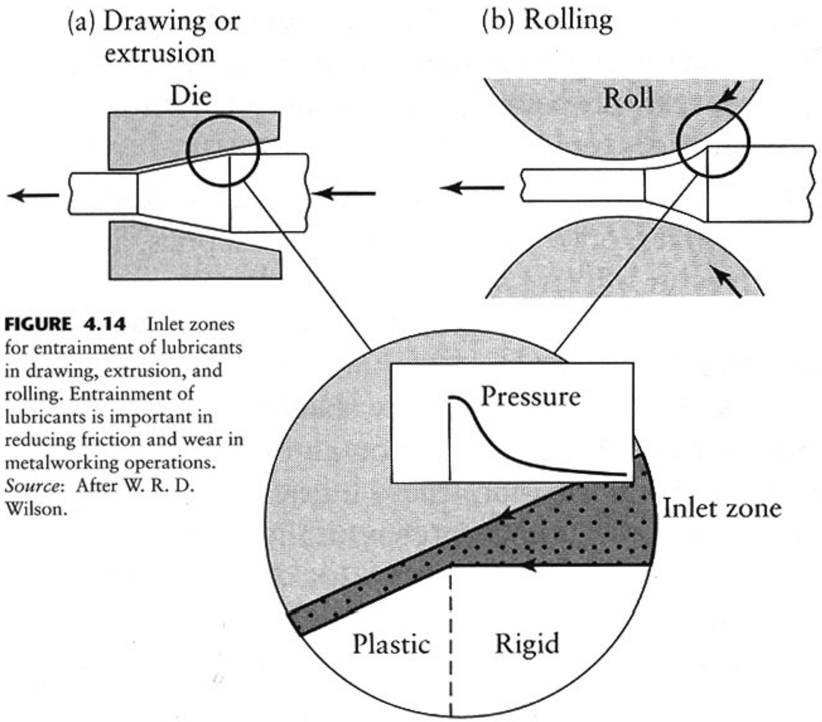


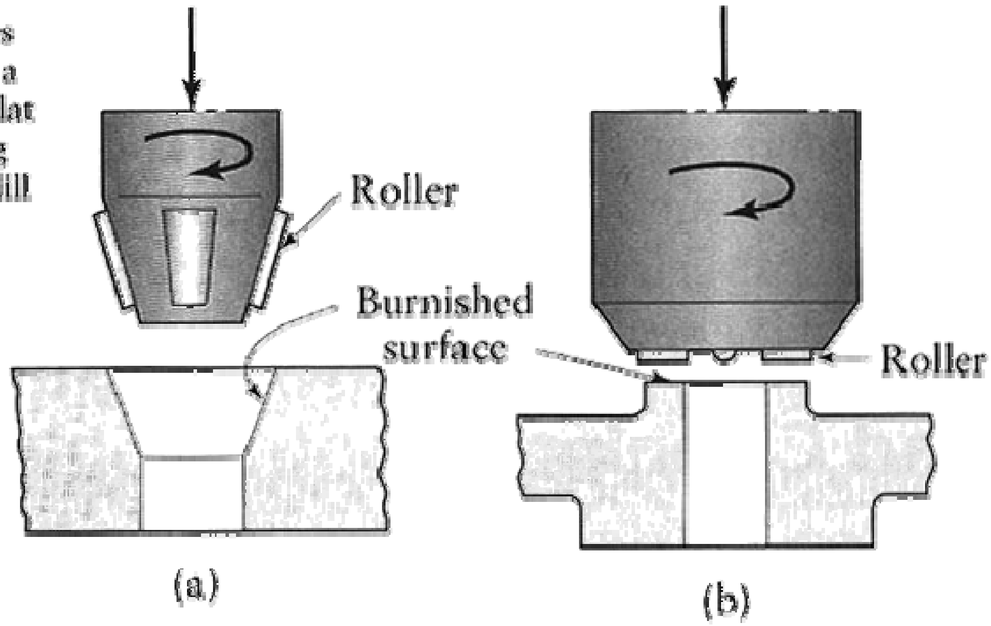
FIGURE 4.14 Inlet zones for entrainment of lubricants in drawing, extrusion, and rolling. Entrainment of lubricants is important in reducing friction and wear in metalworking operations. *Source*: After W. R. D. Wilson.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Surface Treatment (1)

- **Shot peening, water-jet peening, laser peening**
- **Roller burnishing (surface rolling)**
- **Cladding (clad bonding)**
- **Mechanical plating**
- **Thermal spraying**
- **Surface texturing**

FIGURE 4.15 Examples of roller burnishing of (a) a conical surface and (b) a flat surface and the burnishing tools used. *Source:* Cogsdill Tool Products.



Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Surface Treatment (2)

- **Vapor deposition (CVD/PVD/ Ion implantation)**
- **Electroplating/ electroless plating**
- **Electroforming**
- **Anodizing**
- **Diamond coating**

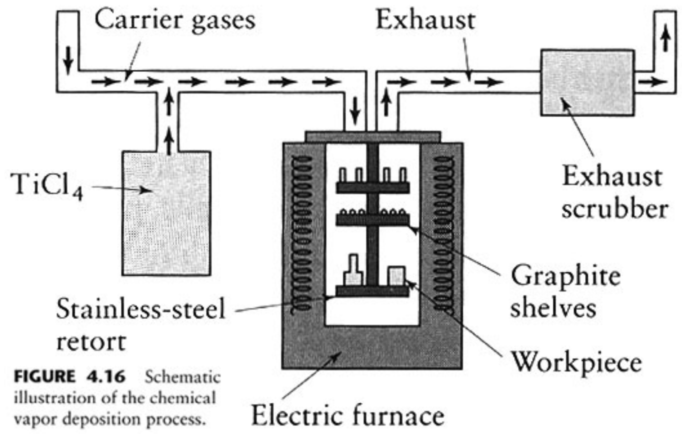


FIGURE 4.16 Schematic illustration of the chemical vapor deposition process.

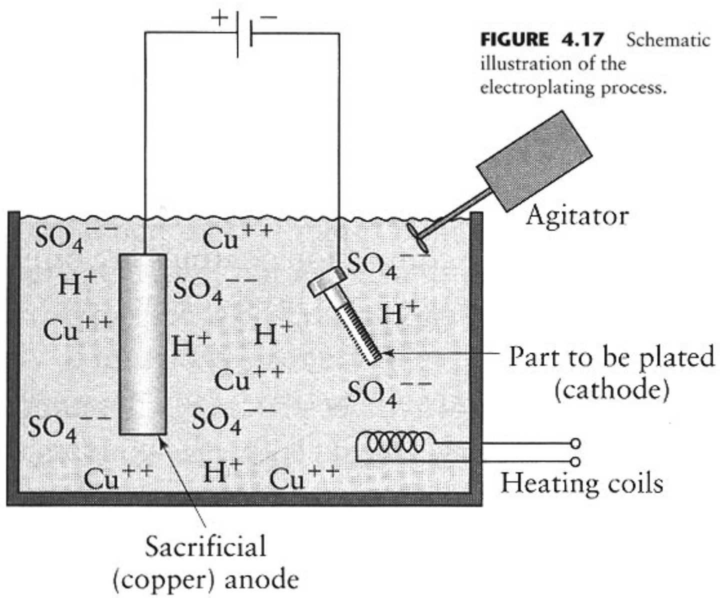
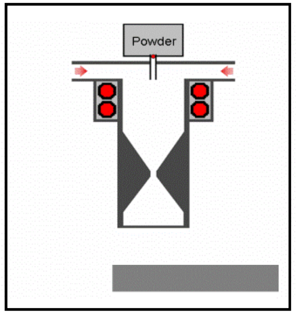


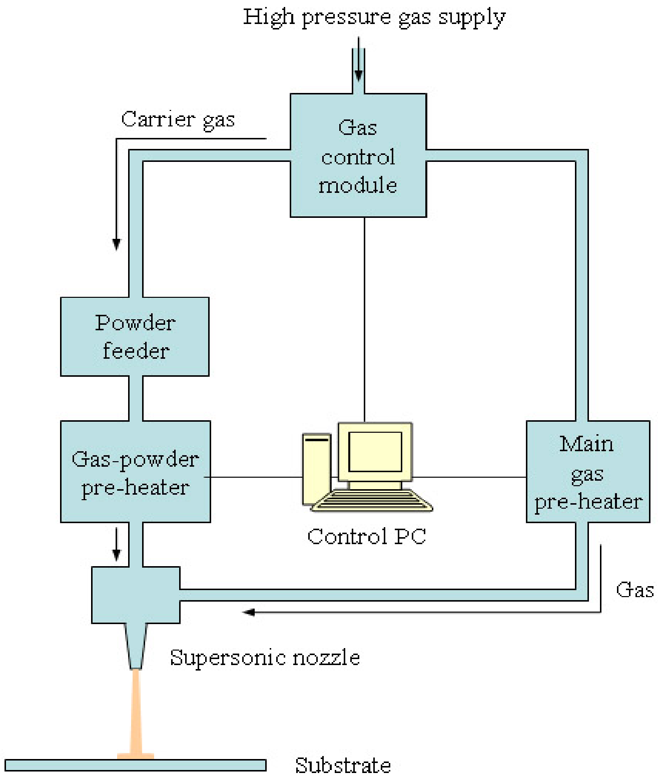
FIGURE 4.17 Schematic illustration of the electroplating process.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

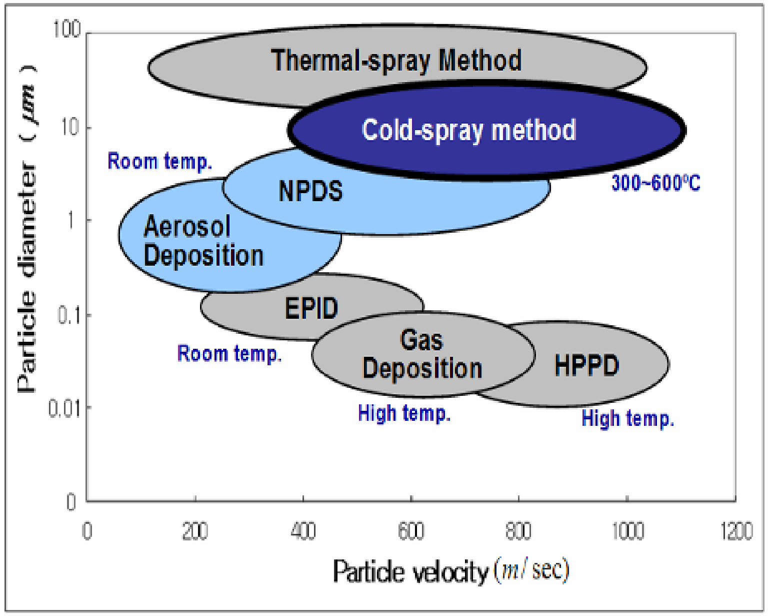
Cold spray (1)

