TED 226

Application and Processing of Engineering Materials

Course Packet

Revised Spring 2006

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Syllabus

1. **Course Number**: TED 226
   Course Name: Application and Processing of Engineering Materials
   Credits: 3
   Prerequisite: None

2. **Instructor:** Dr. Larry Horath or any qualified TED faculty member

3. **Rationale for the Course:**

   Students are required to develop technological literacy, especially those aspiring to become technology education teachers. This course addresses the needed skills and competencies and serves as an introduction to metallic, ceramic, and plastic materials including the selection, preparation, conditioning, forming, shaping, and finishing of these materials. There will be approximately two lecture hours and four laboratory hours per week which allow students to explore facets of materials science, selection, processing, and testing. This course will further serve as the skills foundation for other laboratory courses that require the processing of materials.

4. **Objectives:**

   Upon successful completion of this course the student will be able to

   a. Describe primary and secondary methods of processing common industrial materials.
   b. Identify and differentiate between different industrial materials.
   c. Define, describe and evaluate different physical, mechanical, chemical, thermal, electrical, and other common properties.
   d. Analyze various properties through accepted, standardized tests.
   e. Use permanent and consumable molds to produce castings.
   f. Identify the various molding and casting techniques along with their advantages, disadvantages, and applications.
   g. Change the shape of metallic, ceramic, and plastic materials using a variety of techniques including cold and hot forming, extruding, blow molding, calendering, and mechanical forming.
   h. Perform common lathe and milling operations to shape materials.
   i. Identify and properly apply various mechanical fasteners.
   j. Apply electric arc welding, oxy-acetylene welding, brazing, and soldering processes in joining similar and dissimilar materials.
   k. Perform drilling, sawing, tapping, grinding, sanding, and similar common industrial processes.
   l. Cut, trim, and shape metallic materials using a variety of techniques such as flame cutting, shearing, and assorted hand tools.
   m. Heat treat metals using annealing, normalizing, hardening, tempering, and work hardening.
   n. Chemically condition plastic materials using catalytic action and polymerization.
   o. Assemble various materials using mechanical fasteners, adhesives, and cohesive processes.
   p. Apply suitable surface finish preparation techniques, correctly select a proper finish, and properly apply the finish for a variety of materials.

5. Proposed Catalog Description:

This course is designed to serve as an introduction to metallic, ceramic, and plastic materials including the selection, preparation, conditioning, forming, shaping, and finishing of these materials. There will be approximately two lecture hours and four laboratory hours per week. These activities allow students to explore the many facets of materials science, selection, processing, and testing. Additionally, this course serves as the foundation for other laboratory courses that require the processing of materials.

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   1. Syllabus
   2. Topic Schedule and Calendar
   3. Policies and Procedures
   4. Safety Issues

B. Properties of Materials
   1. Materials Science and Selection
   2. Chemical Basis for Materials and Properties
   3. Physical Properties
   4. Chemical Properties
   5. Mechanical Properties
   6. Thermal Properties
   7. Electrical Properties
   8. Other Factors

C. Types of Processing
   1. The Nature of Manufacturing
      a. Primary Processing
      b. Secondary Processing
      c. Casting and Molding
      d. Separating and Shaping
      e. Conditioning
      f. Assembling and Joining
      g. Finishing
   2. Types of Industrial Materials
      a. Metals
      b. Wood
      c. Polymers
      d. Ceramics
      e. Composites
      f. Other
   3. Summary

D. Casting and Molding
   1. Introduction to Casting and Molding Processes
      a. Historical Background and Development
      b. Common Industrial Types
      c. Advantages and Disadvantages
      d. Details and Applications
   2. Casting Metals Using Consumable Molds

        a. Sand Casting
        b. Shell Mold Casting
        c. Investment Casting
        d. Other
    3. Casting Metals Using Permanent Molds
        a. Slush Casting
        b. Die Casting
        c. Centrifugal Casting
        d. Other
    4. Casting and Molding Plastic Materials
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        b. Injection Molding
        c. Compression Molding
        d. Blow Molding
        e. Transfer Molding
        f. Rotational Molding
        g. Dip Casting
        h. Slush Casting
        I. Foaming
    5. Summary
E. Forming and Shaping
    1. Introduction to Forming and Shaping
        a. Basic Techniques in Forming
        b. Common Devices Used to Form and Shape Materials
        c. Temperature as a Factor in Forming and Shaping
        d. Methods of Applying Force in Forming and Shaping
    2. Hot Forming Materials
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        b. Techniques
        c. Safety Concerns
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        b. Techniques
        c. Safety Concerns
    4. Forming and Shaping Plastics
        a. Thermoforming
        b. Extrusion
        c. Blow Molding
        d. Calendering
        e. Mechanical Forming
    5. Summary
F. Separating Materials
    1. Introduction to Separating Techniques
        a. Process Development
        b. Elements and Techniques
        c. Machines and Motion
        d. Proper Selection, Support, and Safety
    2. Turning and Related Operations
        a. Turning
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    c. Tapers
    d. Necking and Parting
    e. Threading
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    b. Normalizing
    c. Hardening
    d. Tempering
    e. Work Hardening
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    b. Polymerization
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H. Assembling and Joining
  1. Introduction to Assembling and Joining
    a. Mechanical Assembly
    b. Adhesive and Cohesive Processes
  2. Welding Processes
    a. Soldering and Brazing
    b. Oxy-acetylene Welding
    c. Electric Arc Welding
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    h. Other
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    a. Adhesives
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  4. Mechanical Fastening
    a. Physical Structures
    b. Fasteners
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- I. Finishing
    1. Introduction to Finishing
    2. Finishing Techniques for Various Materials
        - a. Selecting Finish Materials
        - b. Preparing Surface for Finish
        - c. Proper Finish Application
    3. Inorganic Coatings
        - a. Conversion Processes
        - b. Coating Processes
    4. Organic Coatings
        - a. Types
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    5. Summary
- J. Testing of Materials
    1. Introduction to Materials Testing
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    3. Data Collection
    4. Proper Analysis of Data
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7. Teaching Methodology and Format

A variety of teaching methods will be employed including lecture, group discussion, demonstration, individual and group research and outside assignments, laboratory activities and projects, and presentations. There will be approximately two lecture hours and four laboratory hours per week.

8. Specialized Equipment or Supplies Needed:

There are no additional specialized equipment or supplies required for this course. The support, in terms of equipment and supplies, currently exists.

9. Assessment Activities

Assessment Activities include the following:

Quizzes, Tests, Individual Projects/Activities, Class Participation,
Performance Evaluations and Presentations.

Specific point values and percentages will be discussed during class as specific assignments and projects vary.

10. Recommended Textbook and Supplemental Materials

DuVall, B. (1996). Contemporary Manufacturing Processes. Goodheart-Wilcox: South Holland, IL.

Horath, L. (2000). (2nd ed.) Fundamentals of Materials Science for Technologists. Prentice-Hall: Englewood Cliffs, NJ.

11. Supportive Library Materials

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Introduction to sheet metal processing. (1983). Lynn Technical Training Operation: Lynn, MA.

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In addition to the various materials available in Manderino Library, web links are available through my website at workforce.cup.edu\horath\geninfo.html.

Information Sheet on the Structure of Materials

Background

All of us live in a world dominated by materials. Steel, aluminum, plastics, ceramics, glass, copper, brass, bronze, paints, and many other materials are used in planning and designing new products.

The history of western civilization contains records of material use since recorded history. History texts describe these epochs as the Stone Age, Bronze Age, Iron Age, and Information Age.

Today, there are several hundred times as many different materials as there were at the turn of the 20th Century. Conservative estimates are between 50,000 and 70,000 different compositions and grades of metals alone! For example, automobiles in 1900 used a total of 100 different materials. Modern cars use over 5,000 different materials.

Information

The large world of materials processing can be divided into two parts: production and application. Production involves the making of materials for industrial use. This includes the mining and refining of raw materials into usable forms. This would include steel beams, aluminum sheet, plastic pellets, sheets of glass, and rubber. The application of materials involves the utilization of raw materials by processing them into useful products. Examples include bridges, pop cans, plastic milk jugs, glass windows, and automobile tires.

Structure of Materials

The production of materials is based, primarily, on physics and chemistry. All materials obey established laws in their formation, reactions, and combinations. The smallest part of any element is the atom. All matter is comprised of atoms bonded together in different combinations and patterns.

All matter can be categorized as organic or inorganic. Organic materials contain carbon and, usually, hydrogen together. These are termed hydrocarbons. Hydrocarbon based materials come from living things or the decomposition of once-living things. One example is crude oil. Inorganic materials are not derived from living matter. Items such as sand, rock, water, many metals, and gases are inorganic.

The Periodic Table of Elements lists pure substances that cannot be broken down into smaller units by chemical action. Atoms are elements that are combined to form new materials. For example, water is composed of the elements hydrogen and oxygen. Please refer to the Periodic Table ***(http://pearl1.lanl.gov/periodic/default.htm)*** and determine for yourself, which are metals, metalloids, and nonmetallic elements.

Systems Model

A material application can be thought of as a system with inputs, processes, outputs and feedback. Graphically, this would look like the following:

Inputs →PROCESS→OUTPUTS
^ \/
:……………………. FEEDBACK

In addition to meeting design specifications for the present application, a material should be stable over time, reliable, and safe. To help ensure that a material is all of these things, one must evaluate material properties.

Properties of Materials

The performance requirements and application conditions can be reduced to simple terms:

1. Mechanical – loads and stresses
2. Thermal – hot or cold
3. Chemical – atmosphere, chemicals, oxidation
4. Electrical – current requirement, resistance
5. Radiation – UV, IR, nuclear

These properties influence the action of a material in application. They are also used as design criteria in selecting the proper material for an application. Material properties are also chosen based on other criteria or constraints.

Constraints

Constraints are criteria that must be taken into account when selecting a particular material for an application. These are generally items, which are outside the designer's control, such as:

1. Cost
2. Existing processing facilities
3. Compatibility with other materials
4. Marketability
5. Availability
6. Disposability, and
7. Recyclables

These are just a select few.

Microstructures and Bonding

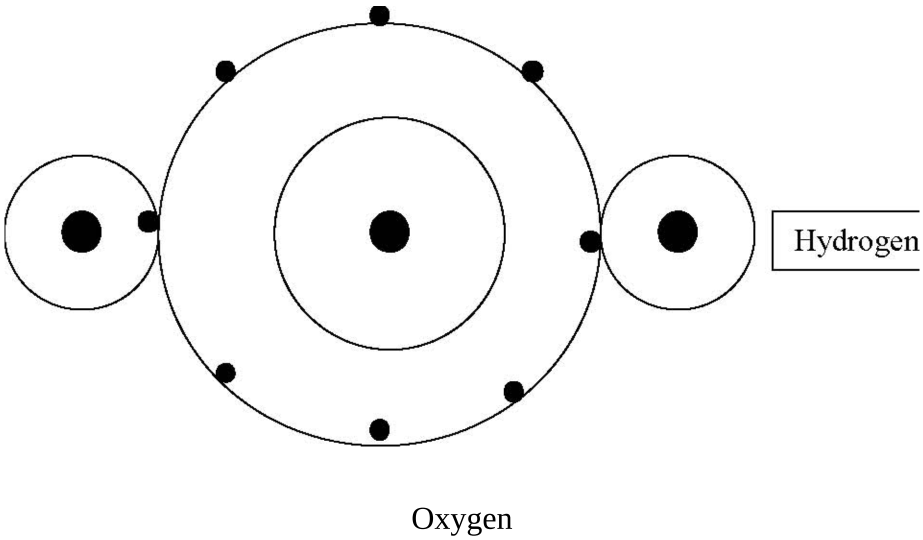
All matter is comprised of building blocks called atoms. Atoms are made up of a nucleus, which contains neutrons and protons, surrounded by electrons. Neutrons are electrically neutral while protons are positively charged and electrons are electrically negatively charged. The opposite charges of the protons and electrons help hold the fast-moving electrons in crude orbits called shells.

Forming Engineering Materials

Some elements can be seen in their pure form, such as gold, silver, lead, and copper. Other elements are more common in their combined form as compounds, such as water. Still further, there are many elements, which can be observed as mixtures, such as latex compounds and paints. The combined forms of elements are described as:

1. Alloys – metals combined to form new materials with different properties than the originals.
2. Compounds – chemically combined elements with specific proportions of component elements
3. Mixtures – physical blends of two or more substances.

It is the total number of electrons and the number of shells of electrons that helps determine the properties of these materials. The outermost shells called valence shells combine atoms in these materials. Electrons in these outermost shells are called valence electrons and they determine the aggressiveness of an atom to combine with other atoms. The two atoms intending to combine must have complimentary valence shells. For example, an oxygen atom has two available spaces in its outermost shell. Combined with two hydrogen atoms, which have one electron apiece, the three atoms combine together to form water. Put another way, hydrogen has a valence of 1 and oxygen has a valence of 6. Take, for instance, the Water Molecule:

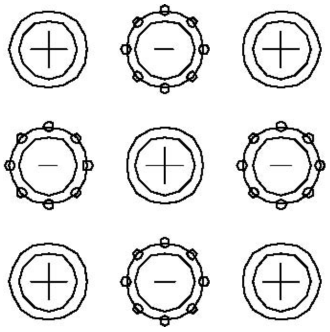


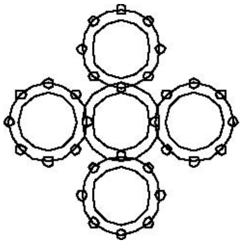
Another example of how bonding influences properties is based on carbon atoms. Graphite, for example, consists of layers of carbon atoms arranged in flat hexagonal rings. Each of these hexagonal rings is formed with carbon atoms at each of the six points of the hexagon. Therefore, each of the carbon atoms is bonded to three others, fulfilling its need to complete its outer shell. Graphite is black in color and relatively soft. It is often used as a dry lubricant because the planes of atoms slide easily over each other. Another carbon-based material is diamond. Unlike graphite, diamonds are very hard, colorless, and nonconductors of electricity. The basis for the change in properties is based on the different bonding structure of diamonds. Diamonds have a three-dimensional, face-centered cubic structure where each carbon atom is bonded to four other atoms, all in other planes.

The bonding mechanism between atoms is based on the atom's need to complete its outer shell and remain in a stable condition. Atoms without completed outer shells can achieve stability through bonding. There are three major types of bonding:

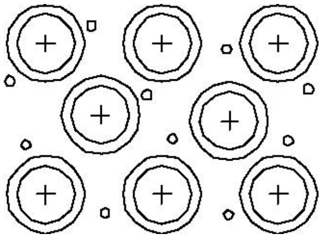
1. Gaining an electron – ionic bonding
2. Sharing electrons – covalent bonding
3. Losing electrons – metallic bonding.

Ionic bonding involves gaining electrons from one or two other atoms. The provider loses the electron and becomes a positively charged ion. The receiver gains the electron and becomes a negatively charged ion. Together, they are stable, being attracted to each other by the opposite charges. Materials, such as sodium chloride and many ceramics, which are ionic bonded, are quite strong but very brittle.





Covalent bonding, often found in polymeric materials, share negatively charged electrons. This sharing completes the outer shell and is, therefore, a more stable condition. For example, many hydrocarbons are covalently bonded. Covalently bonded materials exhibit good plasticity and moderate strength.



Metallic bonding occurs in metals. Metals tend to have only few electrons in their outer shells. These valence electrons are detached from the host relatively easily. These electrons, once freed, form a cloud in the metal structure and the hosts become positive ions. The cloud has a negative charge and holds the positive ions together.

Another weak force is called ***Van Der Waals*** forces that hold the atom together. These weak internal forces help stabilize the structure of the atom through attraction between the positive nucleus and the surrounding electrons.

Amorphous Structures

Amorphous (without body) structures differ from those previously discussed in that they do not exhibit a repetitive pattern. These materials include glass, liquids, and gases. Glass, for example, is composed of smaller atoms bonded to three larger atoms. It is sometimes referred to as a super cooled liquid. Glass has the ability to flow over time and at elevated temperatures. It is relatively stable at normal temperature.
There are exceptions to amorphous structures. For example, liquid crystal displays where properties can be affected by passing current through a matrix. The properties of other liquids, such as rheological fluids, can be altered by current passing through them. Once the current is removed, the fluid returns to its original condition.

