MSE 440/540: Processing of Metallic Materials

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Lecture 16: Surface Processing
Surface treatments
SURFACE PROCESSING OPERATIONS

1. Industrial cleaning processes
2. Diffusion and ion implantation
3. Plating and related processes
4. Conversion coating
5. Vapor deposition processes
6. Organic coatings
Overview of Industrial Cleaning

- Almost all workparts must be cleaned one or more times during their manufacturing sequence
- Processes used to clean the work surfaces
  - Chemical cleaning methods - use chemicals to remove unwanted contaminants from the work surface
  - Mechanical cleaning - involves removal of contaminants by various mechanical operations
Chemical Cleaning Processes

- Alkaline cleaning
- Emulsion cleaning
- Solvent cleaning
- Acid cleaning
- Ultrasonic cleaning
Alkaline Cleaning

Uses an alkali to remove oils, grease, wax, and various types of particles (metal chips, silica, light scale) from a metallic surface

- Most widely used industrial cleaning method
- Alkaline solutions include sodium and potassium hydroxide (NaOH, KOH), sodium carbonate (Na$_2$CO$_3$), borax (Na$_2$B$_4$O$_7$)
- Cleaning methods: immersion or spraying followed by water rinse to remove residue
Emulsion Cleaning

Uses organic solvents (oils) dispersed in an aqueous solution

- Suitable emulsifiers (soaps) results in a two-phase cleaning fluid (oil-in-water), which functions by dissolving or emulsifying the soils on the part surface
- Used on either metal or nonmetallic parts
- Must be followed by alkaline cleaning to eliminate all residues of the organic solvent prior to plating
Solvent Cleaning

Organic soils such as oil and grease are removed from a metallic surface by chemicals that dissolve the soils

- Common application techniques: hand-wiping, immersion, spraying, and vapor degreasing
  - *Vapor degreasing* (a solvent cleaning method) uses hot vapors of chlorinated or fluorinated solvents
Acid Cleaning

Removes oils and light oxides from metal surfaces using acid solutions combined with water-miscible solvents, wetting and emulsifying agents

- Common application techniques: soaking, spraying, or manual brushing or wiping carried out at ambient or elevated temperatures
- Cleaning acids include hydrochloric (HCl), nitric (HNO₃), phosphoric (H₃PO₄), and sulfuric (H₂SO₄)
Acid Pickling

More severe acid treatment to remove thicker oxides, rusts, and scales

• Distinction between acid cleaning and acid pickling is a matter of degree

• Generally results in some etching of the metallic surface which serves to improve organic paint adhesion
Ultrasonic Cleaning

Mechanical agitation of cleaning fluid by high-frequency vibrations (between 20 and 45 kHz) to cause cavitation (formation of low pressure vapor bubbles that scrub the surface)

• Combines chemical cleaning and mechanical agitation of the cleaning fluid
• Cleaning fluid is generally an aqueous solution containing alkaline detergents
• Highly effective for removing surface contaminants

https://www.youtube.com/watch?v=3CxQzfrjQ3Y
Mechanical Cleaning

Physical removal of soils, scales, or films from the work surface by abrasives or similar mechanical action
• Often serves other functions also, such as deburring, improving surface finish, and surface hardening
• Processes:
  – Blast finishing
  – Shot peening
  – Mass finishing processes
Blast Finishing

High velocity impact of particulate media to clean and finish a surface

• Media is propelled at the target surface by pressurized air or centrifugal force

• Most well-known method is sand blasting, which uses grits of sand as blasting media
  – Other blasting media:
    • Hard abrasives such as Al₂O₃ and SiC
    • Soft media such as nylon beads

https://www.youtube.com/watch?v=upggnYpfKY0&feature=autoplay&list=PL76EFFAD678A2DF73&playnext=2
Shot Peening

High velocity stream of small cast steel pellets (called *shot*) is directed at a metallic surface to cold work and induce compressive stresses into surface layers