- **High deposition rate at low temperature**
- **Accelerated powder particles are sprayed onto substrate.**
- **Fabrication type : constructive process**
- **Typical substrate materials : metal**



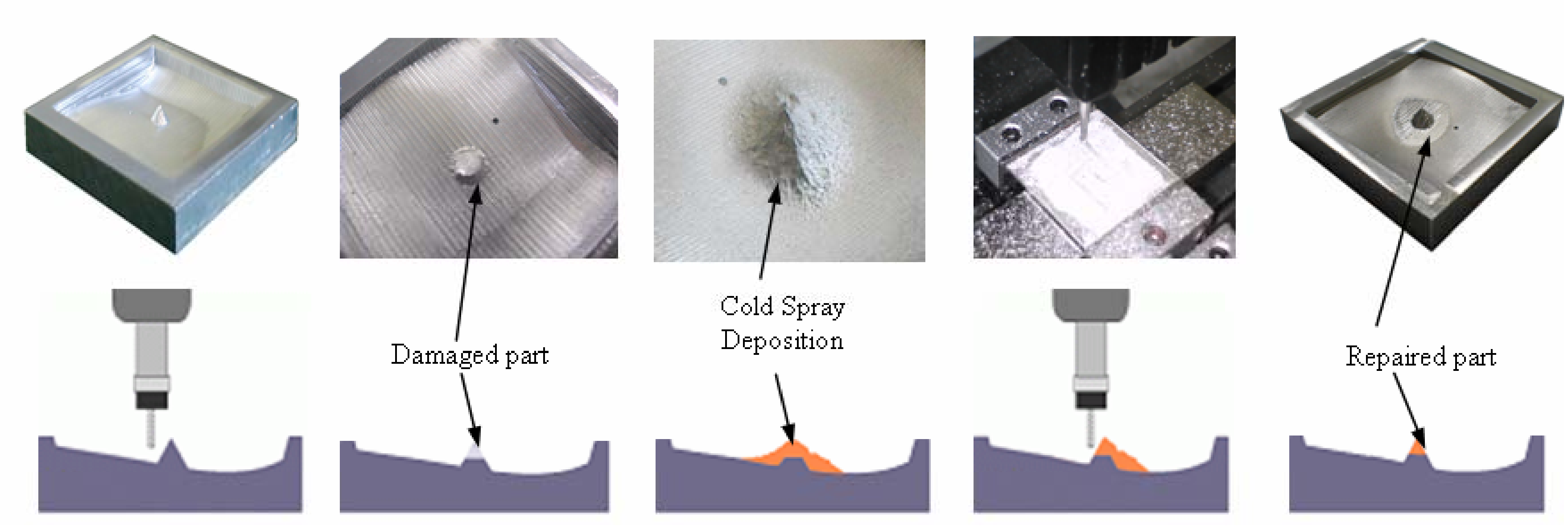


Schematic diagram



Cold spray (2)