Macrostructures of Composites

Composites are available in many forms: fibers, particles, layers, flakes, fillers, and various matrices. The binder is the body of the composite and may be any of several materials such as metal, polymer, glass, or any of a number of materials, which hold their form and bind the filler together. The filler may take many forms such as fibers, particles, flakes, mat, weave, lamina, or strands. The filler may be oriented or random. For example, plywood is comprised of various plies oriented perpendicular to each other. OSB or oriented stranded board is another example. A further example is graphic-epoxy fibers composites used in fishing rods and bike frames. Stronger and lighter than many steels, these exhibit excellent flexibility with exceptional strength.

Composites can be divided into many categories. There are five general types, based on their structural constituents:

1 Laminar – composed of layers or laminar components
2 Particulate – composed of particles with or without a matrix
3 Fiber – fibrous fillers

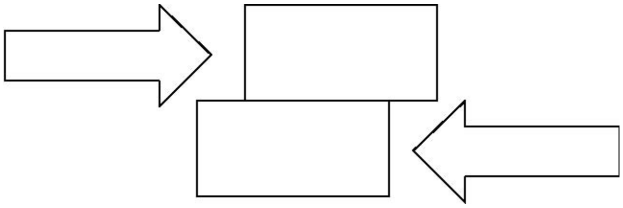
4 Flake – flat flakes suspended in a matrix
5 Filled – continuous skeletal matrix filled with a second material.

Material Properties and Testing

In materials testing, it is often desirable to determine the resultant deformation or fracture, which results from applying a mechanical force or stress. Many properties can be determined from graphing and calculations based on collected data.

There are three basic types of stress: tension, compression, and shear. These are sometimes found in combination, such as in flexural or bending stresses.

Compressive stresses tend to push toward each other along an axis. Tensile stress tends to pull in opposite directions along an axis.



Shear forces act in opposing directions along an axis.

A material that exhibits good strength in reaction to one type of stress may not exhibit the same when the stress is changed. For example, concrete has excellent compressive strength, but is relatively weak in tension.

Properties of Metals

Some of the more important mechanical properties of metals and their definitions are:

1 **Hardness** – resistance to surface penetration.
2 **Hardenability** – the property of a metal to harden uniformly and completely.
3 **Brittleness –** refers to how easily a metal will break with little or no bending.
4 **Ductility –** the property of a metal to be bent, rolled, or otherwise changed in shape without breaking. Ductile metals are often drawn into wire or rolled into thin sheets without breaking.
5 **Malleability –** refers to how easily a metal can be hammered or rolled into shape without breaking. Most malleable metals are also ductile.

6 **Toughness** – refers to a metals ability to withstand sudden shocks without breaking. Tough materials will bend or break without breaking. Very hard materials will become brittle and break easily. Therefore, many cutting tools are tempered to reduce their hardness while increasing their toughness. Springs, axles, shafts, and similar applications require toughness.

7 **Machinability** – the ease with which a metal may be machined or cut by machine tools. It is generally expressed as a percentage referencing a known standard.

8 **Strength** – the resistance of a metal to deformation.

9 **Elasticity** – the ability of a material to return to its original size and shape after the external force causing the change has been removed. Elastic limit is the maximum stress that a material can withstand without taking a permanent set or deformation.

10 **Plasticity** – the ability of a material to deform without fracture.

Information Sheet on the Making of Steel

Brief History of Steel Making

Before Industrial Revolution: Iron bars are soaked in hot, open-fire pits with granulated charcoal. The carbon from the charcoal soaks into the iron over time. The higher the carbon content required; the longer the soaking time. This product is referred to as blister steel.

Mid-18th Century: Crucibles are loaded with steel bars and placed over intense coke fires where further refinement produces a better product. Working in batches, the process is tedious.

Blast Furnace: Continuous process where iron ore, limestone, and coke are charged in layers through the top of a large shell. Hot air is blown through the mixture and, along with the burning coke, melts the iron ore. The carbon from the coke unites with the oxygen from the hot air to form carbon monoxide, which further unites with more oxygen to form carbon dioxide. As the fuel is consumed and the flux (limestone) carries impurities to the top of the batch, iron settles to the bottom of the still where it is tapped off and cast into molds.

1860s Bessemer converter: Prior to the Bessemer converter, steels were largely produced by the crucible method. This method produced high-quality, yet expensive, steels in relatively smaller batches. This method produced a medium-quality steel, suitable for general purposes, in relatively large qualities. Typically, pig iron tapped directly from the blast furnace is loaded into a pear-shaped furnace, which has been tilted horizontally. Once loaded, the furnace is then turned upright and hot air is blown through the molten metal, carrying out excess carbon and impurities. Once this process is complete, the apparatus is tilted and the molten metal poured into ladles and alloying elements added to desired levels. This process is fast and efficient.

Open Hearth Converter: A regenerative-type furnace, the open-hearth converter is lined with highly refractory material in a flat, dish-shaped configuration. Burners at each end send out long flames of intense heat, which flow out over the top of the molten metal. At one end, the burner supplies the flame and air and is collected at the other end by chambers called checkers. After a period of time, the roles reverse. This improves combustion. The furnace is loaded with iron ore, scrap, and limestone. When ready, the molten iron is tapped into a large ladle and alloying elements are added to desired levels.

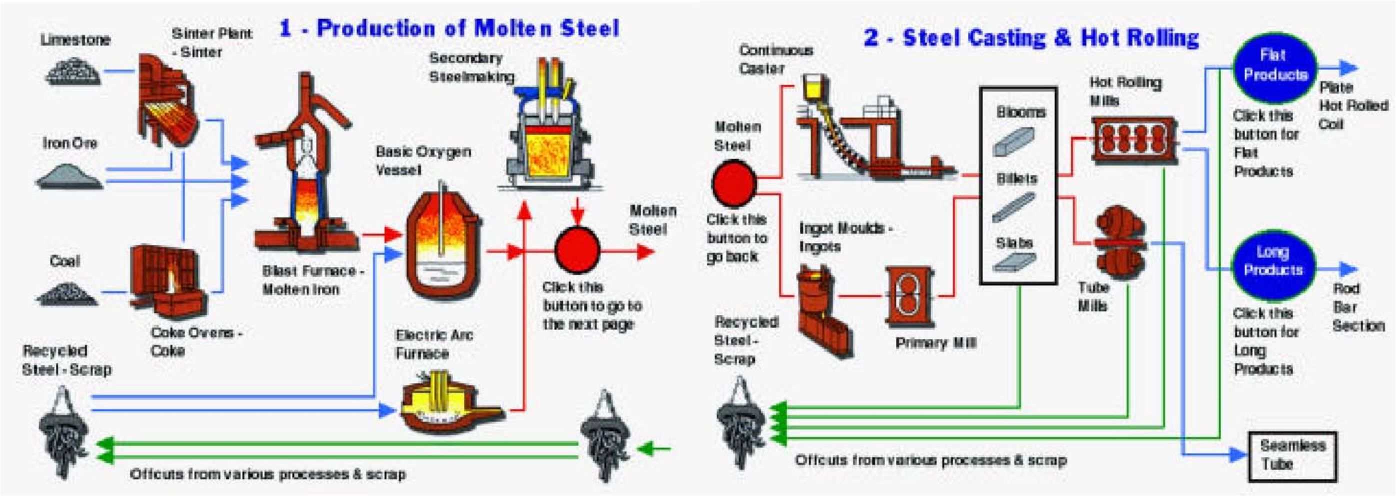
Electric Arc Furnace: Typically used for stainless, high-heat, and tool steels, it allows for better control of the melt. Scrap is loaded into the furnace and large electrodes lowered until an arc strikes between the electrodes and the scrap. The intense heat created by the current melts the metal. Impurities rise to the top and can be skimmed off. Once skimmed, alloying elements are added and the result tapped off. Induction-type furnaces operate in a similar fashion with a different current source.

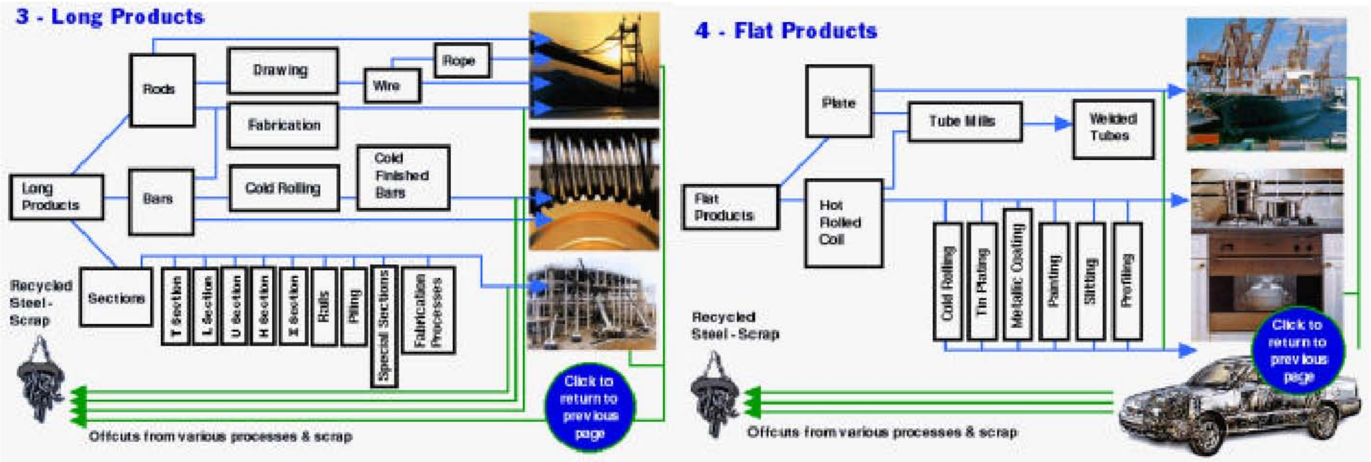
Basic Oxygen Furnace: Rapidly growing process by which a water-cooled lance is lowered into the furnace and pure oxygen is blown into the furnace at supersonic speeds. This burns off impurities, but requires great amounts of pure oxygen.

Raw Materials Used in Making Steel

The term iron is generally used to refer to the many alloys of which iron is the principal constituent. The first production of iron, starting what historians term the Iron Age, probably occurred around 1500 B.C. Iron ores are abundant and readily available. However, to produce a ton of steel requires almost three tons of iron ore. This is due, in part, to the large percentage of impurities found in these ores.

The ore is mined and carried to smelting furnaces for refining. Refining iron from ore requires tremendous heat, iron ore for raw material, coke (purified coal) for fuel, and limestone for flux. Making pig iron is the first step in purifying iron. Iron ore becomes pig iron when the impurities have been extracted from it in a blast furnace. Some impurities will remain for later extraction.





Source: *http://www.uksteel.org.uk/*

Cast Iron

Cast iron is formed by remelting pig iron and other materials in a cupola furnace. Limestone and fluxes aid in further separating impurities in the pig iron. They help extract various oxides and ash from the fuel. Cast iron generally contains more than two percent carbon.

Malleable Cast Iron

Malleable cast iron is made stronger, softer, and tougher by baking in an oven for a prolonged period. This tends to burn out some of the carbon.

Wrought Iron

Wrought iron is almost pure iron. It is often black in color. It is soft and ductile, making it easy to work with in making decorative projects. It is very tough.

Steel

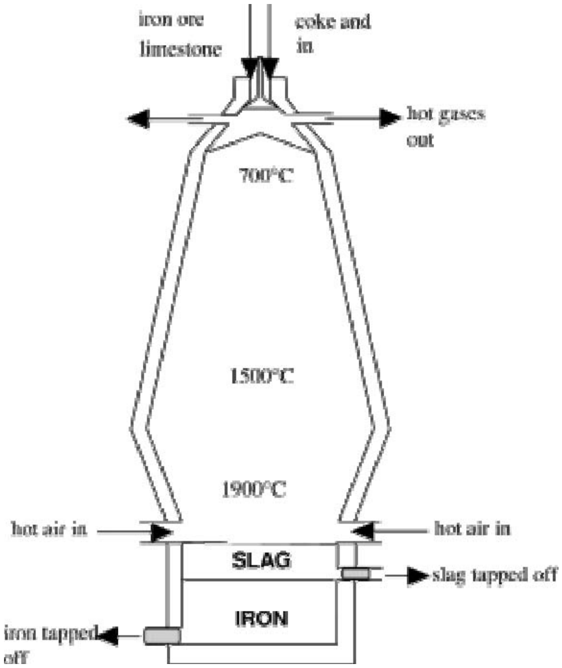
Early attempts at making steel involved packing charcoal around wrought iron bars and heating the combination. The bars absorbed enough carbon from the charcoal to become steel. The Steel Age began around 1850 with the invention of the Bessemer process. Steel making is a conversion process using pig iron as a raw material. Other alloying elements are added to alter the steels properties. More information will be provided later.

Pig iron from the blast furnace contains a number of additional elements such as phosphorous, manganese, silicon, and other elements. It also contains approximately four percent carbon. To produce steel, these impurities must be removed. If carbon is the only principal alloying element the steel is referred to plain carbon steel. Plain carbon steel is the majority of all steel produced.

Steel is produced by one of the following general processes:

1 Bessemer converter
2 Open Hearth furnace
3 Crucible furnace
4 Electric Arc furnace
5 Basic Oxygen process.

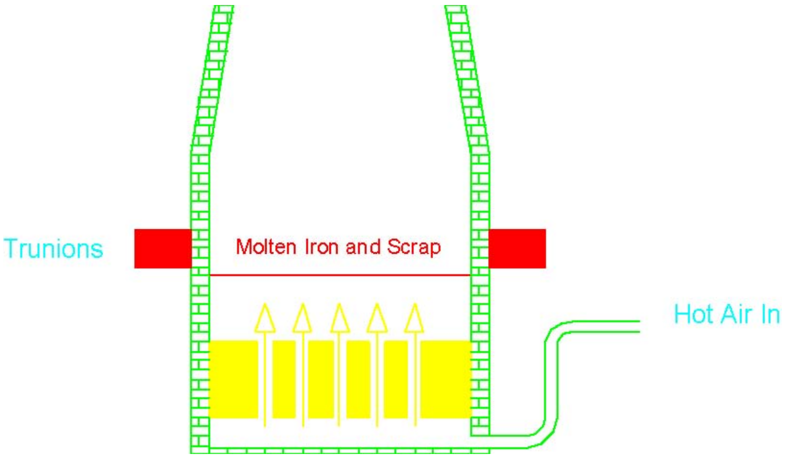
Blast Furnace



The blast furnace is a steel shell approximately 100 feet tall, lined with ceramic firebrick. The iron ore, coke, and limestone are poured into the top of the furnace. Hot air is blown through the melt. The burning coke and the hot air blast melt the iron ore. The carbon in the coke unites with the oxygen in the air to form carbon monoxide. The hot gas passing through the melt helps carry impurities out of the melt. The limestone provides a flux action to carry off the impurities or gangue. This lighter slag floats on top of the melt. The slag is periodically skimmed off the top of the melt. Molten iron is drawn from the bottom through a tapping hole and poured into ingots. Larger furnaces can put out more than 1,000 tons of pig iron a day.

Bessemer Converter

Sir Henry Bessemer developed a process of blowing a stream of hot air through a molten mass of pig iron in a pear-shaped furnace. The first recorded use of this process was in 1864. It ruled as the primary conversion process until 1909 when the open-hearth furnace gained superiority. The Bessemer converter is still used although it is a small minority of total production.



Bessemer Converter

A charge of molten iron is placed into the converter, which is tilted to the horizontal position. Once charged, the furnace is returned to the vertical position. Air is blasted through the melt to oxidize the various metals found in the melt. Total time varies according to the impurities in the melt, but generally ranges from twelve to fifteen minutes. Once converted, the white-hot molten metal is poured into ladles, which transfer the liquid where they are poured into ingots.

