DIMENSIONS, TOLERANCES AND SURFACE

1. Dimensions, Tolerance and Related Attributes
   - Dimensions – ‘a numerical value expressed in appropriate units of measure and indicated on a drawing along with lines, symbols and notes to define the size/geometric characteristics of a part’
     - How well the parts of a product fits together.
   - Variations in the part size comes from manufacturing processes. Why?
   - Tolerance – Allowable variation in dimension.
   - Surface – affects product performance, esthetic and ‘wear’

2. Surfaces
   - Nominal Surface - intended surface contour of part
   - Actual surface - determined by the manufacturing processes
   - Wide variations in surface characteristics
   - Important reasons to consider surface
     - Esthetic reason
     - Safety
     - Friction and wear
     - Affects the mechanical integrity of a material
     - Ability to assemble
     - Better contact

3. Effect of Manufacturing Processes

Surface Technology
- Relationship between process and surface characteristics
- Characterization of a surface
  - Surface texture
  - Altered layer – result of some processes
    - Oxide film - except a nobel metal such as gold or platinum. (ex.) Fe - FeO/FeO2/Fe3O4, Al - Al2O3 layers, Cu - CuO/Cu2O, Stainless steel - chromium oxide.
    - Substrate – grain structure

Surface Texture
- Repetitive deviation from the nominal surface.
- Roughness - the small, finely spaced deviations from the nominal surface
- Waviness – the deviation of much larger space that come about from deflection, vibration, heat treatment and etc.
- Lay – the predominate pattern of surface texture
- Flaws – irregularity such as cracks, scratch, inclusions and etc.
Surface Roughness & Finish

- Surface finish – a subjective term
- Surface roughness - a measurable characteristic based on roughness deviations.
- Arithmetic Average (AA):
  \[ R_a = \frac{1}{L_m} \sum_{i=1}^{n} |y_i| \]
  where: 
  - \( R_a \) = arithmetic mean value of roughness
  - \( y_i \) = the vertical deviation from nominal surface
  - \( L_m \) = the specified distance
- Root-mean-square (RMS) – the square root of the mean of the squared deviation over the measured length:
  \[ RMS = \sqrt{\frac{1}{L_m} \sum_{i=1}^{n} y_i^2} \]
- RMS > AA usually.
- A problem with the \( R_a \) computation is that waviness may get included.
- A parameter called the cutoff length: a sampling distance along the surface.
  - By choosing the sampling distance shorter than the waviness width, waviness deviation is eliminated.

Surface Integrity

- Metallurgical changes in the altered layer beneath the surface can significantly affect the mechanical properties of a material.
- Surface integrity is the study and control of this subsurface layer and its evolution during processing:
  - Absorption
  - Alloy depletion
  - Cracks
  - Craters
  - Heat-affected Zone
  - Inclusion

3. Effect of Mfg Processes

- Typical tolerance:
  - Sand Casting ±1.3mm
  - Cast Iron ±1.55mm
  - Steel ±0.5mm
  - Aluminum ±0.5mm
  - Die Casting ±0.12mm
  - Plastic Molding ±0.03mm
  - Polyethylene ±0.15mm
  - Machining
    - Drilling ±0.08mm
    - Milling ±0.08mm
    - Turning ±0.05mm
  - Abrasive processes
    - Grinding ±0.008mm
    - Lapping ±0.005mm
- Surface finish, roughness:
  - Casting
    - Die Casting Good 1-2µm
    - Investment Good 1.5-3
    - Sand Casting Poor 12-25
  - Metal forming
    - Cold rolling Good 1-3
    - Hot rolling Poor 12-25
  - Machining
    - Boring Good 0.5-6
    - Drilling Medium 1.5-6
    - Milling Good 1-6
    - Turning Good 0.5-6
  - Abrasive Processes
    - Grinding Very Good 0.1-2
    - Lapping Excellent 0.05-0.5

FRICTION, WEAR AND LUBRICATION

1. Friction
2. Wear
3. Lubrication

1. Adhesion

- The work of adhesion, \( W_{ab} \), is the work (energy) required to separate 1cm² of the interface between A and B. As \( W_{ab} \) increases, typically the friction coefficient increases.
  \[ W_{ab} = \gamma_a + \gamma_b - \gamma_{ab} \]
  where \( \gamma_a \) is the surface energy of Material A
  \( \gamma_b \) is the surface energy of Material B
  \( \gamma_{ab} \) is the energy of interface (NOT KNOWN).
- \( W_{ab} = 2 \gamma_a \) : identical materials
- \( W_{ab} = 3/4(\gamma_a + \gamma_b) \) : compatible but not identical
- \( W_{ab} = 1/2(\gamma_a + \gamma_b) \) : incompatible
- The work by Rabinowicz (Chart):
  \[ W_{ab} = c(\gamma_a + \gamma_b) \]
  where \( c \) = the metallurgical effect.
2. Friction

- Testing concrete blocks
- Barreling in compression test
- In forging, rolling, sheet metal forming and machining
- Friction – the resistance to relative motion between two bodies in contact.
- Force to overcome friction
- Static ($\mu_s$) and Kinetic ($\mu$) frictions

2. Wear

- Wear Mechanism
  - Adhesion Wear
  - Abrasion – two-body and three-body
  - Oxidation and other chemical reaction
  - Diffusion
  - Other Wear – spalling (fatigue), fretting, erosion etc.
- Protection from friction and wear
  - Proper material selection
  - Surface treatment
  - Smoother surface (dry)
  - ‘Rough’ surface (lubrication)
  - Proper operating condition (speed, temperature and pressure)