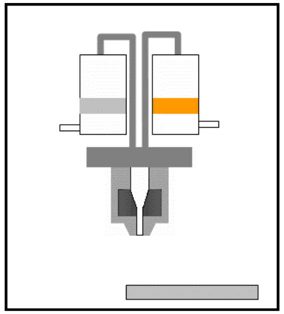
- **Repair of damaged mold**

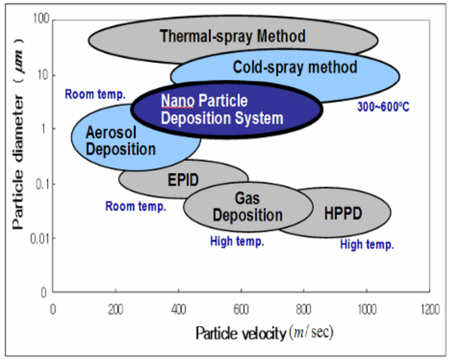


1. Mold fabrication
2. Damaged mold
3. Deposition of particles
4. Machining mold surface
5. Repaired mold

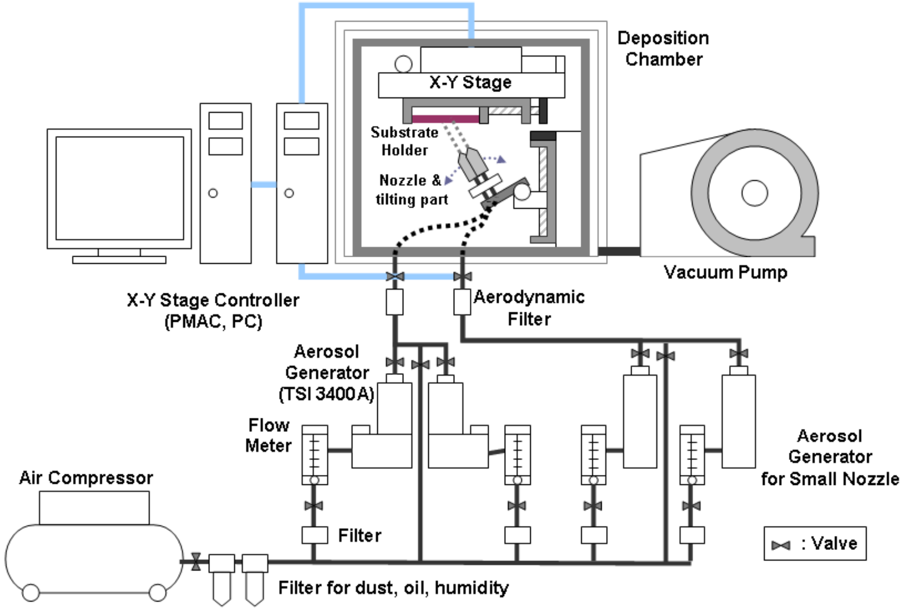
Nano particle deposition system (NPDS)

- **High deposition rate at room temperature**
- **Aerosol with particles is accelerated by a gas flow and sprayed onto substrate.**
- **Fabrication type : constructive process**
- **Typical substrate materials : metal, ceramic**

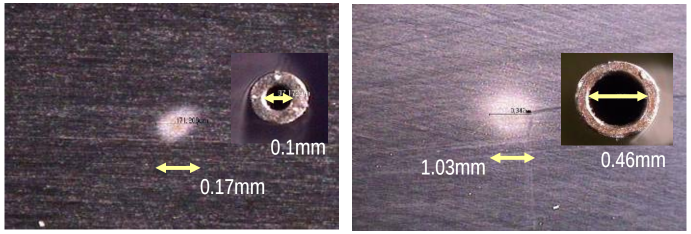




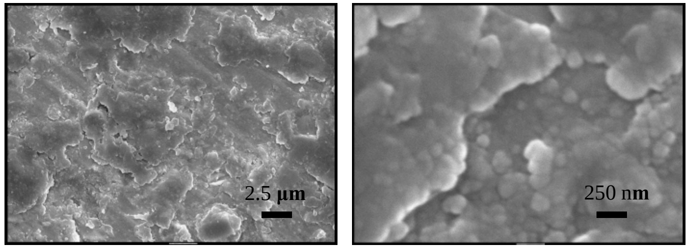
Fabrication envelop



Schematic diagram



Mn-Zn ferrite coating on Al 6061 with niddles



TiO_2 coating on Stainless steel

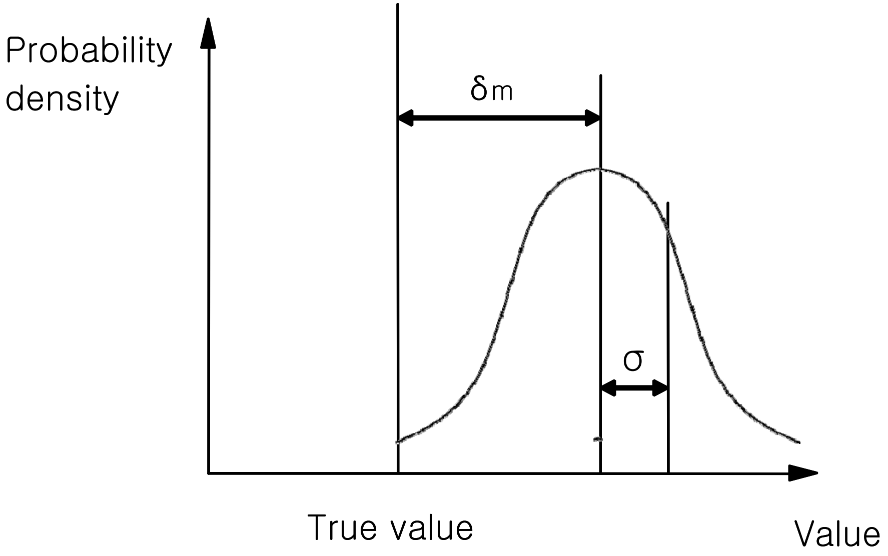
Measurement

- **Length: dial indicator, LVDT**
- **Straightness : autocollimators**
- **Flatness: interferometry**
- **Roundness: total indicator reading (TIR), full indicator movement**
- **Profile**
- **Coordinate measuring machines (CMM) and layout machines**
- **Gages**
- **Microscopes**

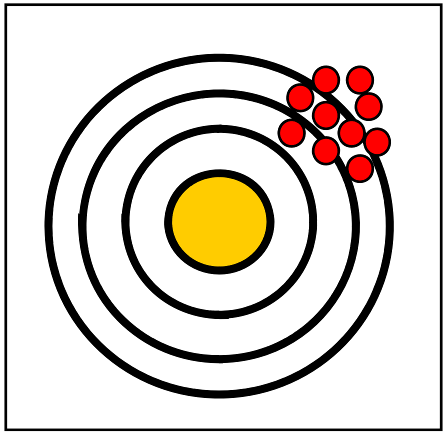
Precision & Accuracy

- **Accuracy(정확도)**
  - degree of conformity of a measure to a standard or a true value(closeness to the true value, δ_m)