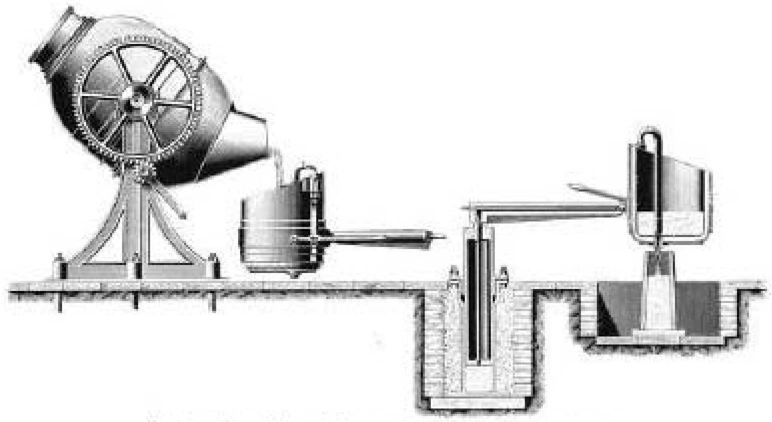
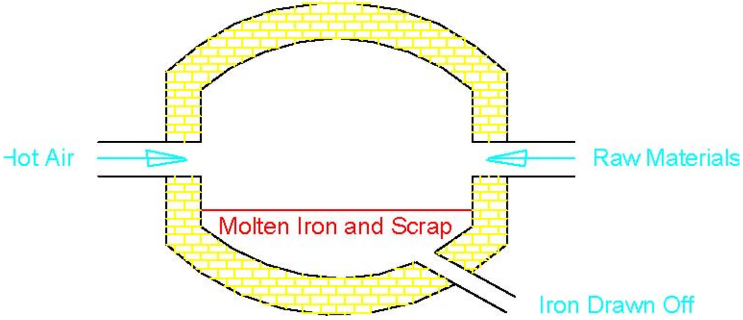


Fig. 44. Early Form of Bessemer Converting Plant at Sheffield.

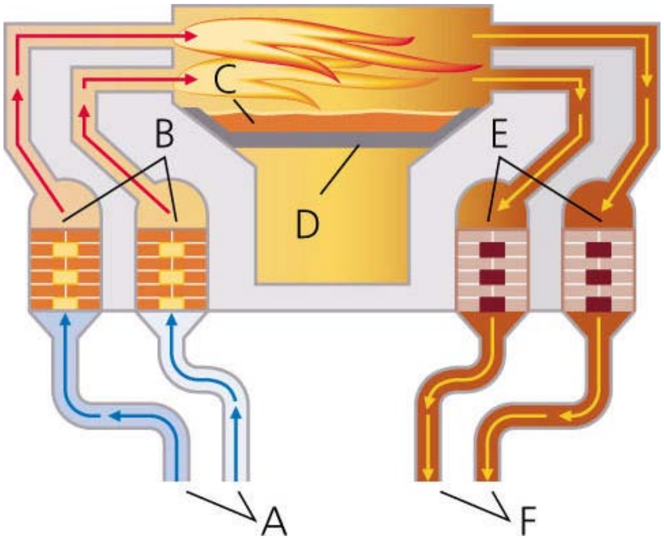
Source: http://www.history.rochester.edu/ehp-book/shb/

Open Hearth Furnace

The open-hearth furnace is a regenerative type. It is a dish-shaped opening about two feet deep. Gas and air unite at the burners at each end of the dish or hearth. The flame supplies the heat, which is blown over the melt.



The furnace is charged with limestone and iron ore, followed by iron or steel scrap. The charge is heated with the flame alternating direction for about two hours. Then pig iron is added. After eight to twelve hours, the furnace is tapped into a large ladle. Alloying elements are added to finish off the particular batch of steel.



A. Air and Gas Enter

B. Pre-heated Chamber

C. Molten Pig Iron

D. The Hearth

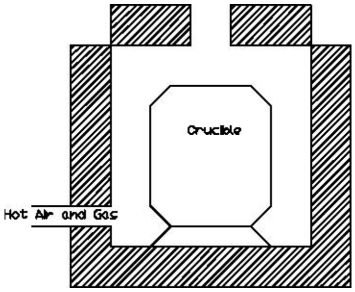
E. Heating Chamber (cold side)

F. Gas and Air Exit

Source: The American Heritage® Dictionary of the English Language, Fourth Edition. Published by the Houghton Mifflin Company.

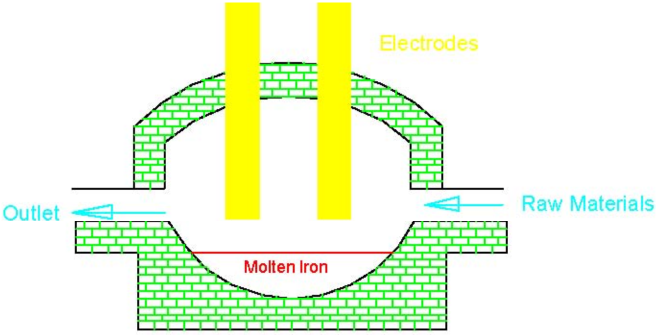
Crucible Furnace

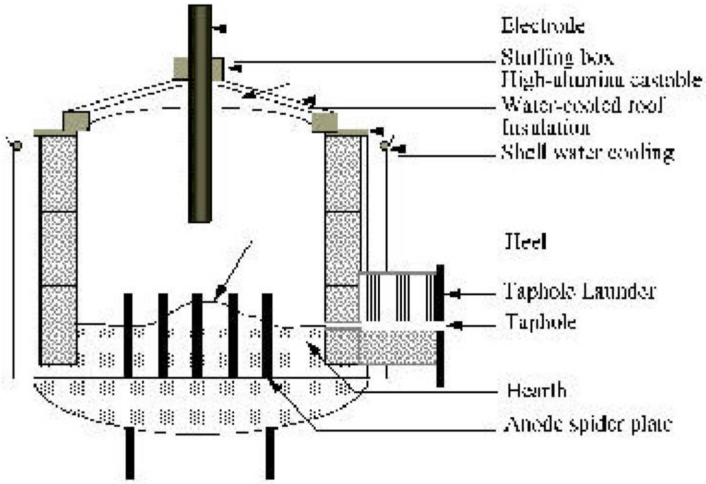
The crucible furnace is the oldest method by which high carbon steels are produced. It is virtually obsolete. One reason for this is the small amount produced by the crucible method. All of the constituents are placed in the crucible and melted. Excellent quality steels are produced, but the process is slow and expensive. The electric arc furnace has largely replaced it.



Electric Arc Furnace

Electric arc furnaces are used to make stainless, heat-resistant, and tool steels. The heat produced by the electric arc from large electrodes is used to melt the batch. This process produces superior alloy steels. One reason is that the process can be more strictly regulated than other processes previous ly discussed. The main charge consists of steel scrap. The current is introduced and the electrodes lowered until an arc strikes between the electrodes and the batch. Once the batch is melted, the impurities are driven off by oxidation that forms a slag on top of the melt. The slag is then skimmed off. Alloying elements are then added to specifications for the steel. After four to twelve hours, the furnace is tapped.

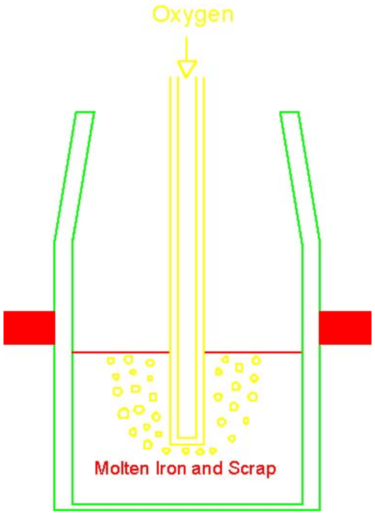




Source: http://www.mintek.co.za/Pyromet/Cobalt/Cobalt.htm

Basic Oxygen Furnace

Also known as the Oxygen Lance Method, this process has grown in popularity. A water-cooled lance is lowered into the top of the container. Pure oxygen is forced into the furnace at supersonic speed. The oxygen quickly burns off the undesirable elements in the charge. The Basic Oxygen furnace can produce steel at a rate between 50 to 500 tons per hour.



Types of Steel

Carbon steels are generally classified by the amount of carbon contained in the steel. This percentage is expressed as points where 100 points equals one percent carbon.

1 Low carbon steel, or mild steel, contains between 10 and 30 points carbon. This low carbon content makes it soft and malleable, but difficult to harden.
2 Medium carbon steel contains between 30 and 60 points carbon. It is often used for bolts, shafts, and light duty machine tools that require hardness.
3 High carbon steel, or tool steel, contains between 60 and 150 points carbon. It is called tool steel because it is often used for such tools as taps, dies, drills, and other similar applications. Alloys are added to increase its properties to make it more suitable for these applications. As one would expect, adding alloys typically increases the cost of these steels.

Hot Rolled and Cold Rolled Steels

Some steel is formed into ingots. These ingots may be rolled and formed while hot between rollers. These rollers gradually get closer and closer together until the final form is achieved. Water is sprayed on the steel as it passes through the last set of rollers, which forms a dark scale on the surface of the steel. Hot rolled steels are general-purpose steels.

Cold rolled steels are produced by drawing the steel through a die or rollers to form bars and shapes much like hot rolled. The difference is that it is performed cold. These steels are work hardened and have a smoother, shinier finish.

Alloy Steels

Alloy steels are specifically alloyed for distinct properties and applications. An alloying element or elements are added to improve or reduce certain properties in the steel. Percentages of alloying elements vary according to the desired result. Carbon can be thought of as an alloying element. Alloying elements are typically added to increase: hardness and hardenability, strength, toughness, ductility, heat resistance, magnetism, and strength. Some of the more common of these alloying elements include:

1 Manganese – added to steel in amounts from one to fifteen percent for hardness and wear resistance. Makes steel easier to forge and hot roll.
2 Chromium – increases hardness and hardenability. Also contributes luster, wear resistance, corrosion resistance, and toughness.
3 Nickel – increases strength and toughness. Along with chromium, nickel is often used as a plating material for corrosion resistance and high luster.
4 Vanadium – acts as a deoxidizer and cleanser, which helps make a finer-grained steel. Increases toughness in tool steels.
5 Silicon – acts much the same as manganese. Facilitates casting and hot working. Also adds toughness and hardenability in tool steels.
6 Tungsten – produces a fine, dense grain structure. Increases heat resistance. Often used in tool steels in larger percentages to increase their working heat range.
7 Molybdenum – Increases the toughness and strength of tools steels when used in conjunction with other alloying elements. Chrome-moly steels are an example.

Identifying Steels

The Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI) have developed a system for identifying carbon and alloy steels. A prefix letter is used to initially identify the steel:

A – Basic open-hearth alloy steel B – Acid Bessemer carbon steel C – Basic open hearth carbon steel D – Acid open hearth carbon steel E – Electric Arc steel

These designations tell the kind of furnace that the steel was made in.

Following the letter designation are four to five digits that further identify the steel and its constituents. The first digit tells the kind of steel (principal alloying element): 1 is plain carbon steel, 2 is nickel steel, 3 is nickel-chromium, and so forth.

The second digit tells the percentage of the alloy represented by the first digit. The last digits show the carbon content in points. For example, A 3130 steel is basic open-hearth furnace produced steel, which has nickel as its principal alloying element at one percent with 30 points carbon. The table below summarizes the SAE/AISI system:

Classification of Carbon and Alloy Steels

Type of Steel	AISI No.	SAE No.	Characteristics	Common Uses
Plain Carbon	C1010	1010	Low strength	Nails, bolts, wire
	C1020	1020	Very tough	Pipe, structural shapes, sheet
	C1030	1030	Good heat treat	Shafts, gears
	C1040	1040	Average	Cranks, bolts, rods
	C1045	1045		Screwdriver, auger
	C1060	1060	Soft tool steel	Lock washers, valve springs

	C1070	1070	Very tough and hard	Wrenches, dies, knives, anvils
	C1080	1080	Holds good edge	Chisels, hammers, shear blades
	C1085	1085	Tool steel-hard	Taps, dies, music wire, bumpers, knives
	C1090	1090	Tool steel – very hard	Mill cutters, springs, taps, saw blades
	B1112	1112	Good machining	Machine parts, bolts, screws
	C1115	1115	Strong, tough	Machine parts
	C1117	X1314	Case hardens	Surface products
	C1132	X1330	Good machinability	High hardness applications
Manganese	A1330	1330	Hard wear and shock	Safes, rails
Nickel	A2317	2317	Shock resist	Rails, armor plate, wire, cable
Nickel-chromium	A3115	3115	Very hard, strong	Gears, springs, axles, plate
Molybdenum	A4130	4130	High heat and hard blows	Ball and roller bearings
Chromium	A5120	5120	Hard, tough	Safes, cutting tools, bearings, rollers
Chromium-vanadium	E6150		Corrosion resistance	Axles, frames, tools, chisels
Stainless-chromium	414	51310	Heat treatable	Sinks, cooking utensils

Information Sheet on the Structure of Steel

Plain Carbon Steel

The usefulness of carbon steels is increased by the fact that its properties can be controlled by alloying and by heat-treating. Steel, for example, can be softened to make it easier to form and work, hardened to help resist abrasion and increase toughness, or a combination of these. It can be hardened and softened repeatedly.

There are two main compositions or grain structures found in carbon steels. One is ferrite, pure iron. The other is cementite, iron carbide. There are three more structures of importance: pearlite, austenite, and martensite. These will be explored later.

Carbon combines chemically with iron to form iron carbide, a harder form of steel. It has a distinct grain structure. These grain structures are distinct from each other and indicate the condition of the steel.

Steel containing 0.83% carbon will appear as all pearlite. Less than 0.83% will be a combination of pearlite and ferrite. Steel over 0.83% carbon will contain cementite. For practical purposes, the upper limit of carbon is 2%. Steel containing more than 2% becomes hard and brittle and is called cast iron.

Heat Treating Processes

When steel is heated to the transformation temperature, 1333 degrees F, a physical change occurs. The grains of pearlite become finer and the carbon in the cementite goes into solution with the ferrite. This new structure is termed austenite. It is a solid solution of carbon in the iron. The temperature at which this begins is termed the lower transformation temperature. The formation of austenite is complete when the upper transformation temperature is reached. The first step in heat treatment is achieving and holding the correct temperature.

The second step is the rapid cooling or quenching. Quenching involves air, water, oil, or brine. The fastest is brine; the slowest is air. When heated above the lower transformation temperature and held there, the physical change from austenite to martensite occurs. To “freeze” this structure, the work piece is rapidly quenched. The more rapid, the better.

The final step is to relieve some of the stresses developed during the hardening process. By reheating the work piece, hardness is reduced and toughness increased. This is essential for tooling. Toughness increases the ability of a tool to withstand sudden shocks. Tempering temperatures vary from 300-600 degrees F. Tools that require extreme toughness may be tempered at higher temperatures, ranging from 800-1100 degrees.

Further information can be found in the web links or *http://www.advancement.cnet.navy.mil/products/web-pdf/tramans/bookchunks/14250_ch2.pdf.*

Common Shapes Used in Metal Working

Material	*Common Sizes Available*	*Sold By*	*Characteristics*
Band	1/8” thick ½”, ¾”, 1” wide	12’ lengths	C1018 mild steel Aluminum, Brass, Bronze
Round	½”, ¾”, 1” diameter	12’ lengths	Same
Squares	½”, ¾”, 1” across flats	12’ lengths	Same
Flats	½” x 1”, 1-1/4”, 1-1/2”, etc.	12’ lengths	Same
Angle	1” x 1” up to 8” x 8” in even or uneven legs	12’ lengths	Same
Hexagon	3/8”, ½”, ¾”, 1”	12’ lengths	Same
Octagon	3/8”, ½”, ¾”, 1”	12’ lengths	Same
Drill Rod	1/8”, 3/16”, ¼”, 5/16”, etc.	3’ lengths	Tool steel
Pipe	From 1/8” up to 6” diameter	10’ lengths	Steel, galvanized, brass, copper, plastic
Rivets	Diameter x length	Per pound or per 1000 pieces	Soft iron, aluminum, brass
Machine screws, bolts, studs	Diameter x lengths with head design	Each, per pound, box	Steel, zinc chromate coated, galvanized
Wire, cable	Standard gage number, diameter	By weight or by length	Steel, aluminum, copper
Foundry metal	Standard pig	Per pound	Aluminum, lead, etc.

Information Sheet on Nonferrous Metals

Nonferrous metals are grouped into base metals, alloys, and precious metals. Base metals include aluminum, copper, lead, nickel, tin, and zinc. Alloys include brasses, bronzes, and pewter. Precious metals include gold, silver, titanium, and platinum. These are some of the more popular in each category.