- Used primarily to improve fatigue strength of metal parts
  - Purpose is therefore different from blast finishing, although surface cleaning is accomplished as a byproduct of the operation

https://www.youtube.com/watch?v=UzTgXpu9_iU
Mass Finishing

Finishing parts in bulk by a mixing action in a container, usually in the presence of an abrasive media

• Mixing causes parts to rub against media and each other to achieve desired finishing action

• Parts are usually small and therefore uneconomical to finish individually

• Processes include:
  – Tumbling
  – Vibratory finishing

https://www.youtube.com/watch?v=y21Zi_MY9wA&feature=related
Use of a horizontally oriented barrel of hexagonal or octagonal cross section in which parts are mixed by rotating the barrel at speeds of 10 to 50 rev/min

- Finishing by "landslide" action - media and parts rise in the barrel as it rotates, then top layer tumbles down due to gravity
- Drawbacks: slow, noisy, and large floor-space required

https://www.youtube.com/watch?v=4venlmzvg8A&feature=related
Vibratory Finishing

- Alternative to tumbling
- Vibrating vessel subjects all parts to agitation with the abrasive media, as opposed to only the top layer as in barrel finishing
  - Processing times for vibratory finishing are significantly reduced
- Open tubs permit inspection of parts during processing, and noise is reduced

https://www.youtube.com/watch?NR=1&feature=endscreen&v=rHzik_z-1C8
Mass Finishing Media

- Most are abrasive
- Some media perform nonabrasive operations such as burnishing and surface hardening
  - Natural media (corundum, granite, limestone) - generally softer and nonuniform in size
  - Synthetic media ($\text{Al}_2\text{O}_3$ and SiC) - greater consistency in size, shape, and hardness
  - Steel - used for surface-hardening, burnishing, and light deburring operations
Processes to Alter Surface Chemistry

- Two processes that impregnate the surface of a substrate with foreign atoms
  - Diffusion
  - Ion implantation
Metallurgical Applications of Diffusion

• Surface treatments to increase hardness and wear resistance
  – Carburizing, nitriding, carbonitriding, chromizing, and boronizing

• Surface treatments to increase corrosion resistance and/or high-temperature oxidation resistance
  – Aluminizing - diffusion of aluminum into carbon steel, alloy steels, and superalloys
  – Siliconizing – diffusion of silicon into steel surface
Ion Implantation

Embedding atoms of one (or more) foreign element(s) into a substrate surface using a high-energy beam of ionized particles

- Results in alteration of the chemistry and physical properties of layers near the substrate surface
- Produces a much thinner altered layer and different concentration profile than diffusion
Advantages and Applications of Ion Implantation

• **Advantages**
  – Low temperature processing
  – Good control and reproducibility of impurity penetration depth
  – Solubility limits can be exceeded without precipitation of excess atoms

• **Applications**
  – Modifying metal surfaces to improve properties
  – Fabrication of semiconductor devices
Plating and Related Processes

Coating thin metallic layer onto the surface of a substrate material

• Substrate is usually metallic, although methods are available to plate plastic and ceramic parts

• Processes:
  – Electroplating (most common plating process)
  – Electroforming
  – Electroless plating
  – Hot dipping
Electroplating

Electrolytic process in which metal ions in an electrolyte solution are deposited onto a cathode workpart

- Also called *electrochemical plating*
- Anode is generally made of the plating metal and serves as source of the plate metal
- Direct current from an external power supply is passed between anode and cathode
- Electrolyte is an aqueous solution of acids, bases, or salts

https://www.youtube.com/watch?v=OdpvTr-7bYI
Theoretical Electroplating Equation

• Faraday’s laws can be summarized:

\[ V = C \cdot I \cdot t \]

where \( V \) = volume of metal plated, mm\(^3\) (in\(^3\));
\( C \) = plating constant which depends on electrochemical equivalent and density, mm\(^3\)/amp-s; \( I \cdot t \) (current x time) = electrical charge, amps-s

• \( C \) indicates the amount of plating material deposited onto the cathodic workpart per electrical charge
Common Coating Metals