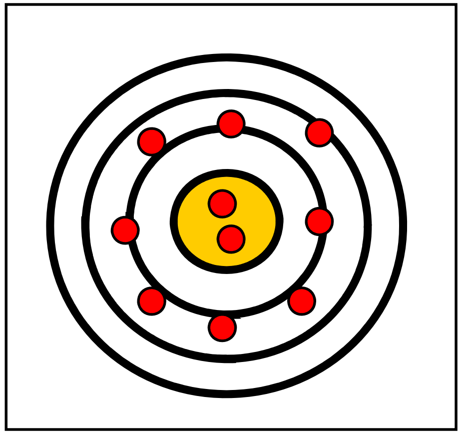
- **Precision(정밀도)**
  - the degree of refinement with which an operation is performed or a measurement stated(size of standard deviation, σ)



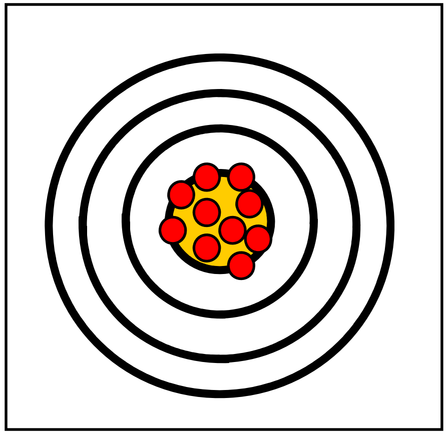
Precision & Accuracy – example



- Precise
- Not accurate



- Accurate
- Not precise



- Accurate
- Precise

Dimensional Tolerance

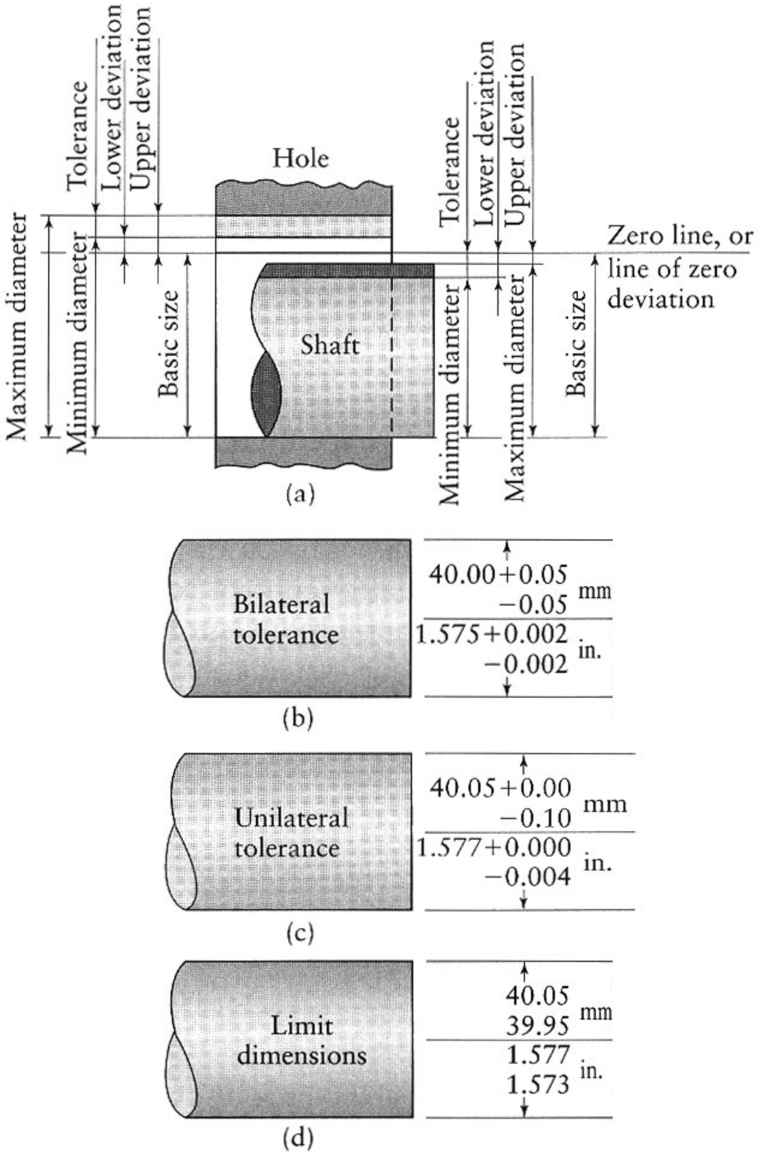


FIGURE 4.19 (a) Basic size, deviation, and tolerance on a shaft, according to the ISO system. (b)–(d) Various methods of assigning tolerances on a shaft. *Source*: L. E. Doyle.