Properties of Nonferrous Metals

Copper is very popular and widely used throughout industry. It is extremely malleable, ductile, and electrically conductive. It conducts heat and is normally non-corrosive. Copper is the basis of brasses and bronzes.

Aluminum has a dull, silvery appearance and is often used because of its lightweight and recyclability. Aluminum comes from the ore bauxite. Bauxite is mined near the surface of the earth. It is then crushed, washed, separated, and dried. Normally, the Bayer process is used to separate the aluminum hydrate is dissolved out by caustic soda. Further processing produces aluminum oxide. To separate the oxygen from the aluminum oxide, the mixture is dissolved in molten cryolite, a compound of sodium, aluminum, and flourine. An electric current is passed through the mixture where the oxygen is driven off. Molten aluminum precipitates to the bottom of the tank where it is then drawn off and poured into ingots. These "pigs" can then be remelted and alloying elements added to enhance properties. Elements such as chromium, iron, nickel, copper, zinc, manganese, silicon, and magnesium are used. Aluminum has its own designation system:

Group Major Alloy
1 pure aluminum 2 copper 3 manganese
4 silicon 5 magnesium 6 magnesium and
silicon 7 zinc 8 other elements 9 special

The final two digits indicate the percentage of the alloying element.

Tin is a shiny, silvery, white metal, which has excellent corrosion resistance. Therefore, it is often used as a coating. Tin is very malleable and is used as a coating for "tin" cans which are actually tin coatings over an iron base.

Nickel is also a white metal. It is malleable, ductile, and has good strength. Nickel is often used as an alloy for strength. Nickel is often used as a base coating metal, i.e. bumpers and decorative items. However, it is not as bright as chromium. A thin layer of chromium is then bonded to the nickel.

Chromium is a bright, shiny metal. It is used as a corrosion resistant coating. It is used as an alloying element to add strength. It is one of the principal alloys for stainless steel.

Zinc is a bluish gray metal with a coarse crystalline structure. It is often used as an alloying element with copper and aluminum. It is also a popular corrosion-resistant coating. When it is used as a coating, it is termed galvanizing.

Lead is bright, almost white. It is a heavy, dense metal, which is malleable and ductile. It will alloy with many metals to increase machinability. Historically, it was used as a pigment in paint and one of the primary components of solder. It is extremely toxic and has been replaced by other elements in these applications.

Brass varies in color based on its constituents. Red brasses have higher percentages of copper while yellow brasses have higher percentages of zinc. Brasses come in a variety of sizes and shapes. Brasses are alloys of copper and other elements, primarily zinc.

Bronze is a copper-tin alloy commonly used for bearings, gun metal, and similar applications. Bronzes are identified by their principal alloying element such as phosphor, silicon, manganese, and other elements. Bronzes are alloys of copper and elements other than zinc.

Pewter, or Britannia metal, is an alloy, which has a rich history and distinctive appearance. In the past, pewter contained a high percentage of lead. Modern pewter does not.

Silver is soft, ductile, and malleable. It is an excellent conductor of heat and electricity. It has excellent corrosion resistance. It is often used for electrical connections, jewelry, plating, and coins. Coins are actually alloys of silver and copper.

Sterling silver has additional alloying elements, but is at least 92.5% pure silver. It is often used in tableware, kitchenware, and jewelry.

Gold has a rich, yellow appearance that is ductile and malleable. It is an excellent conductor of electricity and heat. It has excellent corrosion resistance. Alloying it with copper, silver, and other metals may harden it.

Information Sheet on Industrial Ceramics and Related Materials

Ceramics

Ceramics are crystalline compounds of metallic and nonmetallic elements. Ceramics include a wide variety of materials including refractories, glass, brick, cement, plaster, abrasives, heat shields, and porcelain enamel. One individual case are hybrid compounds called cermets—mixtures of ceramics and metals.

Class	***Material***	***Application***
Oxides	Alumina	Electrical insulators
	Chromium Oxide	Coatings
	Zirconia	Thermal insulation
	Titania	Pigment
	Silica	Abrasive, glass
	Kaolinite	Clay products
Carbides	Vanadium carbide	Wear-resistant materials
	Tantalum carbide	Wear-resistant materials
	Tungsten carbide	Cutting tools
	Titanium carbide	Wear-resistant materials
	Silicon carbide	Abrasives
	Chromium carbide	Wear coatings
	Boron carbide	Abrasives
Sulfides	Molybdenum disulfide	Lubricant
	Tungsten disulfide	Lubricant
Nitrides	Boron Nitride	Insulator
Metalloids	Germanium	Electronic devices
	Silicon	Electronic devices
Intermetallics	Nickel aluminide	Wear coatings

Ceramics are crystalline materials with free few electrons. This fact makes them highly stable, poor conductors or heat and electricity, and gives them high thermal stability. They are generally the hardest of common engineering materials and extremely stiff and rigid.

In terms of composition, a nonmetallic element has a valence of 5, 6, or 7. Elements with a valence of 4 are a metalloid—sometimes acting as a metal, sometimes not. Elements with a valence of 8 are inert gases. For example, Aluminum oxide has one aluminum atom combined with three oxygen atoms, which are covalent bonded.

An ion is an atom that has gained or lost an electron. In ionic bonding, valence electrons are transferred to another atom. Atoms are held together by the electrical attraction between the charged ions.

To prepare ceramic products, 1) the ingredients are first prepared by washing, drying, and crushing; 2) shaped and formed into products; 3) dried; and 4) fired or sintered. The complexity and actual activity depends on the type of ceramic, the application, and properties desired.

Many ceramics are available in powder form. To prepare them, the ingredients are weighed, mixed, and blended either wet or dry. The mixture is sometimes heated to initiate chemical reactions. In wet processing, the material is blended to form a desired plastic mass for shaping and molding.

Slip casting consists of suspending powdered raw materials in a liquid to form a slurry or slip that can be poured into molds or worked by hand. The mold absorbs the liquid, leaving a layer of hardened material on the mold surface. Of primary concern is the nearly 30% shrinkage.

Jiggering is used on round or oval shaped products. In this process, a liquid or paste quantity is placed on a machine, which resembles a potter's wheel. The wheel is then rotated while a profiling tool forms the surface of the part, removing excess material. The process may be manual or automatic.

Pressing is accomplished by pressing the desired shape in a metal mold by high pressure. It is used to produce smaller, uniform products. The wetter the product, the easier it is to mold.

Extrusion is used for regularly cross sectional areas. Simply, extrusion is forcing material through a shaped die under pressure and cutting the product to the desired length.

Drying dries off excess water before firing. Excessive drying may cause cracking, warping, and other undesirable errors. Therefore, it is essential that any water be driven off before further processing.

Finally, the product is fired or **sintered** to convert the ceramic product into a useful product. The process parameters depend on the type of material and desired properties.

Glass and Ceramics - Processing

Glass

The majority ingredient of most glasses is sand or silica (SiO_2). Typical window glass is primarily a fused mixture of silica, limestone ($CaCO_3$), and soda ash (Na_2CO_3). Oxides may be added to the mix to impart color and other properties to the product. Crystalline glasses, such as Pyrocerams, are grown off of a seed crystal. These glasses exhibit properties that exceed typical, amorphous glass.

Glass products are generally cast into molds, extruded into uniform, cross-sectional shapes, blow-molded into hollow shapes, or cast as a sheet. For many applications, such as lenses, the glass is then ground and polished to improve its appearance and functionality.

Ceramics

Advanced ceramics, such as aluminum oxide, silicon carbide, and silicon nitride, are used in applications such as tooling, abrasive wheels, and structural shapes. We will focus on the engineering applications of ceramics, although there are many applications, which use ceramics, such as pottery, porcelain, computer chips, and decorative tiles. These are typically made of these same clays, containing primarily silica and alumina (Al_2O_3) and are fired to cure them. A glaze may then be applied to decorate and seal the product. The focus here will be on advanced ceramics, which include those, used in the engineering applications.

One method of processing ceramics is ***sintering***. In sintering, the ceramic powder is compacted in a mold and fired to fuse the particles together. The product may be treated with a resin prior to firing. Ceramic products may also be produced by bonding the particles together in a glass matrix. This process is termed ***vitrification***. Glass provides the bonding agent for the larger ceramic particles. Cemented carbides and cermets are ceramic particles held together with metals, such as cobalt.

Take, for example, bricks and concrete blocks. Concrete block is a ceramic, which is poured and allowed to cure without additional environment. Brick is mixed, poured in a mold, and fired to fuse and finish the product.

Refractory brick is produced from clays and different oxides, which enhances the materials thermal properties.

Other ceramics, such as titanium dioxide (white sand), are cast into molds, compacted to retain their shape, and fired to fuse the particles together. Many ceramics are sintered in this fashion. Silicon carbide, used for abrasive wheels, paper, and other products, can be vitrified or sintered. To process silicon carbide, silica is mixed with coke and heated. The carbon from the coke is allowed to diffuse throughout the silicon to produce silicon carbide. The resultant product is crushed to a powder. Allowing viscous glass to flow through the particles, suspending them in this glass matrix, can then vitrify it. Optionally, the silicon carbide can be impregnated with a thermosetting resin and fired to fuse the particles together and cure the resin.

Suspending the ceramic particles in metallic binders such as chromium, cobalt, molybdenum, nickel, or a combination of these produces tungsten carbide, titanium carbide, and tantalum carbide. The most common is tungsten carbide, using cobalt metal as the binder. These ceramic and metal combinations are termed ***cermets***. Tungsten carbide tooling may contain other carbides such as those of columbium, niobium, tantalum, and titanium. These products are manufactured through compaction and sintering. For example, the raw material (tantalum, titanium, tungsten…) is converted into carbide by controlled heating in the presence of carbon. The resultant product is crushed and rolled into balls or pelletized with the binder metal and compacted into semi-finished or finished shapes. The product is then sintered into the finished cemented carbide. Cemented carbides are harder than tool steels and have a higher wear resistance, making them well suited for machine tooling. Many ceramics are hard and tough which makes for good tooling, but are too brittle to be of widespread, practical application in metal cutting.

Glass and Ceramic Properties

Introduction

In general, the properties of glass and glass products include the following:

1 Glass is harder than many metals.
2 Tensile strength ranges from $4\text{-}10 \times 10^3$ lb/in^2, but can reach up to 3.5×10^6 lb/in^2 in glass fibers.
3 Glass is a brittle substance with low ductility when cooled.
4 Glasses have low coefficients of thermal expansion when compared with many metals and polymers.
5 Glasses have low thermal conductivity compared with many metals.
6 The modulus of elasticity for amorphous glass is about 10×10^6 lb/in^2.
7 Glasses have compressive strengths of about 140×10^3 lb/in^2.
8 Glass is a good electrical insulator.
9 Glasses can be used at elevated temperatures; some can withstand up to 900 F.
10 Glasses are resistant to most acids, solvents, and harsh chemicals. However, they can be fogged by water and attacked by some alkaline solutions.
11 Glasses offer the finest optical properties for their applications.

Refractory materials are used in applications, which require high strength at elevated temperatures. For example, they are used in furnace linings and heat shields. Common ceramic and refractory properties are included in the applications section.

Selection Criteria

Glass is generally specified by the following properties:

Translucence - the ability of light to pass through the glass, important in most optical and decorative applications.

Index of Refraction - degree to which light is bent as it passes through the glass. Important for lenses, for example.

Softening Temperature -the ability of the glass to withstand heat without melting.Transparency to either ultraviolet waves, infrared waves, or both.

Strength -tensile, compressive, impact, fatigue, etc.

Tempered -important safety issue.

Photo chromatic -whether it darkens when exposed to ultraviolet radiation.

Properties Tables

The physical properties of soda-lime glass are typical of many glasses. They are provided here as an example and for reference and comparison with other materials.

Physical Properties of Soda-Lime Glass	
Property	Value
Density (g/cm3)	2.3-2.6
Tensile Strength (x103 lb/in2)	10
Compressive Strength (x103 lb/in2)	50
Modulus of Elasticity (x106 lb/in2)	10
Coefficient of Thermal Expansion (in./in./ F)	4-6 x 10-6
Thermal Conductivity (Btu/ft2/ft/F)	0.4-0.6
Softening Point (F)	1300
Heat Capacity (Btu/lb/ F)	0.16-0.2
Index of Refraction	1.51

Glass Composition and Application

Glass	**Composition (%)**	**Application**
Aluminosilicate	59 silica, 20 alumina, 9 magnesia, 6 lime, 5 boron oxide, 1 sodium oxide	High thermal shock resistance, high heat resistance Applications requiring high chemical resistance and high softening temperature

Borosilicate	80 silica, 13 boron oxide, 4 sodium oxide, 2 alumina, 1 potassium oxide	Low thermal expansion, High chemical stability, good electrical resistivity Piping, tubing, sight glass, lab products, electrical insulation, kitchenware
Flint Glass	58 lead oxide, 35 silica, 7 potassium oxide	Lenses and prisms
Fused Silica	99+% pure silica	Aka quartz glass, high optical transparency, high softening point, transparent to UV waves Most expensive to produce, most difficult to fabricate, withstands greater temperatures Telescopes, melting crucibles
High-content silica	96.5 silica, 3 boron oxide, 0.5 alumina	Easier to fabricate than fused silica, highly heat resistant Space shuttle windows, missile nose cones, lab glassware, heat-resistant coatings
Lead Glass	67 silica, 16 lead oxide, 10 potassium oxide, 7 sodium oxide	Low softening temperature Decorative cut glass, high refractive applications
Low-lead Glass	57 silica, 29 lead oxide, 8 potassium oxide, 5 sodium oxide, 1 alumina	High electrical resistance, high density Decorative cut glass, laboratory products
Phosphate	72 phosphorus pentoxide, 18 alumina, 10 zinc oxide	Contains no silicates, highly transparent to infrared waves Heat-seeking missiles
Pyrex	81 silica, 12 boron oxide, 4 sodium oxide, 3 alumina	See Borosilicate
Rare-earth	28 lanthanum oxide, 26 thorium oxide, 21 boron oxide, 20 tantalum pentoxide, 3 barium oxide, 2 barium tungstate	Contain no silicates, highest refractive index, high clarity Lenses and optical applications
Soda Lime	70 silica, 15 sodium oxide, 10 lime or calcium oxide	Good workability, high durability Windows, bottles, light bulbs

Information on the Structure, Processing, and Properties of Polymeric Materials

Background Information

Polymers are the raw materials from which ***plastic*** products are made. They are synthetic materials which have large molecules made up of chains of atoms. They are classified into two basic types: ***thermoplastic*** and ***thermosetting*** materials. They are available in many different forms and shapes, including sheets, films, rods, extruded shapes, piping, and tubing, among many others.

Thermoplastic materials become soft and pliable when heated and solidify when cooled. This process can be repeated indefinitely for thermoplastic materials. This property allows them to be reshaped, reformed, and reused many times. Important thermoplastics include: acrylics, cellulosics, polystyrene, polyethylene, fluorocarbons, and vinyl.

In contrast to thermoplastics, thermosetting materials are set or cured into a permanent shape, with or without heat and pressure. Once cured, they cannot be reformed or reshaped. When an attempt is made to reheat them, they often char or burn. They will become soft, but not to the point that they can be reformed. Important thermosets include: alkyds, aminos, epoxies, phenolics, and polyesters.

Plastic Structure

In the formation of polymers, connecting links called valence bonds joins atoms. These formations resemble long strings of pearls connected end-to-end. In thermoplastics, these chains are independent of each other. When heated, these bonds weaken and allow the chains to slip over each other, allowing plastic flow. Once cooled, the chains and bonds once again become rigid. There is a practical limit to the number of heating cycles that a thermoplastic can be subjected to and still remain intact. The result of too many cycles is loss of color, flaking, and reduction in many properties.

Thermosets also contain chains of atoms. However, thermosets form cross-links which tie these chains together. There are bonds within and between chains, which form a complex, ladder-like structure. These cross-linkages prevent slippage and reduce the plasticity of the thermoset.