• Zinc - plated on steel products such as fasteners, wire goods, electric switch boxes, and sheetmetal parts as a sacrificial barrier to corrosion

• Nickel - for corrosion resistance and decorative purposes on steel, brass, zinc die castings, etc.
  – Also used as base coat for chrome plate

• Tin - widely used for corrosion protection in "tin cans" and other food containers
More Coating Metals

- Copper - decorative coating on steel and zinc, either alone or alloyed as brass
  - Also important in printed circuit boards
- Chromium - decorative coating widely used in automotive, office furniture, and kitchen appliances
  - Also one of the hardest electroplated coatings for wear resistance
- Precious metals (gold, silver) - plated on jewelry
  - Gold is also used for electrical contacts
Electroless Plating

Metallic plating process driven entirely by chemical reactions - no electric current is supplied

• Deposition onto a part surface occurs in an aqueous solution containing ions of the desired plating metal
  – Workpart surface acts as a catalyst for the reaction in the presence of reducing agent

• Metals that can be plated: nickel, copper, and gold

• Notable application: copper for plating through-holes of printed circuit boards
Hot Dipping

Metal substrate (part) is immersed in a molten bath of a second metal; when removed, the second metal is coated onto the first

- Common substrate metals: steel and iron
- Coating metals: zinc, aluminum, tin, and lead
- Primary purpose is corrosion protection

https://www.youtube.com/watch?v=c2J07n5hSbs
Hot Dipping Processes

- **Galvanizing** - zinc coated onto steel or iron
  - Most important hot dipping process

- **Aluminizing** - coating of aluminum onto a substrate
  - Excellent corrosion protection, in some cases five times more effective than galvanizing

- **Tinning** - coating of tin onto steel for food containers, dairy equipment, and soldering applications
Conversion Coatings

- Chemical conversion coatings - chemical reaction only
  - Phosphate and chromate conversion coatings are the common treatments

- Anodizing - oxide coating produced by electrochemical reaction
  - Anodize is a contraction of anodic oxidize
  - Most common on aluminum and its alloys
Chemical Conversion Coatings

• *Phosphate coating* - transforms base metal surface (e.g., steel, zinc) into phosphate film by exposure to phosphate salts and dilute phosphoric acid
  – Useful preparation for painting of automobiles

• *Chromate coating* - transforms base metal (e.g., aluminum, copper, magnesium, zinc) into various forms of chromate films (sometimes colorful) using solutions of chromic acid, chromate salts, etc.
Anodizing

Electrolytic treatment that produces a stable oxide layer on a metallic surface

• Applications: aluminum and magnesium common
  – Also zinc, titanium, and other metals
• Dyes can be incorporated into anodizing process to create a wide variety of colors
  – Especially common in aluminum anodizing
• Functions: primarily decorative; also corrosion protection

https://www.youtube.com/watch?v=eGlj9yn2DEo
Physical Vapor Deposition (PVD)

Family of processes in which a material is converted to its vapor phase in a vacuum chamber and condensed onto substrate surface as a very thin film

- Coating materials: metals, alloys, ceramics and other inorganic compounds, even some polymers
- Substrates: metals, glass, and plastics
- Very versatile coating technology
  - Applicable to an almost unlimited combination of coatings and substrate materials
Processing Steps in PVD

• All physical vapor deposition processes consist of the following steps:
  1. Synthesis of coating vapor
  2. Vapor transport to substrate
  3. Condensation of vapors onto substrate surface

• These steps are generally carried out in a vacuum chamber, so evacuation of the chamber must precede PVD process
Physical Vapor Deposition

- Setup for vacuum evaporation, one form of PVD, showing vacuum chamber and other process components
Chemical Vapor Deposition (CVD)

Involves chemical reactions between a mixture of gases and the heated substrate, depositing a solid film on the substrate

• Reaction product nucleates and grows on substrate surface to form the coating
• Most CVD reactions require heat
HW assignment

• Reading assignment: Chapters, 20.4, 21


• Problems: 21.1, 21.12,