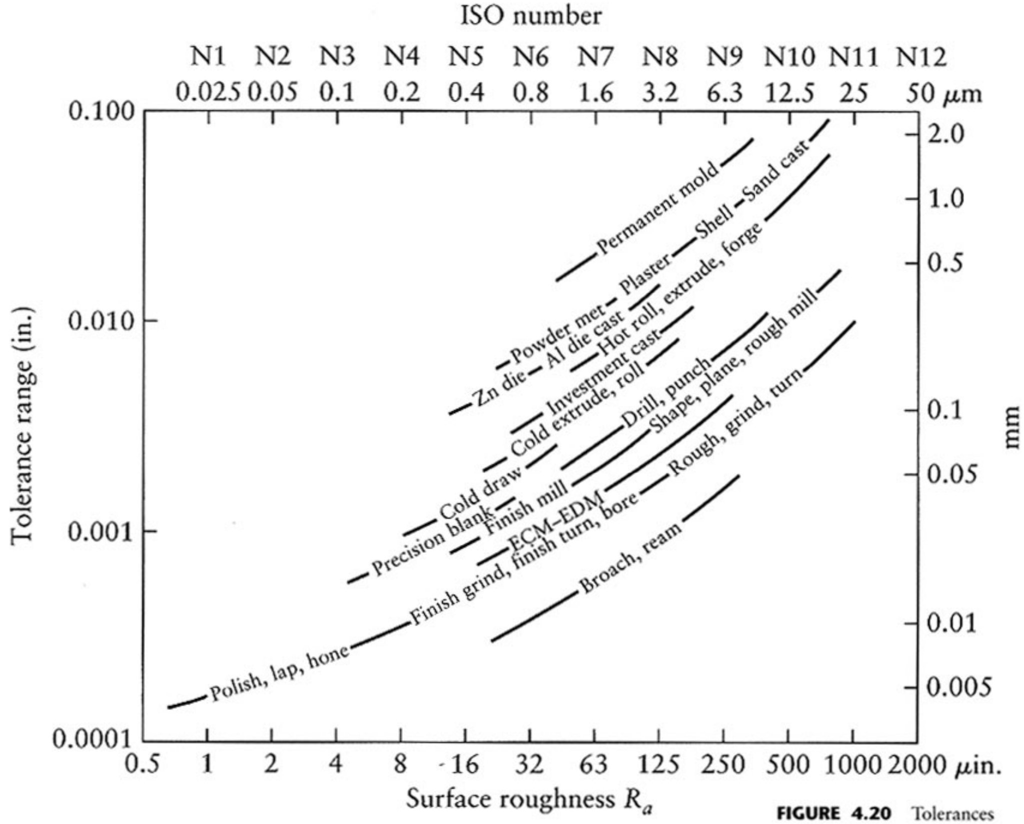


FIGURE 4.20 Tolerances and surface roughness obtained in various manufacturing processes. These tolerances apply to a 25-mm (1-in.) workpiece dimension. *Source*: Schey, J.A., *Introduction to Manufacturing Processes*, 3rd ed. New York, McGraw-Hill, 2000, p. 68.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Quality Assurance

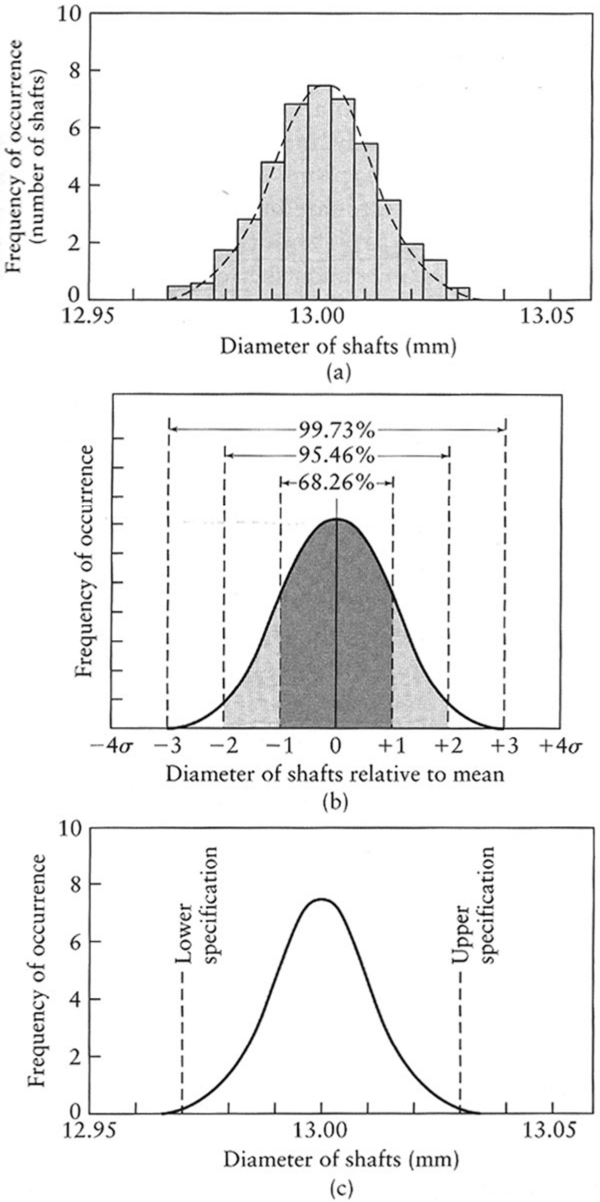


FIGURE 4.21 (a) A plot of the number of shafts measured and their respective diameters. This type of curve is called a *frequency distribution*. (b) A normal distribution curve indicating areas within each range of standard deviation. *Note:* The greater the range, the higher the percentage of parts that fall within it. (c) Frequency distribution curve, showing lower and upper specification limits.