Manufacture of Polymers

Polymers are synthetic materials produced from common natural materials such as coal, natural gas, petroleum, and wood. Complex chemical reactions produce a large variety of polymers by breaking down naturally occurring bonds and reforming them into new structures and materials. For example, a chemist can break down petroleum into selected hydrocarbons and reform these into new structures. In the manufacture of polystyrene, benzene is extracted from coal and ethylene gas is produced from petroleum or natural gas. These two materials are then combined to form ethyl benzene, which is then processed under heat and pressure to form polystyrene. Polyethylene is produced from the ethylene gas under heat and pressure. If the ethylene gas is combined with chlorine, a vinyl chloride is produced.

Available Shapes and Forms

Plastics are available in a wide variety of shapes and forms; many of which you will recognize and some you will not:

Adhesives

Polymer resins have replaced many natural materials in the manufacture of adhesives. These resins, such as cyanoacrylate ester (super glue), offer unique properties not found in natural adhesives. These synthetic adhesives come in a variety of forms: solid, liquid, gels, emulsions, and two-part adhesives. For example, urea wood glues may come in a dry powder for use in plywood applications; "white" household glues are commonly polyvinyl acetate emulsions; common adhesive tape is typically a mylar film with a permanently tacky adhesive and a release coat on the top of the tape; and many epoxy adhesives are two-part, one being a catalyst to initiate the reaction.

Coatings

Polymer resins resemble many naturally occurring resins once used in paints, varnishes, lacquers, and other coatings. Alkyd resins (paint), polyurethanes (sealants), phenolics (varnish), cellulosics (paper), and epoxies (metals) are just a few of these applications.

Expanded or Expandable

Many thermosets and thermoplastics are available in expanded or expandable forms. These lightweight plastics appear to be full of air bubbles. Expanded plastics are low-density cellular materials of open or closed-cell design. Structures that appear as interconnecting, continuous design are referred to as open-cell structures while those which exhibit discrete, bubbles fused together with air trapped between are termed closed-cell. Styrene cups are an example of expanded plastics. Expanded or foamed plastics may be either rigid or flexible in application. Styrofoam is a common rigid foam product while vinyl and urethane cushions are flexible foams.

Expandable plastics are ready to be foamed. They are typically tiny, gas-filled globules or spheres, which expand and fuse together under heat. Aerosol foams are expandable plastics, which mix with inert gases, such as carbon dioxide or nitrogen, under pressure during application. The typical insulation foams are an example. Other types are two-part liquids, which produce a gas as a byproduct of the reaction.

Fibers and Filaments

Some plastics are extruded into filaments, such as monofilament fishing line. As filaments, these extrusions are used as bristles in brushes, woven into fabrics, cloth, and mats, and used as fillers in composite constructions. Some common fibers are Orlon, Dacron, Nylon, and Polyester.

Laminates

Laminates are layered products where layers may be made up of various materials. Typically, each layer is impregnated or coated with a polymer resin and then bonded to each successive layer. Once constructed, the entire construction is bonded under heat and pressure to form an engineered product, such as countertop, plywood, engineered lumber, and other such constructions. Fiber-reinforced plastics (FRPs) or more commonly fiberglass is a laminated construction with a polymer resin binder and glass fiber or mat reinforcement.

Liquid Casting Resins

Both thermosets and thermoplastics are available as liquid casting resins. Often a two-part system, these materials work together, one being a catalyst for curing. Many polyester and epoxy resins operate on this principle. Another type of casting resin is plastisol. These materials, such as vinyl, solidify when contacting a hot surface. Plastisols are often used for tool handles and kitchenware.

Molding Compounds

Many thermosetting and thermoplastic materials are available as either bulk molding or sheet molding compounds. Additives such as plasticizers, fillers, stabilizers, dyes and colorants, and reinforcements are added to the basic resin. These are then produced in either a bulk or sheet form. Many of these start out as powders, pellets, preforms, or premixes.

Processing of Plastics

Mechanisms of Polymerization

Polymerization takes place through addition polymerization, copolymerization, or condensation polymerization. In the process of polymerization, large-unit molecules are combined to form large chains or repeating units. The degree of polymerization is the number of repeating units with identical structures within the polymer. This is calculated by taking an average of many samples of polymer chains. The average molecular weight of the chains in these samples is divided by the known weight of one mer.

In copolymerization, two or more polymers are combined to form new polymers. For example, Acrylonitrile-Butadiene-Styrene (ABS) is a copolymer. The ABS copolymer exhibits different properties than its constituents.

Condensation polymerization involves the chemical reaction of two or more chemicals to form a new molecule. This reaction has a condensate product, usually water. A catalyst is often required to initiate and maintain the reaction or control the reaction rate. Thermosetting polymers are often formed by condensation polymerization.

Manufacturing Processes Involving Polymers

Some of the more common processes used to produce polymer products are simple casting, blow molding, compression molding, transfer molding, injection molding, extrusion, vacuum forming, cold forming, filament winding, calendaring, and foaming. Each has advantages, disadvantages, and applications, which differ according to the material being processed. Please refer to the appropriate sections in the text describing: Blow Molding, Compression Molding, Transfer Molding, Extrusion, Injection Molding, Vacuum Forming, Cold Forming, Filament Winding, and Calendaring.

Forming Process	***Polymers and Products***
Casting - forming parts by filling a mold with molten polymer or premixed two-part resins.	Epoxies, Vinyls, Most Urethanes and Silicones Four basic types: simple casting, dip casting, slush molding, and rotational molding. Solid and hollow shapes such as toys, tanks, containers.
Blow Molding - forming hollow shapes by blowing air into hot polymer tube, called a parison, which expands to fit the interior of the mold.	Most thermoplastic polymers. Bottles, containers, toys.

Compression Molding - pre-measured material is placed into a mold. The mold is then closed and heat and pressure are applied for a predetermined time to cure the polymer.	Most thermoset polymers Knobs, handles, trays, buttons, electrical components and parts, auto hoods and door skins.
Transfer Molding - raw material is placed in a plunger cavity and heated; the plunger then forces the molten material into the mold cavity where, under heat and pressure, the polymer cures.	Most thermoset polymers Distributor caps, cups, and caps.
Extrusion -raw material is hopper-fed into a heated cylinder containing a screw-feed system, which forces the molten material through a die to form uniform cross sections.	Thermoplastic polymers such as acrylics, cellulosics, flourocarbons, nylon, styrene, polyethylene, and vinyl. Any uniform cross-section such as pipe, tubing, rods, and sheets.
Injection Molding - polymer pellets are fed by hopper into a heated cylinder containing a screw-feed system which forces molten material into a mold.	Most thermoplastic materials such as acrylics, flourocarbons, nylon, polyethylene, polystyrene, and vinyls. High production items such as toys, tile, food containers, cases, knobs, tool handles and some foamed products.
Laminating -(rods and tubes) sheet stock is wound over a mandrel to correct diameter and cured by heat and pressure in a molding press. -(sheet) layers of fabric, cloth, paper, or other product impregnated with resin are placed in, on, or over a mold; secured; and allowed to cure.	Typically, thermoset polymers such as phenolics, melamines, silicones, epoxies, and polyester. Counters, paneling, sheets, engineered panels and beams, gears and pulleys, helmets.
Vacuum Forming -a thin sheet of thermoplastic material is placed over a form where it is heated until it softens. Once softened, a vacuum is drawn through the form, pulling the material down to conform to the die form. Once cooled, the finished product is removed.	Any thermoplastic material. Panels, signs, trays, and packaging.
Cold Forming - raw material is placed in an open mold cavity where it is pressed into final form.	Most thermoset polymers. Electrical parts, switch plates, plugs, handles, knobs.

The product is then removed and cured.	
Filament Winding - high-strength filaments are wound over a form using a pattern after being coated with a resin.	A variety of polymers may be used, epoxies are typical. Variety of storage media, including tanks and drums.
Calendaring -a pre-mixed elastomer or thermoplastic is rolled or calendared through a series of heated rollers, aimed at controlling and resizing the sheet. Occasionally, one or more rollers will contain embossing, image transfer or other information.	High-speed, high-volume, process used with a variety of elastomers and polymers. Paper, linoleum, sheet metal, plastic sheet and film.
Foaming -(physical) foaming process involving the injection of a gas during the molding process. Upon heating, the combination expands and fills the mold cavity. -(chemical) results from the chemical reaction, which occurs when two or more chemicals are mixed.	Many polymers can be foamed. Styrenes and urethanes are most popular. Physical - expanded polystyrene as an example. Chemical - polyurethane foaming sealants.

Properties and Applications of Plastics

The properties of polymers and plastics of most concern are typically strength, stiffness, hardness, and melting point or heat resistance. Various additives are used to enhance properties. These include fillers, plasticizers, coloring agents, and lubricants. These may be divided into performance-related and processing-related additives: Typically, plastics are lightweight, good electrical insulators, good thermal insulators, have a low modulus of elasticity, provide good corrosion resistance, provide good abrasion resistance, and offer good resistance to chemicals. They are produced using a variety of processes, offering a wide variety of colors, textures, and properties. However, without reinforcement, they are generally lower strength compared with other materials such as steels and composites. In addition, they may exhibit high creep rates and low fatigue strengths.

Common Additives		
Material	Use	Examples
	Processing-related	
Plasticizers	Increase and control the flow of materials during processing	Typically, low molecular weight polymers that separate the polymer chain and reduce crystallinity
Reinforcement	Increase strength	Carbon fiber, cloth and fabric, glass fiber, mica
Foaming/Blowing	Enhances foaming and blowing abilities	

Lubricants	Prevents plastic from sticking to processing equipment and separating sheets, films, etc.	Internal: graphite, silicone, stearates, wax External: Stearates, wax, soap, graphite, silicone
Catalysts, curing agents, and promoters	Initiates, promotes, or increase rate of cross-linking in thermosets	Amines, peroxides
Mold Release	Prevents plastic from sticking to processing equipment or tooling	Teflon, silicone, stearates, wax
Performance-related		
Biocides/fungicaides	Reduce formation of bacteria, mildew, fungus	
Flame retardants	Reduce flammability	
UV stabilizers	Helps prevent breakdown from UV rediation	
Antioxidants/Thermal stabilizers	Helps prevent thermal breakdown and oxidation	
Plasticizers	Improves flexibility and toughness	
Fillers	Control shrinkage and reduce cost	Powders, fabrics, and fibers such as wood flour, alumina, talc, silica
Deodrants	Reduces or eliminates odors	
Colorizing Agents/Dyes/Pigments	Change the color of the product by coating or conversion	Carbon, metal oxides, titanium dioxide

With this in mind, polymers are typically used to produce lightweight, corrosion-resistant materials of low to medium strength, electrical insulation and insulators, thermal insulation, acoustic foam insulation, pliable packaging foam and packing materials, adhesives, coatings, and replacement parts for automotive applications such as fenders and panels. With proper reinforcement, their properties may be improved to rival or exceed that of many other materials.

Polymers are generally organic materials, which are lightweight, good thermal and electrical insulators, and offer good corrosion and chemical resistance. They may be used either by themselves or with reinforcement materials to increase their mechanical properties. Copolymers are products of more than one polymer.

Common Polymers, Copolymers, and Their Characteristics
ABS (Acrylonitrile-Butadiene-Styrene) Lightweight, good strength, excellent toughness
Acrylic Trade names: Lucite and Plexiglas; excellent optical quality, high impact, flexural, tensile, and dielectric strengths
Cellulose acetate Good insulator, easily formed, high moisture absorption, low chemical resistance
Cellulose acetate butyrate Similar to cellulose acetate, but will withstand more severe conditions

Epoxies	Good toughness, elasticity, chemical resistance, and dimensional stability; used in coatings, adhesives and cements, electrical components, and tooling
Ethyl cellulose	High electrical resistance, high impact strength, retains properties at low temperatures, low tear strength
Fluorocarbons	Inert to most chemicals, high temperature resistance, low friction coefficient: Teflon used for self-lubricating products and non-stick coatings
Melamine	Excellent resistance to heat, water, and chemicals, excellent arc resistance; used in tableware and to treat water-repellant paper and cloth
Polyamide	Good abrasion resistance and toughness, excellent dimensional stability; used in bearing materials that require little lubrication, textiles, fishing line, and rope
Phenolics	Hard, relatively strong, inexpensive, easily-formed, generally opaque; wide variety of available shapes and uses
Polycarbonates	High strength and toughness; used in safety glasses and shields
Polyethylene	High toughness, high electrical resistance; used in bottles, caps, unbreakable utensils, and wire insulation
Polypropylene	Lightest weight, used in many of the same applications as polyethylene, but is harder
Polystyrene	High dimensional stability, low moisture absorption, excellent dielectric, burns readily, low resistance to chemicals; used for the familiar beads and insulation
Silicone	Heat-resistant, low moisture absorption, high dielectric strength; used in caulks, sealants, and adhesives
Urea Formaldehyde	Similar to phenolics, but used in interior applications
Vinyl	Tear-resistant, good aging, good dimensional stability, good moisture resistance; used in wall and floor coverings, fabrics, and hoses

	Summary of Polymer and Elastomer Physical Properties
Product	Density (g/cm3) Tensile Strength (x103 lb/in2) Compressi ve Strength (x103 lb/in2) Modulus of Elasticity (x103 lb/in2) Maximum Elongation (%) Continuo us Heat Resistanc e (F)
	Thermoplastics
Polyethylene	0.9-0.97 1-5.5 1.5-10 14-160 15-700 180-250
	Applications: Electrical insulation, piping and tubing, bottles and containers, films, packaging
Polypropylene	0.9-0.97 4.3-5.5 2.5-10 1400-1700 200 190-300
	Furniture, sterilized chemical containers, drink containers, piping and tubing, packaging, electrical insulation, high-fatigue-strength parts
Polyvinyl Chloride	1.1-1.6 1.5-9 1-13 200-600 2-400 150-175
	(Rigid) Piping and tubing, plumbing supplies, tiles (Soft) upholstery, rain gear, tapes, wire insulation, films, hoses
Polystyrene	0.981.08 5-10 5-16 400-600 1-2.5 150-200
	Electrical insulators, expansion foams, floatation devices, toys, food and drink containers (Alloys) ABS piping and tubing, molded parts, panels and cases, containers, housing, brushes
Polytetrafluoroethylene (Teflon)	2.1-2.3 2-4.5 1.6-80 33-65 200-400 500-550
	Non-stick coatings and films, pump pistons, insulation, corrosion-resistant linings, fittings, wrappings and coverings, bearing materials
Polyamide	1.131.15 9-9.5 7.5-13 60-300 450-550
	Nylon clothing and fibers, gears and washers, bushings, brushes, food-processing equipment
Polyaramid fibers	1.45 400 20,000 500
	Kevlar helmets, composite reinforcement
Polymethy methacrylate (PMMA)	1.181.20 7-11 12-18 350-500 2-10 140-200
	Acrylic guards, glasses, lenses, fibers, canopies, signs, jewelry, combs and brushes
Polycarbonate	1.2 8-9.5 15-18 300-325 20-100 200-250
	Impact-resistant lenses, shields, pump impellers, cams, appliance and power tool housings
	Thermosets

Phenol	1.366-9 15-50 900-1300 0.5-1.0 250

formaldehyde	1.43
	Bakelite molded parts, cases, electrical insulators, preservative
Urea-formaldehyde	1.471.52 5.5-13 25-45 1300-1400 0.6 170
	Adhesives in plywood, particle board, coatings, furniture padding, thermal insulation, gaskets, industrial tires
Melamine-formaldehyde	1.471.78 5.5-13 25-45 1300-1950 0.6-0.9 250-400
	Formica counters, shelving, kitchenware, cabinetry, laminates
Epoxy	1.14 4-5 13-28 300 2-6 250-500
	Adhesives, coatings, floor coverings, small parts
Silicone	1.5-2.8 3-4 10-15 1200 0-700 500-600
	Liquid and paste waxes, scratch removers, pressure-sensitive adhesives, insulators, caulks and sealants
	Elastomers
Butadiene	0.94 3.5 3000 200
	Tires, hoses, belts, gaskets
Butadiene - styrene (Buna-S)	1.00 0.6-3 600-2000 200
Acrylonitrile-Butadiene-Styrene (ABS)	1.06 7 1-2 190-230
	Piping and tubing
Chloroprene	1.24 3.5 800 250-350
	Neoprene hoses, belts, lines, gaskets
Isoprene	0.93 3 800 180
	Natural rubber

Summary of Polymers and Plastics

Common Thermosetting Plastics

Alkyds -Polyester derivatives produced by the reaction of an alcohol and an acid. Their most important use is in paints and lacquers.