3. Lubrication

- Fluid Film Lubrication
  - thick-film or hydrodynamic lubrication.
  - Viscosity of a lubricant
  - Results erosion
  - Thin-film lubrication
  - Friction increases
- Mixed-film lubrication
- Boundary Lubrication – presence of boundary layer that carry normal force
  - Extreme pressure lubrication for high T and P
- Solid Lubrication

Lubricants in Manufacturing

- Functions of Metal Working Lubricants
  - Separate surfaces
  - Protect surfaces
  - Remain stable and durable
  - Cools the materials
  - Not Health-hazard
  - Inexpensive
- Mineral oil, Natural oil, synthetic fluids, Compounded lubrication, Aqueous lubrication, and coating and barrier.
Introduction

- Heat Treatment: Heating and cooling procedure to manipulate structural changes (affect materials properties) for mostly metals.
- Also for glass ceramics, tempered glass, powder metals and ceramics
- Before shaping
  - To soften a metal for forming
- After forming
  - To relieve strain hardening
- Final finish
  - To achieve final strength and hardness.

Principal Heat Treatment

- Annealing
- Martensite formation in steel
- Tempering of martensite
- Precipitation hardening
- Surface hardening

1. Annealing

- **Heating** the metal to a high enough temperature for a certain time and **cooling** slowly.
- **Reasons**
  - To reduce hardness and brittleness
  - To alter microstructure
  - To soften metal for improved machinability or formability
  - To recrystallize the cold worked metals
  - To relieve residual stresses

Annealing

- Full annealing – heating ferrous metals into the austenite region and slow cooling to form coarse pearlite.
- Normalizing – similar to full annealing but cooling at faster rate (e.g.: in air) to form fine pearlite (higher strength and hardness).
- Process anneal – annealing to allow additional deformation processes
- Anneal – similar except no subsequent deformation process
- Recovery anneal – retain most of strain hardening but toughness improved.
- Stress-relief annealing – to relieve residual stress.

2. Martensitic Transformation

- Martensite - Body Centered Tetragonal
  - Nonequilibrium transformation of austenite under conditions of rapid cooling.
  - The extreme hardness results from the lattice strain created by carbon atoms trapped in the BCT structure, thus providing a barrier to slip
- Bainite – fine needle-like structure consisting of ferrite and fine carbide regions.
- Time-Temperature-Transformation (TTT) diagram
Heat Treatment Process

- **Austenizing**
  - Heating the steels to a high enough temperature until they convert to at least partial austenite.

- **Quenching**
  - Media: brine (salt water), fresh water, oil and air
  - Dependency on mass and geometry

- **Tempering**
  - Heat treatment to reduce brittleness on martensite (tempered martensite)
    - Precipitation of fine carbide particle
    - BCT -> BCC

Hardenability

- **Jominy end-quench test**

3. Precipitation Hardening

- **Strengthening Heat treatment**
- **Solution Treatment** - alloy is heated to a temperature $T_s$ above the solvus line into the alpha phase region and held for a period sufficient to dissolve the beta phase
- **Quenching** - to room temperature to create a supersaturated solid solution
- **Precipitation treatment** - cause precipitation of fine particles of the beta phase at $T_p$
  - Aging
    - Natural aging – aging at room temperature
    - Artificial aging – aging at elevated temperature
    - Overaging (similar to annealing)
4. Surface Hardening

- Thermochemical process to alter the surface
- Carburizing
  - Pack carburizing – with carbonaceous materials in a chamber (thickness of 0.6-3.8mm)
  - Gas carburizing - hydrocarbon fuel in a chamber (thickness of 0.13-0.75mm)
  - Liquid carburizing – molten salt bath with chemicals (thickness of 0.13-0.75mm)
- Chromizing – requires higher temperature and longer treatment
  - Not only harder and wear resistant but also corrosion resistant

- Nitriding (Steels with 0.85-1.5% Al & 5% or more Cr, which form fine nitride compounds particles) (thickness of 0.025-0.05mm)
  - Gas Nitriding – heated in an ammonia atmosphere at 510°C
  - Liquid Nitriding – dipped into molten cyanide salt bath at 510°C
- Carbonitriding – heating in a furnace of carbon & ammonia (thickness of 0.07-0.5mm)
  - Borizing – on tool steels, nickel- & cobalt based alloys and Cast iron
  - High hardness and Low friction

5. Heat Treatment Methods

- Furnace
  - Fuel Fired
  - Electric Heating
- Batch and Continuous furnace
- Atmospheric control furnaces
  - Desirable in conventional heat treatment to avoid excessive oxidation or decarburization
  - Include C and/or N rich environments for diffusion into work surface
- Vacuum furnaces
  - Radiant energy is used to heat the workparts
  - Disadvantage: time needed each cycle to draw vacuum

Surface Hardening

- Selective Surface Hardening
  - Flame Hardening
  - Induction Heating – high frequency alternating current
  - High Frequency Resistance Heating
  - Electron Beam (EB) Heating - Electron beam focused onto a small area, resulting in rapid heat buildup
    - Involves localized surface hardening of steel austenitizing in less than a second
    - With removal of the beam, heated area is immediately quenched to surrounding metal
  - Laser (Light amplification by stimulated emission of radiation) Beam (LB) Heating - High-density beam of coherent light focused onto a small area along a defined path
    - With removal of the beam, heated area is immediately quenched to surrounding metal
    - Laser beams do not require a vacuum to achieve best results