- **Normal (Gaussian) Distribution**

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n}$$

$$Range\ , R = x_{\max} - x_{\min}$$

$$\sigma = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 + \cdots + (x_n - \bar{x})^2}{n-1}}$$

- **Control Chart**

$$\text{Upper control lmit}(UCL_{\bar{x}}) = \bar{x} + 3\sigma = \bar{\bar{x}} + A_2\bar{R}$$

$$\text{Lower control lmit}(LCL_{\bar{x}}) = \bar{x} - 3\sigma = \bar{\bar{x}} - A_2\bar{R}$$

- **Six sigma (3~4 ppm)**
- **ISO 9000 (quality management & quality assurance)**
- **ISO 14000 (environmental management)**

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Control Chart

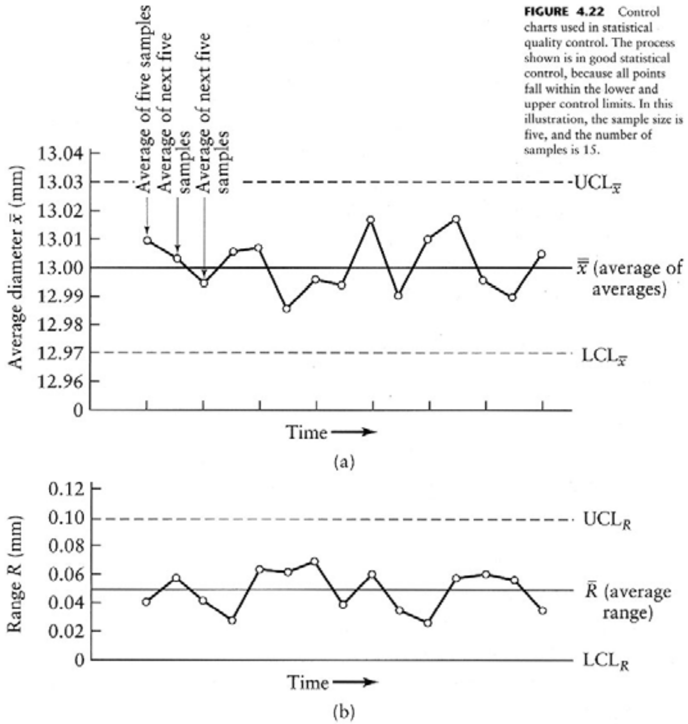


FIGURE 4.22 Control charts used in statistical quality control. The process shown is in good statistical control, because all points fall within the lower and upper control limits. In this illustration, the sample size is five, and the number of samples is 15.

TABLE 4.3

Constants for Control Charts

Sample Size	A_2	D_4	D_3	d_2
2	1.880	3.267	0	1.128
3	1.023	2.575	0	1.693
4	0.729	2.282	0	2.059
5	0.577	2.115	0	2.326
6	0.483	2.004	0	2.534
7	0.419	1.924	0.078	2.704
8	0.373	1.864	0.136	2.847
9	0.337	1.816	0.184	2.970
10	0.308	1.777	0.223	3.078
12	0.266	1.716	0.284	3.258
15	0.223	1.652	0.348	3.472
20	0.180	1.586	0.414	3.735