Allyl Plastics - Produced from an alcohol are very scratch resistant, hard, and clear plastics are used for lenses, prisms, eyeglasses and window glass. Fairly costly, but resists most solvents and has high strength.

Aminos -Include urea and melamine that have an unlimited range of colors. Urea formaldehyde plastics are produced by reacting urea with formaldehyde in the presence of a catalyst and mixing in a filler. These are used directly for knobs, handles and household items. Urea formaldehyde materials are also used for adhesives in plywood, cores and other materials. Melamines are used to bond exterior plywood and for electrical breakers and terminal blocks as well as in furniture and countertops.

Epoxies -These are brittle, but exhibit good electrical properties and chemical resistance. They cure at normal temperatures and pressures. They are used for adhesives, paints and surface coatings.

Phenolics -Phenolic-formaldehyde plastics are low-cost molding compounds with high strength and good electrical and thermal properties. The most common is known by its trade na me Bakelite®. Formica® and Micarta® are also common phenolic laminates. Major drawback is their lack of colorability--they are comonly brown or black.

Polyesters -Saturated types are best known as Dacron® fibers and Mylar® films. Unsaturated types are used in molding and casting. Polyesters have considerable shrinkage when molded or cast. They can be either thermoset or thermoplastic depending on configuration and formulation.

Polyurethane -Can also be either thermoset or thermoplastic. Often found in foamed products such as mattresses and insulation. Can be used for oil seals (last longer than rubber), solid truck tires (good shock and abrasion resistance), gears, drive belts, floor coverings, and paint and roofing materials.

Silicones -Type of synthetic rubber that is very temperature resistant (up to 500ºF). Widely used for their electrical properties for encapsulation and insulation. Also used for sealants and caulk since they remain pliable and are good bonding agents. Also used as lubricants.

Common Thermoplastic Materials

Acrylonitrile-Butadiene-Styrene (ABS) Copolymer-Very strong, tough and rigid. Major disadvantage is flammability and solubility in many solvents. First introduced in 1938 as polystyrene. Due to its low cost, it is often used for plastic utensils and disposable products.

Acetals -Excellent engineering properties used in gears, butane cigarette lighters and handles.

Acrylics -Used for their light transmission properties and optical clarity. Not as satisfactory as allyls for eyeglasses. Used for car lenses, jewelry, and crafts. Lucite® and Plexiglas® are common acrylics in the form of sheets, rods and tubes.

Cellulosics -Among the toughest of all plastics, there are five major groups: nitrate, acetate, propionate, butyrate and ethyl cellulose. Cellulose plastics are rolled into thin sheets and sold as cellophane.

Flouroplastics-These include polytetraflouroethylene (PTFE) or Teflon. TFE has the highest chemical resistance of all plastics. Flouroplastics have the lowest coefficient of friction of any plastic and are used for slides, bearings, paints and nonstick surfaces.

Polyamides -Nylon is the name given to this family of DuPont products. It was first used for the production of fibers for webbing, parachutes and stockings to replace silk. They are often used as fibers for composite construction, gears, wheels and carburetors as well as in films and tubing.

Polycarbonates -Can be used for many of the same applications as polyamides. They are very strong and are often used to replace glass in similar applications such as eyeglasses, unbreakable bottles and bulletproof glass. Lexan® is a common brand name.

Polyester -Mentioned earlier in another form, thermoplastic polyesters are used in electrical parts, fibers, gears, housings and pump impellers.

Polyolefins -Includes polyallomer, polypropylene, and polyethylene. Polyethylene is used for bottles, trays, film and containers. Polyethylene terephthalate (PET) is being increasingly used for beverage bottles since it is highly recyclable. Polypropylene is used for electrical insulation. Polyallomer is used in similar applications, but has lower production cost than the others.

Polyvinyl Chloride (PVC) -Comes in two types rigid and flexible. Rigid is used in pipes and fittings. Flexible is used in making gaskets, vacuum tubing, garden hoses, shower curtains, floor mats and toys.

Additive and Finishes

Antioxidants -These materials increases UV stability for such resins as ABS, polyethylene, polypropylene, and polystyrene.

Blowing agents -Create voids and porosity in plastics processed at low temperatures.

Colorants -Pigments and dyes to provide attractive or identifying colors. Colors which may be used for the distinction in safety or health concerns or to make them more attractive to the consumer. May be solid, neon, translucent or glow-in-the-dark luminous.

Fillers -Reduce the cost of plastic products by reducing the amount of necessary resin. They may also lower the weight while maintaining or increasing the mechanical properties of the product. Common fillers are wood flour, quartz, limestone, clay and metal powders.

Plasticizers -Some plastics are normally hard, brittle materials, which adversely affect their applications. Plasticizers are added to increase their flexibility and workability.

Reinforcements -Resins tend to have low mechanical strength. Through the use of reinforcing materials in the form of fibers, matte, etc. these properties can be increased. Some common reinforcement materials include glass fibers, mica, sisal, jute and graphite. The orientation of these materials also increases the strength of the product.

Stabilizers -These are added to increase resistance to UV light, chemical compounds, heat and other such agents.

Adhesives

Glues -Glues is the term usually applied to materials that occur naturally, such as those derived from animal, vegetable (starch), casein and soybean origins.

Adhesives -Adhesive is a generic term applied to synthetic bonding agents.

Cements -Cements are adhesive materials used for a specific purpose: rubber cement, plastic cement, glass cement, stone cement, and leather cement.

Pastes -Pastes are water-soluble products used for paper and paper products.

Pressure-sensitive adhesives -Do not wet the surface to which they adhere. Adhesive tape is one example. The adhesive does not set, but remains permanently tacky. On the backside of the tape is a release agent: this allows the tape to be unrolled without sticking.

Natural Adhesives

Animal glues - also called protein-based adhesives, are made from by-products of the animal packing industry.

Vegetable glues -such as mucilages, are made from cassava (tapioca) flour dissolved with caustic soda. Corn or potato starch is also used in vegetable glues. They are used in stamps, envelopes, and labels and in lower-grade plywood and furniture.

Casein glue -made from dried milk curds, lime and other chemical ingredients. It is often used for wood-towood applications such as plywood and furniture. It is also used to seal the seam of cigarette papers.

Other glues -Soybean glue (soybean meal), Albumin glue (dried animal blood), Sodium silicate glue (grinding wheels and flexes).

Pastes -Mixtures of starch or dextrine with water and a strengthener such as glue, resin or gum. Widely used in the paper industry and in wallpaper, decorations and tapes.

Emulsions -dispersed globules of adhesive in a base (typically water). Bonding takes place when the carrier evaporates. Latex adhesives are a common example. They can often be rubbed off or rolled into balls.

Cements

Rubber cement -mixture of uncured rubber and a chemical solvent.
Pyroxylin cement -made from scrap celluloid or cellulosic materials dissolved in a solvent such as ether alcohol. These are the common “household” cements.

Thermoplastic Adhesives

Generally made from cellulose, acrylic or polyvinyl plastics. These products are dissolved into a volatiles solvent, applied, and then cured by evaporation of the solvent base. These tend to have about a 30% shrinkage and cause stress at the joint. White household glues are typically solvent-release polyvinyl acetate resins.

Polychloroprene (neoprene) adhesives are the most common thermoplastic adhesives. These are available in liquid form and are generally used with a filler and a curing agent. These materials may be mixed prior to application and allowed to cure at room temperature.

Hot melt adhesives are a recent application based on an old principle. Asphalt emulsions have been used for years for roofing applications. Hot melts are a mixture of polymers that may be heated and applied while hot. Once applied, the adhesive bonds to the surfaces and cools.

Thermosetting Adhesives

Thermoset adhesives generally consist of epoxy, melamine, phenolic or urea resins. When subjected to heat and pressure, these partially cured polymers cross-link to form hard, strong bonds. Epoxies are expensive, but offer better mechanical properties than previous adhesives. These are often two-part adhesives that have a base and a catalyst--often mixed in equal parts, mixed, applied and allowed to cure. The workable time depends on the materials and additives of the adhesive.

Phenolic, Urea-formaldehyde and melamine-formaldehyde adhesives are used in the production of sandpaper and abrasive cloth, and plywoods, respectively. They are comparatively expensive to other adhesives, but offer unique resistance to environmental attack.

Cyanoacrylate adhesives, often called super glues, quickly bond surfaces (such as fingers) by absorbing moisture from the adherend materials. Isocyanates, such as toluene diisicyanate, diphenylmethane diisocyanate, and triphenyl methane triisocyanate, are very reactive and react instantly with accelerants such as alcohols and hydroxyls. These are generally the most expensive, but offer good strength with excellent stability.

Types of Adhesives

Pressure Sensitive	**Hot Melt**	**Moisture Reactive**	**Heat-Activated**
Rubber	Polyamide	Silicone	Polyamide
Polyvinyl ether	Polyester	Urethane	Epoxy
Silicone	Polyethylene	Cyanoacrylate	Polyvinyl acetals
	Polypropylene		Phenolic
	Polyvinyl acetate		Rubber

Two -Part Component Adhesives		**Water- or Solvent-based**		
Epoxies	Silicone	Butyl rubber	Butadiene-styrene	Nitrile rubber
Phenolics	Polyester	Neoprene	Acrylic	Cellulose ester
Polysulfide	Polyurethane	Phenolics	Polyamide	Vinyls

3-D Casting Procedure Sheet

PROCESS TYPE: Casting TITLE: Three-dimensional casting MACHINE(S): N/A MATERIALS REQ'D: Molds, Wax paper cup, Hardener, Clear casting resin, Color.

PROCEDURE: THREE DIMENSIONAL CASTING

1 Clean and inspect vinyl molds prior to utilization.
2 Clean vinyl molds by inverting mold using soap and water for lubricant and cleaning agent.
3 Dry mold completely before using. NOTE: Do not scratch molds.
4 Arrange all molds in appropriate holders.
5 Measure out desired amount of clear casting resin in appropriate container.
6 Add appropriate amount of catalyst (hardener) to casting resin. NOTE: Amount of hardener will be determined by enclosed instructions for each mold, or as determined by the instructor.
7 Optional: Add desired amount of color now or after resin and hardener have been mixed.
8 Mix resin and hardener thoroughly. Minimum time 2 minutes.
9 Add color now if swirl effect is desired.
10 Pour catalyzing resin into vinyl three-dimensional mold. NOTE: Do not over fill mold.
11 Squeeze out mold gently to force all trapped air to the surface.
12 Let mold set for 4 to 24 hours.
13 Remove three-dimensional casting from vinyl mold. NOTE: Use soap and water to lubricate vinyl for removal of casting.
14 Let casting set for minimum of 3 hours. NOTE: Longer the casting sets, the less tacky it will be.
15 Trim off excess resin with band saw. NOTE: Handle casting gently to avoid finger printing.
16 Sand off bottom to flat surface using the disc sander. NOTE: Handle gently to avoid fingerprints.
17 NOTE: Some finger printing will occur. Rub out as much as possible.
18 Place casting on scrap piece of wood and spray with clear acrylic paint. NOTE: Do not over spray - clean out nozzle of spray can.
19 Let three-dimensional casting set for at least 24 hours.
20 Re-spray if necessary.
21 Apply felt to bottom of casting, if desired.
22 Replace all materials and tools.
23 Turn finished product in for grading.

Problem	**Solution**
Color bleeds through	Color must be mixed or swirled completely
Air pockets on surface of casting	Filled vinyl molds must be squeezed thoroughly
Hard spots and soft spots on casting	Resin, hardener, and colors must be mixed completely

Compression Molding Process

PROCESS TYPE: Molding TITLE: Compression Molding MACHINE (S): Hydraulic Press MATERIALS REQ'D: Thermosetting Resin

DESCRIPTION: Compression Molding

Compression molding is a process where heat and pressure are applied to a thermosetting resin to form a desired shape for a product. In compression molding a mold is first preheated, then a charge of thermosetting resin is placed in it. The mold is then placed into a press. The press can be one of three types: hydraulic, air or mechanically operated. Pressures ranging from 1,000 to 10,000PSI are applied to the mold by the press (typical compression molding pressures). While being pressed the mold must be kept at a constant temperature. The temperatures for compression molding range from 280 to 400°F, depending on the type of resin used. The heat causes the resin to melt and flow through the openings of the mold cavity causing polymerization to take place. Complete polymerization of the resin takes from 3 to 20 minutes, depending on the type of resin used. Once polymerization is completed the product can be removed, while still hot, and then excess material can be trimmed off. Once the product is removed, the mold is ready for the next charge of resin.

Molds used for compression molding consist of a single or multiple cavities and a force or plunger. Guide pins are usually placed in molds to maintain a proper relation between mold halves. The mold cavity forms one surface of the product and the resin is generally placed in this half. The plunger forms the other side of the product and serves to compress the compound when the mold is closed. The resin is thus confined to the open space between the plunger and the cavity, while polymerization takes place. Knockout or ejector pins are often located in molds to push the product out of the mold. The molds are usually made of tool steel and are highly polished to produce the desired finish.

- Thermosetting resin (phenolic, alkyd, diallyphtalate, melamine, urea)
- Clean cloth or paper towels (used to wipe the mold clean)
- Mold release
- Safety glasses (to be worn at all times)
- Heat resistant gloves (when handling preheated mold)
- Heat resistant surface (to place heated mold on)
- Hydraulic press
- Desired mold
- Brass release bar (for getting product out of mold)
- Scale (used for weighing resin)
- Wax paper cup (used for weighing resin)
- Utility knife (used to cut off excess plastic)
- Sand paper (used to smooth rough edges)

(Using Phenolic Resin)

1 Preheat press to 300°F

2 Apply mold release with a clean cloth.

3 Preheat mold to 300°F in press. NOTE: A) Press preheating takes at least 15 minutes and make sure that enough time is allowed for the mold to be completely heated. B) Set press so that the maximum stroke is always less the 6 inches or you will blow the piston out of the machine!

4 When mold is preheated remove it from the press and place on heat resistant surface, while wearing safety gloves.

5 Measure out thermosetting plastic. NOTE: A) The mold should come with a list of the amount of resin that is needed to fill the mold. B) Be sure to take the weight of the wax paper cup into consideration when weighing resin.

6 Fill bottom of mold cavity with resin. Level plastic off. Do not get any plastic on lip of mold or it will not close.

7 Place mold halves together making sure that they are in correct alignment.

8 Place mold in press so that it is centered on lower platen.

9 Rapidly close mold and pump up to 15 tons of pressure.

10 Maintain pressure for 5 seconds then breathe mold slightly - This is done by cracking open the mold slightly to that the gasses or air out, then immediately pump the press back up to 15 tons of pressure. NOTE: Do not over open mold.

11 Leave mold under pressure and a temperature of 300°F for 4 to 6 minutes.

12 Remove mold from press -take care not to drop mold. Wear safety gloves, as the mold will be very hot.

13 Open mold. NOTE: If part will not come out of mold, remove it with a brass or copper release bar (strip). Avoid scratching mold.

14 If another part is desired, go and start at procedure 4. NOTE: It is important to get the mold back into the press as soon as possible so that the mold doesn't cool off.

15 Trim and sand part to the desired finish.

16 Turn off press and return equipment to proper storage location and wipe mold clean.

17 Work in a well-ventilated area. Do not breathe fumes.

18 Always work on a heat resistant surface.

19 Use caution when handling hot molds and when working between heated platens.

20 Wear safety glasses at all times.

21 Wear heat resistant gloves when handling the mold and while working near heated hydraulic press.

22 Be aware of pinch points on the press.

23 Keep a fire extinguisher in the work area.

24 Read owners manual for the hydraulic press.

25 Be careful not to cut yourself when using the utility knife, while trimming the product.

26 Avoid getting resin on skin.

27 Treat the press is if it is hot at all times.

28 Remove all jewelry and confine long hair and loose clothing.

SYMPTOM	***POSSIBLE CAUSES***	***SOLUTIONS***
External blister	A. Mold temperature too high B. Moisture in material	A. Lower mold temp B. Dry material in oven
	C. Incorrect degas sequence D. Insufficient curing time E. Inadequate venting	C. Check degassing procedure D. Increase cure time E. Check degassing procedure
Internal pockets	F. Insufficient pressure A. Insufficient load	F. Recalculate pressure A. Check the amount of material
	B. Improper location of charge C. Mold temperature too high D. Incorrect degas sequence	B. Center charge & spread evenly C. Lower mold temp D. Check degassing procedure
	E. Moisture in material F. Insufficient curing time	E. Dry material in oven F. Increase cure time
Incomplete	G. Insufficient pressure A. Insufficient charge B. Improper location of charge	G. Increase pressure A. Check amount of part material B. See internal pockets
	C. Press closing too slow	C. Check hydraulic cylinder
	D. Mold cavity too hot E. Plasticity too low F. Material too cold	D. Lower mold temp E. Change material F. Preheat it

	G. Inadequate venting H. Material sticks in mold	G. See external blister H. Check mold release
Poor gloss	A. Slightly insufficient charge B. Excessive or incorrect release agent C. Poor mold polish	A. Increase material volume B. Check mold release C. Polish mold with soft rag
	D. Press closing too slow E. Material too old	D. See incomplete part E. Use new material
Orange peel	F. Degas sequence too long G. Insufficient pressure A. Press closing too slow	F. Degas only a few seconds G. Increase pressure A. See incomplete part surface
	B. Mold temperature too high C. Fine particles in resin	B. Lower temperature C. Sift material
xcessive flash E	A. Improper location of charge B. Press closing too fast C. Uneven mold temperature	A. See internal pockets B. Slow down press C. Preheat mold longer
	D. Plasticity too high E. Excessive amount of charge	D. Change material E. Remeasure material
cking in cavity Sti	F. Platen misaligned G. Cavity distorted A. Insufficient or incorrect mold release	F. See instructor G. See instructor A. Check mold release
	B. Non-uniform or low temperature	B. Preheat press at correct
	C. Lack of mold polish or scratched	temperature C. Polish mold with soft cloth and cleaner
	D. Flash not removed from previous cycle	D. Clean & polish mold
Brittle part	E. Insufficient curing time F. Broken or inoperable ejector pins A. Press closing too slow	E. Increase cure time F. Clean pins A. Speed up press
	B. Mold temperature too high C. Cure time too long	B. Lower temperature C. Shorten cure time
Cracking on ejection	D. Material too cold A. Sticking in one area B. Ejector mechanism	D. Try heating it in oven A. Check mold release B. Realign
rsizedOve	C. Undercure or overcure A. Flash on lands**vertically**	C. Check molding time A. Clean mold
	B. Insufficient pressure and cure time C. Improper degas sequence D. Poor location of charge	B. Increase both C. Check degassing procedure D. Center & spread charge
	E. Excessive molding of charge F. Moisture in material	E. Reweigh resin F. Dry in oven
Undersized vertically	A. Slightly undercharged B. Distorted internal lands A. Worn mold parts	A. Add more resin B. See instructor A. Get new mold

	A. Worn mold parts	A. Get new mold
Oversized horizontally	B. Insufficient mold closingC. Incorrect grade of material A. Non-uniform mold temperature B. Temperature variation	B. Check mold pressureC. Obtain new material A. Preheat mold longer B. Preheat mold, check

between	platens for
mold halves	heat
C. Insufficient pressure and cure time	C. Increase pressure and mold time
D. Sticking on ejection	D. See sticking in cavity

Polymer	*Temperature (°F)*

350 325 350 280 300 300 325 325 500 325 300 300 450 300 300 300 425 350 300 550 425 350 325 325

PSI

200

2000 2000 1000 5000 3000 2000 N/A 8000 N/A 1000 1000

Acetal Acrylic Acrylonitrile Butadiene Cellulose Acetate Diallyl Phthalate Epoxy Ionomer Melamine Formaldehyde Nylon Phenol Formaldehyde (ex. Bakelite) Phenoxy Polyallomer Polycarbonate Polyester Polyethylene L.D. Polyethylene H.D. Polyphenylene Polypropylene Polystyrene Polysulfone Polyurethane Polyvinyl Chloride Silicone Styrene Acrylonitrile

Polymer

Polyethylene Polyvinyl Chloride

- **A. Unplasticized**
- **B. Copolymer**
- **C. Flexible Polystyrene Polymethyl Methacrylate Polyvinylidene Chloride Polytetrafluoroethyene Polychlorofluoroethyene Cellulose Nitrate Cellulose Acetate Cellulose Acetate Butyrate Ethyl Cellulose Urea Formaldehyde Phenol-Formaldehyde**
- **A. General Purpose**
- **B. Shock Resistant**
- **C. Heat Resistant Polyesters**

1000 4000

1500 6000 5000 500

Vinyl Dipping Procedure Sheet

PROCESS TYPE: Casting, Forming TITLE: Dip casting with plastisol.MACHINE (S): OvenMATERIALS REQ'D: Plastisol, Drip tray, Masking tape, Water, Aluminum mold, Pliers, X-acto knife.

PROCEDURE: DIP CASTING WITH PLASTISOLS

1 Choose desired aluminum mold to be utilized.
2 Check to be sure mold is clean.
3 Pre-heat oven to 450°F.
4 Hang mold on oven rack in center of the oven.
5 Leave mold in the oven for 10 minutes at 450°F.
6 Remove mold from the oven with pliers; dip into vinyl plastisol #65. NOTE: Be sure that vinyl #65 container is large enough to accommodate mold without touching sides or bottom.
7 Dip mold completely into vinyl #65 for 60 to 90 seconds.
8 Remove mold from vinyl and let all excess drain off from mold back into container.
9 Place mold back into oven and turn oven temperature to 350°F.
10 Mold should remain in oven at 350 degrees F for 15 minutes. CAUTION: Do not hang mold directly over heating element of electric oven. Direct heat from the element will burn vinyl and perhaps flame.
11 After 15 minutes, remove mold from the oven using pliers and place under cold tap water for 5 minutes. NOTE: Mold must be completely cool before removal of vinyl is attempted.
12 Using X-acto knife, cut neck portion of mold off.
13 Cut down one side of mold with the aid of a straight edge or free hand.
  14. Remove vinyl from mold and check for completeness of product.
  a. Should have uniform thickness.
  b. Should have smooth and shiny exterior finish.
  c. Should not tear or rip if pulled or turned inside out.
14 Turn oven off once you have completed your product.
15 Replace all materials and tools.
16 Turn product in for grading.

PROBLEM	***SOLUTION***
1a. Very thin walled finished product.	1b. Aluminum mold not hot enough prior to 1b. dipping. Not dipped in plastisol solution long enough. Refer to steps 1-17 in procedure sheet.
2a. Finished produce tears or rips easily.	2b. Product not cured long enough. Refer to steps 1-17 in procedure sheet.
3a. Finished product warps when removed from the mold.	3b. Product and mold not cooled off completely.
4a. Product burns while in the oven to cure.	4b. Do not place mold and product directly over 4b. heating element to cure. Oven temperature too hot.
5a. Marred or dented surface of product.	5b. Take care not to touch any part of the product during and after dipping.

Embedding Procedure Sheet

PROCESS TYPE: Casting
TITLE: Embedding
MACHINE (S): N/A
MATERIALS REQ'D: Mold, Mold release, Clear casting resin, Hardener, Objects, Lint free cloth, and Acetone.

PROCEDURE: EMBEDDING

1 Choose appropriate mold, clean and inspect. NOTE: Clean mold with lint free cloth and acetone - wash with water immediately after cleaning.
2 Do not scratch polyethylene molds.
3 Fasten mold to scrap piece of lumber. Mold is now setting flat and can be carried easily.
4 Measure out desired amount of clear casting resin in appropriate container to be used as the base coat.
5 Add appropriate amount of hardener (catalyst) to the clear casting resin. Normally 3 to 6 drops per ounce for the base coat. NOTE: Larger quantity of resin-smaller quantity of hardener.
6 Mix resin and hardener thoroughly. Minimum mixing time 2 minutes.
7 Pour catalyzed clear resin into appropriate mold.
8 Let mold with base layer set to gel for 30 minutes to an hour.
9 Measure out desired amount of clear casting resin in appropriate container. To be used for the object or anchor layer.
10 NOTE: Measure out only enough resin to cover the object (ex. coins) or anchor large object (ex. insects) to the base coat.
11 Add the appropriate amount of catalyst (hardener) to the clear casting resin. Normally 1 to 3 drops per ounce for the object or anchor layer. Note larger quantity of resin - smaller quantity of hardener.
12 Mix resin and hardener thoroughly. Minimum mixing time 2 minutes.
13 Pour catalyzed resin into mold containing gelled base coat layer.
14 Add object(s) to be embedded, saturate thoroughly to free any trapped air bubbles. NOTE: Be sure that final position of object(s) is upside down.
15 Let mold with base layer and object or anchor layer set to gel for 1 to 1 1/2 hours.
16 Repeat procedures for object or anchor layer as many times as needed. NOTE: Let mold set to gel for 1 to 1-1/2 hours, per each layer, which is added.
17 Measure out desired amount of clear casting resin in appropriate container to be used for the cover layer. NOTE: Normally the amount for the cover coat layer is equal to or slightly more than the base coat layer.
18 Add the appropriate amount of catalyst (hardener) to the casting resin. Normally 2 to 4 drops per ounce for the cover layer. NOTE: Larger quantity of resin-smaller quantity of hardener.
19 Optional: Add desire amount of color and or glitter, now or after resin and hardener have been mixed. NOTE: Average 2 drops transparent color per ounce of resin.
20 Mix resin and hardener thoroughly. Minimum mixing time 2 minutes.
21 Add color now if swirl effect is desired.
22 Pour catalyzed resin into mold containing gelled object or anchor layer(s). NOTE: Do not overfill mold.
23 Let mold set for 12 to 24 hours.
24 Remove embedding from mold by holding mold in both hands and twist until casting releases.
25 To alleviate tacky surface from the cover surface of embedding: Sand off back of embedding (disc sander), apply felt backing to embedding.
26 Sand surface and edges of embedding if desired. Finish sanding and polishing. Optional: Install pen/pencil set.
27 Replace all materials and tools. Turn in finished product for grading.

Flatback casting procedure sheet

PROCESS TYPE: Casting
TITLE: Flatback casting
MACHINE (S): N/A
MATERIALS REQ'D: Mold, Resin, Hardener, Wax paper cup, Scale, Mold release, Drying box, Abrasive paper, Coloring or Glitter

PROCEDURE: FLATBACK CASTING

1 Clean and inspect molds prior to utilization. NOTE: Clean mold with lint free cloth and acetone-wash with water immediately after cleaning. Do not scratch polyethylene molds.
2 Fasten mold to scrap piece of flat lumber. Mold is now setting flat and can be carried easily.
3 Measure out desired amount of clear resin in appropriate container.
4 Add appropriate amount of catalyst (hardener) to casting resin. Normally 3 to 6 drops per ounce. NOTE: Larger quantity of resin--smaller quantity of hardener.
5 Optional: Add desire amount of coloring and or glitter now or after resin and hardener have been mixed. NOTE: Average 2 drops transparent color per ounce of resin.
6 Mix resin and hardener thoroughly. Minimum mixing time 2 minutes.
7 Add color now if swirl effect is desire.
8 Pour catalyzed resin into flatback mold. NOTE: Do not overfill the mold.
9 Let mold set for 12 to 24 hours.
10 Remove mold and casting from mounting board.
11 Hold mold with both hands and twist slightly to remove casting. NOTE: Avoid touching the backside of casting-finger prints marks will result.
    12. To alleviate tacky surface on casting....
    a. Glue on a felt backing.
    b. Utilize 40w to 60w drying box.
    c. Sand off back of casting.
    d. Spray with clear acrylic spray paint.
12 Optional: trim edges of casting with an x-acto knife.
13 Replace all materials and tools.
14 Turn finished product in for grading.

PROBLEM

1a. Resin spilling over sides of the mold.2a. Casting is not hardening after the normal period of time.

3a. Casting hard spots and soft spots.

4a. Back side of the casting is tacky to the touch.5a. Color or glitter bleeding through casting.

SOLUTION

1b. Nail the mold to a flat surface and level.2b. Must have 3 to 6 drops of hardener per ounce of resin. Too much color will cause resin to not harden completely.3b. Resin, hardener and color must be mixed thoroughly.4b. Normal condition for areas exposed to the air. Follow procedures outlined in steps 10-15.5b. Colors and glitter must be mixed or swirled completely.

Fiberglass Reinforcement

PROCESS TYPE: Combining TITLE:
Fiberglass lay up MACHINE (S): See
below MATERIALS REQ': See below

PROCEDURE: Reinforced fiberglass lay up

Reinforced fiberglass lay up is a process of forming a product using a plastic resin and a woven reinforcing material. In most cases glass fibers are used, but fibers other than glass can be used for this process like boron filament and nylon strands. Fiberglass lay up is used to make strong, flexible, and attractive products. These products are resistant to heat, cold, corrosion, water, and electric current.

Fiberglass molds are made of wood, aluminum, steel, cement, or reinforced plastic. The surface should be sealed with an epoxy or urethane finish. The mold should then be washed to rid the surface of unwanted dirt and other materials. After washing, a mold release agent is applied. A clear or colored gel coat is catalyzed and applied to the mold surface and allowed to dry. A polyester resin is applied over the gel coat. Then while still wet, the reinforcing material is applied. To smooth the material a roller or squeegee is used. These layers are built up until a desired thickness is achieved.

Once the product has cured overnight, it is trimmed and sanded to rid the rough edges. Many products are made through the reinforcing process including: skateboards, trays, chairs, skies, and toolboxes. Reinforced fiberglass lay up is a simple process and is commercially widely used.

Items used:-Mold release agent (hard paste wax or water soluble)-Polyester resin-Catalyst and accelerator (to speed up curing time)-Coloring agent (optional)-Gel coat-Fiberglass cloth reinforcing material-Mixing sticks and paper cups-Acetone cleaning fluid and container-Coarse, medium, and fine wet/dry sandpaper-Newspaper and clean cloth or paper towels-Safety glasses or goggles (to be worn at all times)-Disposable gloves (when working with materials)-Mold (wood, aluminum, steel, cement, or reinforced)-Squeegee or roller (to smooth out fiberglass and resin)-Sanding block (so not to round off products edges)-2 one-inch brushes-Band saw (to trim mold)-Coping saw (to trim mold)

Procedure:

1 Obtain all the items listed under tools and equipment and materials needed in the hand lay up process.
2 Cover the bench top with newspaper or some other throwaway material.
3 Wash the mold surface with water. Make sure all old resin, dirt and mold release agents are removed.
4 If a solvent is used, make sure it does not remove the mold finish.
5 Coat the mold surface with an even coat of mold release agent.
6 Place three coats of mold release wax on the lay-up surface. Buff each coat dry before applying the next coat.
7 Let the release agent dry.
8 Weigh the gel coat to cover the mold lay up surface. Ask instructor how much gel coat to weigh out.
9 Add the proper number of drops of catalyst to the gel coat.
10 Mix the catalyst and gel coat well. Wear disposable gloves when handling gel coat, resin, and catalyst. Work in a well-ventilated area.
11 Brush a coat of gel coat on the mold surface. This serves as a water proof outside finish on the product.
12 Be sure to clean the brush with acetone immediately after each use.
13 Let the gel coat dry.
14 Weigh out no more resin than can be used in ten minutes.
15 Add the proper number of catalyst drops to the resin.
16 Mix the catalyst and the resin well.
17 Brush a coat of catalyzed resin on the gel coat surface of the mold.

18 Lay a piece of fiberglass reinforcing cloth on the wet resin surface of the mold.
19 Wet the cloth with a brush or use a roller or squeegee. This removes air bubbles and provides a smoother surface.
20 Let the product cure overnight.
21 Trim the excess material from the product. Use a fine-tooth coping saw or a band saw with a metal cutting blade.
22 Sand the edges for a smooth finish. Start with 100 grit, then 220 grit, and finish with 400 grit.
23 Use a sanding block with the abrasive paper. This helps prevent the plastic edges from being rounded off.
24 Weigh, catalyze, and mix another gel coat.
25 Brush a coat of catalyzed gel coat around the edge of the product. This adds a finish to the products edge and helps stop delaminating.
26 Remove the finished fiberglass product from the mold.
27 Work in a well-ventilated area.
28 Wear a respirator when sanding the reinforced glass material.
29 Wear safety glasses or safety goggles at all times.
30 Wear disposable gloves when handling the reinforcement material and plastic material.
31 Keep a general-purpose fire extinguisher in the work area.
32 Keep the resin away from heat or flame, it is very flammable!
33 Do not mix catalyst and accelerator directly because it can cause a violent explosion.
34 Use all hand lay-up resin parts as recommended by the manufacture.
35 THE CATALYST OR HARDNER COMMONLY USED WITH A POLYESTER RESIN FOR FIBERGLASS IS VERY DANGEROUS. IF ONE DROP OF CATALYST ENTERS YOUR EYE, EYE TISSUE WILL BE PROGRESSIVELY DESTROYED UNLESS THE CATALYST IS WASHED FROM THE EYE WITHIN 4 SECONDS, THERE IS NO KNOWN WAY OF STOPPING DESTRUCTION OF THE EYE. BLINDNESS CAN RESULT.