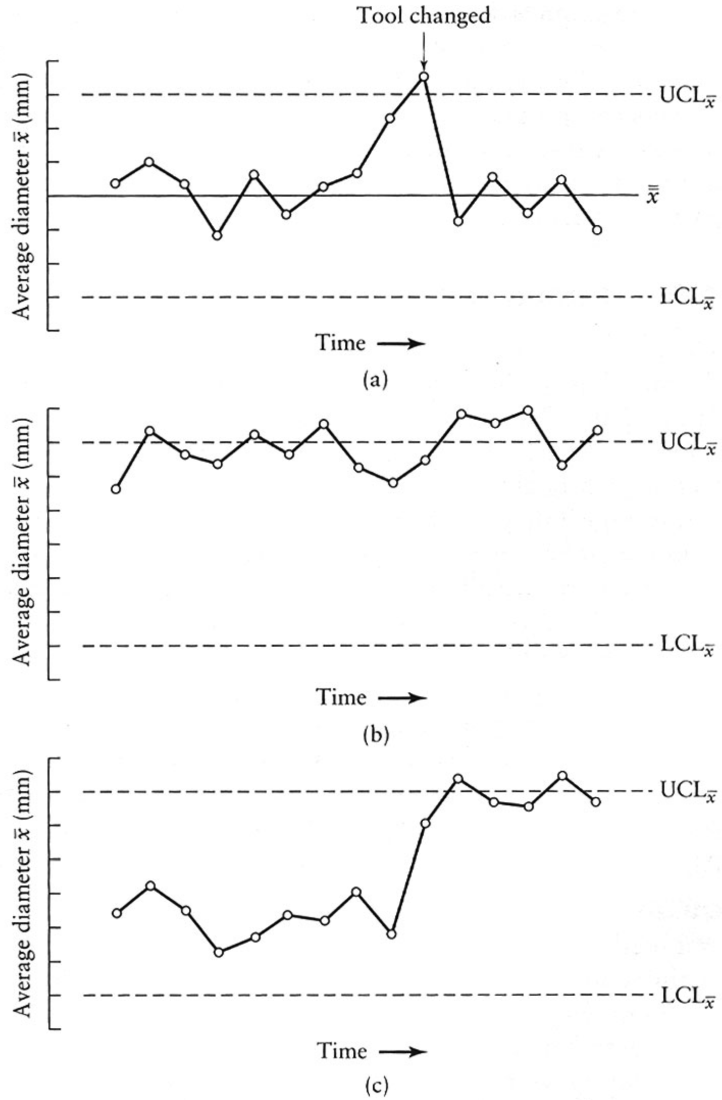


FIGURE 4.23 Control charts. (a) Process begins to become out of control, because of factors such as tool wear. The tool is changed, and the process is then in good statistical control. (b) Process parameters are not set properly; thus, all parts are around the upper control limit. (c) Process becomes out of control, because of factors such as a sudden change in the properties of the incoming material.

$$UCL_R = D_4\bar{R}$$

$$LCL_R = D_3\bar{R}$$

$$\sigma = \frac{\bar{R}}{d_2}$$

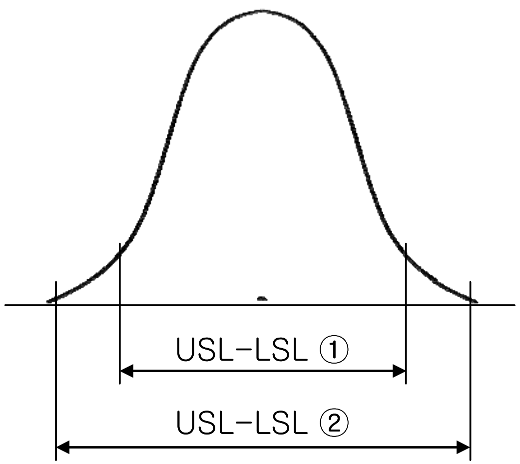
Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Process Capability Indices

- **Process Capability Index, C_p**

$$C_p = \frac{USL - LSL}{6\sigma_x}$$

$\pm 3\sigma$



  - Minimum acceptable value for C_p is 1
  - Desirable value : 1 ~ 2

- **Process Capability Index, C_{pk}**

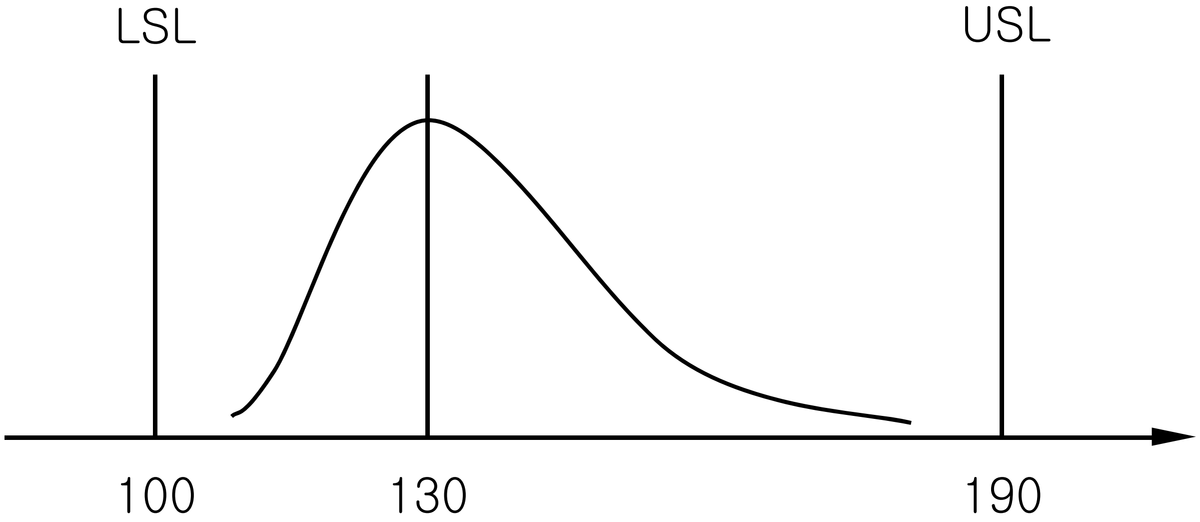
$$Z_{USL} = \frac{USL - \mu_x}{\sigma_x} \qquad Z_{LSL} = \frac{LSL - \mu_x}{\sigma_x}$$

μ_x : process mean

$$Z_{\min} = \min \left| Z_{USL} \ , or \ (-Z_{LSL}) \right|$$

$$C_{pk} = \frac{Z_{\min}}{3} \geq 1.0$$

Process Capability Indices - example



$\sigma_x = 10$

$$Z_{USL} = \frac{190-130}{10} = 6$$

$$Z_{LSL} = \frac{100-130}{10} = -3$$

$$Z_{\min} = \min|6, -(-3)| = 3$$

$$C_{pk} = \frac{3}{3} = 1.0$$