Free Forming Procedure Sheet

PROCESS TYPE: Forming, Conditioning TITLE: Free FormingMACHINE (S): Band saw/Circular saw, Oven, and Buffer.MATERIALS REQ'D: Plexiglas, Abrasive paper (wet-n-dry), Mold/plug, Buffing compound.

PROCEDURE: FREE FORMING THERMOPLASTICS

1 Decide which pre-made mold and plug is to be used and cut a piece of Plexiglas that is the appropriate size, which will fit the mold. NOTE: Student may elect to construct a new mold.
2 Cut Plexiglas into desired dimension.
3 Sand and polish all edges. Sand and polish the surfaces if needed.
4 Remove masking from plastic.
5 Check to be sure that all edges and surfaces are polished.
6 Pre-heat oven to 325 degrees F.
7 Place a clean sheet of asbestos or sheet metal on the oven rack.
8 Place plastic on sheet in the oven for a minimum of 10 minutes.
9 Check to be sure that the mold and plug are readily available and clean.
10 Remove plastic from the oven and press into desired shape.
11 Let product cool off in mold for a minimum of 3 to 5 minutes. Replace all materials and tools.
12 Turn finished product in for grading.

PROBLEM

1a. Plastic cracks during forming process.2a. Appearance of new scratches after forming.3a. Scratches (band saw, scroll saw, or disc sander) on finished edges.4a. Uneven forming process.

SOLUTION

1b. Plastic has not been sufficiently heated.2b. Mold and plug not clean.3b. Plastic not sanded and polished prior to forming.4b. Product was not aligned properly. Reheat Plexiglas and re-form.

Injection Molding Process Sheet

PROCESSES: Forming, Molding TITLE: Injection Molding MACHINE USED: Injection Molder MATERIAL REQ'D: Thermoplastic material, spoon, mold, release, X-acto knife or file.

Injection molding is a process for producing plastic parts by first heating the resin until it becomes a viscous liquid and then forcing this molten plastic into a mold whose cavity is shaped like the required product.

The two models of injection molders that will be described are: the Emco (1/4 oz.), pressure-manual model and the Honajector (1/4 oz.) and Dake (1oz), pressure-air cylinder or pneumatic models. These are both ram or plunger types and not the reciprocating screw type that is used mostly in industry today. Both thermosetting and thermoplastic materials can be injection molded.

A. Manual Models: (Emco, 1/4 oz.)

1 Turn thermostat knob to medium. This should result in a temperature of 250 to 300 degrees. Readjust for correct operating temperature for the plastic being used.
2 Clean the mold being used and check the sprue hole and channel to make sure that the passage is clear.
3 Spray both halves of the mold with mold release.
4 Align the mold on the base so that the sprue hole in the mold is directly under the hole in the nozzle. The alignment is correct when the sprue hole is lined up with the center of the nozzle.
5 Clamp mold in place, making certain that the movement of the clamp does not throw the sprue hole out of alignment. Bring the vise pressure plate snug up against the mold and then tighten one-eighth turn maximum. Excessive tightening may damage the mold or the machine.
6 With the spoon, fill the hopper with the plastic being used. Pack the cylinder full with the handle of the spoon.
7 Slide the end of the lever arm (pipe) over the handle. Stand back slightly from the machine and with one steady deliberate motion press the pipe lever down. Maintain a steady down pressure on the pipe lever for a few seconds at the end of the stroke. The larger the cavity, the longer the dwell.
8 Refill the hopper before removing the mold. This allows the shot that you just made a few extra seconds to cool.
9 Unlock and remove the mold from the machine. Be Careful, as the cylinder is hot. Remove the completed part, break off the sprue and file or trim off any flashing, which may remain. If you need help in removing part from the mold cavity, use an instrument made of soft brass or hard wood.
10 Break all scrap into small pieces and place back into plastic container or hopper. Since we are working only with thermoplastic material, all scrap can be re-used.
11 If the machine is not going to be used again immediately, lower the temperature slightly and raise it again when ready for next shot.
12 Clean-Up Procedure "A" Return all tools and clean your work area. Should the handle accidentally be left in the down position and the ram is "frozen" in the cylinder by solidified plastic, allow it to heat up before attempting to break it free. Turn the machine "on" and allow it to reach operating temperature. The ram will then move freely out of the cylinder.

B: Pneumatic Model: (Honajector, 1/4 oz.)

1. Turn thermostat knob to medium. This should result in a temperature of 250 to 300 degrees. Readjust for correct operating temperature for the plastic being used. To set knob to required temperature, observe dial thermometer and turn knob back to where neon indicator light turns off.
2 Align the mold in the vise so that the sprue hole in the mold is directly under the hole in the nozzle. The alignment is correct when the sprue hole is lined up with the arrow on the cylinder.
3 Clamp the mold solidly in place, but do not over-tighten, bring the vise pressure plate snug against the

mold and then tighten 1/8 turn maximum.
4 Fill the cylinder with plastic material. Place a small quantity of plastic into the opening in the top of the cylinder with your spoon. Pack the cylinder full.
5 Apply the pressure with the 4-way valve.
6 If the next shot is to be with the same material, refill the cylinder while the mold is cooling.
7 Open the vise and remove the mold from the machine. Be careful, as the cylinder is hot.
8 Remove the completed part, break off the sprue and file or trim off any flash, which may remain. If you need help in removing part from the mold cavity, use an instrument made of soft brass or hard wood.
9 Break all scrap into small pieces and place back into plastic container or hopper. Since we are working only with thermoplastic material all scrap can be re-used.
10 If the machine is not going to be used immediately, lower the temperature slightly and raise it again when ready for next shot.
11 Clean-Up Procedure
Return all tools and clean your work area.

C: Pneumatic Model: (Dake, 1 oz)

1 Select the mold and make sure that it is in good condition and cleaned thoroughly. Spray mold with mold release.
2 Fill the hopper with the proper material for the job.
3 Turn on the power with the toggle switch located on the control panel at the front of the press.
4 Turn the temperature control knob to the right to the medium temperature range. This setting will bring the temperature up to approximately 300°F. Allow 15 to 20 minutes for the press to heat up. Then re-adjust the temperature setting for the proper operating temperature of the material being used.
5 When the machine reaches the proper operating temperature for the material being used, turn on the air supply and regulate the pressure. Start with approximately 60 psi. The amount of pressure required will be determined by the type of material being used, the amount of detail of the mold cavity, and the design of the sprue, runners, and gates. The required pressure will vary between 40 and 100 psi. Operate at the lowest air pressure that will fill the cavity.
6 Once the barrel of the machine is hot, place the mold in the machine. Make sure that the sprue lines up with the nozzle of the machine. Adjust the mold stop so that the mold will be aligned with the nozzle each time it is placed in the machine. Tighten the clamp by turning the hand wheel.
7 Check to make sure that the correct molding temperature has been reached. Do not move on to step #8 until you have reached the proper operating temperature. Do not remove the safety heat shield that covers the barrel of the machine.
8 To activate the plunger, move the air valve lever, located on the top of the press, to the right. Allow 3 to 9 seconds for the molding cycle and then move the air valve lever to the left. This will cause the plunger to retract. Do not run the plunger forward when the press is cold or before it is up to the proper operating temperature.
9 Open the clamp by turning the clamp wheel counter-clockwise. Remove the mold from the machine, open the mold and check to see if the mold cavity has been completely filled. It may require several trial shots before the mold cavity will fill properly.
10 If you need help in removing the part from the mold use something made of soft brass or hard wood.
11 Break all scrap into small pieces and put back in original plastic container. Since we are working with only thermoplastic material, scrap can be re-used.
12 Clean-Up Procedure Return all tools and clean your work area. Wear proper eye protection. Remove or contain loose clothing. Tie back long hair. Remove all jewelry. Do not overheat machine. Watch for pinch points and stay clear of them. Do not over-pressure the injection ram on the pressure-manual machine. Use caution when touching the machine after it has been heated. Do not begin plunging operations on either machine until the operating temperature has been reached.

SYMPTOM	*PROBABLE CAUSE*	*POSSIBLE SOLUTION*
Machine will not inject	Mold and nozzle misaligned.	Realign mold.
	Temperature too low. Injection pressure too low.	Raise temperature. Apply more pressure.
Incomplete shot.	Cylinder too full. Short shot blocking. Not enough material in cylinder.	Increase speed. Clean funnel. Recharge cylinder.
	Temperature too low. Not enough pressure.	Increase temperature. More pressure.
	Injection speed too slow. Pause in injection stroke.	Increase speed. Increase size of sprues, runners and gates.
	Mold cavity may be too large for capacity of machine.	
	Poor sprue and gate design.	
Excess flash	Injection pressure too high. Mold not cleaned	Use less pressure. Clean mold properly.
	Temperature too high. Mold warped.	Lower temp. Check mold.
Plastic not a pure color	Clamp loose. Temperature too low. Wrong or contaminated material.	Tighten clamp. Raise temp. Check plastic.
	Temperatures excessively high.	Decrease temp, remove all material, and refill.
Machine sticking or sluggish	Contaminated plastic. Lack of lubrication. High temperatures.	Purge and refill. Lubricate. Lower temp.
Excessive odor, smoking or popping of plastic	Insufficient material. Preheating period too long.	Fill hopper. Reduce time.
Flow marks	Temperature too high. This is normal to a degree.	Reduce temp. Temperature too low. Poor sprue, gate and runners.

Polystyrene Molding Procedure Sheet

PROCESS TYPE: Molding, Separating TITLE: Polystyrene Forming & Molding MACHINE (S): Heating Chamber, Boil Tank MATERIALS REQ'D: Polystyrene beads, Split molds, X-acto knife, and Screwdriver.

PROCEDURE: POLYSTYRENE MOLDING

1 Choose desired aluminum split mold to be utilized.
2 Check to be sure the mold is clean and usable.
3 Check to be sure the two halves match.
4 Pre-heat the pre-expanding raw bead chamber to approximately 180° to 200°F.
5 Determining the correct amount of raw polystyrene beads will depend on the particular mold. NOTE: Raw beads will normally expand 20 to 40 times their raw diameter size.
6 Place the predetermined amount of raw beads into the pre-expanding chamber and rotate with 200°F temperature until 75 to 80% of all the beads are approximately 3/16" in diameter. Normal time for expansion is 8 to 12 minutes.
7 Remove expanded beads from the chamber using a vacuum device. NOTE: Expanded beads should be utilized within 2 to 3 days.
8 Fill both halves of the aluminum mold with expanded beads. Do not overfill or do not pack tightly.
9 Place both halves together and secure with appropriate nuts and bolts. NOTE: Place piece of sheet metal over one half and place that half upon the second half then slide the sheet metal out.
10 Place filled mold in the boil tank for 15 minutes. Do not start the time until the water is boiling.
11 After 15 minutes, remove the mold from the boil tank and place it under cold water for 3 to 5 minutes.
12 Remove all nuts and bolts from the mold.
13 The mold should split apart without applying excessive force.
14 Take the finished product out of the mold. Do not use excessive force. NOTE: Do not insert screwdrivers or other sharp objects to remove the product from the mold unless your instructor gives permission and is present.
15 Place all nuts and bolts back into the mold.
16 Trim seam of the product with a sharp X-acto knife.
17 Replace all materials and tools.
18 Turn finished product in for grading.

PROBLEM

1a. Raw beads are not expanding in the chamber.

2a. Raw beads sticking to each other inside the pre-expanding chamber.

3a. Not enough expanded beads to fill both halves of the mold.

4a. Finished product has voids.

SOLUTION

1b. Pre-expanding chamber temperature is incorrect.1b. Temperature should be at least 200°F. 1b. Shelf life has expired of the raw beads.2b. Temperature is too high inside the chamber.

2b. Beads are left inside the chamber too long.3b. Not enough raw beads expanded.

3b. Raw beads are not expanded to the approximate 3/16" diameter size.4b. Split halves are not filled completely.
5a. Parts of the finished product break off easily.

6a. Finished product is extremely heavy.
4b. Product not in the boil tank for a minimum of 15 minutes.5b. Mold halves are not filled completely.

5b. Product not in the boil tank long enough to completely expand the beads.6b. Utilizing too many beads which were not completely pre-expanded to the approximate 3/16" diameter size.

Rotational Molding Procedure Sheet

PROCESS TYPE: Forming
TITLE: Rotational Molding
MACHINE (S): Rotational Molder
MATERIALS REQ'D: Low-density polyethylene powder, Aluminum split mold, Dry pigment, Silicone mold release, X-acto knife.

PROCEDURE: POLYETHYLENE ROTATIONAL MOLDING

1 Choose desired aluminum split mold to be utilized.
2 Check to be sure mold is clean.
3 Spray mold lightly with silicone mold release.
4 Pre-heat rotational oven to 400°F.
5 Fill one-half of one-half of the total mold with polyethylene powder. NOTE: Dry pigment is used to color the powder.
6 Place all necessary bolts and wing nuts on the mold, tighten finger tight.
7 Shake mold with hands to allow powder to coat entire interior surface.
8 Place prepared mold in appropriate holding clamp if one is not provided on the mold itself.
9 Place mold in the holding axis rod in the rotational molder by inserting the pin through the slot in the holding clamp shaft. NOTE: Place pin through slot and start rotating process as quickly as possible as the powder will start to liquefy as soon as heating process begins.
10 Start drive unit of rotational molder and set timer for 8 to 10 minutes. NOTE: Time set will be determined by the amount of temperature drop while the door was open and size of the mold.
11 After 8 to 10 minutes, remove mold from rotational molder and place under cold tap water for 5 minutes. NOTE: Mold must be completely cool before removal of product is attempted.
12 Remove mold from clamp (if necessary) and remove all bolts and wing nuts from mold.
13 Take finished product out of mold. Do not use sharp objects to remove the project from the mold. Have the instructor present and instructor's permission.
14 Replace all bolts and wing nuts into mold.
15 Trim seam of product with Xacto-knife.
16 Replace all materials and tools.
17 Turn product in for grading.

PROBLEM

1a. Powder does not melt and coat inside surface of mold.2a. Vinyl or powder very thick in one place in the mold.

3a. Product sticks in the mold.

SOLUTION

1b. Oven is not preheated to 400 degrees.

2b. Too much time taken to put the mold in the holding clamp.2b. Molder not operating properly. 2b. Check to see that the molder clamp rotates on both axes.3b. Oven temperature is too high.
4a. Product deflates when mold is opened.

5a. Vinyl product pitting or pocked surface.
6a. Unmelted powder inside of finished product.
7a. Finished vinyl product tears or rips when released.
3b. Remove product by prying out. NOTE: Take extreme care not to damage the mold. Spray the mold lightly with silicone mold to release prior to utilization.
4b. Mold and product is not cooled completely before opening the mold. Extremely thin parts of the product will tend to give. Be sure enough material is utilized.
5b. Temperature is too high.
6b. Too much powder put in the mold. Fill 1/2 of 1/2 of the mold.
7b. Molder is not at right temperature and/or mold is not in oven long enough.

Simple casting procedure sheet

PROCESS TYPE: Casting TITLE: Simple Casting with Resin MACHINE (S): N/A MATERIALS REQ'D: Mold, Resin, Hardener, Wax paper cup, Scale, Mold release, Oven.

PROCEDURE: SIMPLE CASTING WITH RESIN

1 Pick mold and apply mold release, unless plastic mold.
2 Measure the approximate amount of casting resin needed in a wax paper cup.
3 Add approximately 6 drops of hardener per ounce of resin (more for a thin casting, less for a large thick casting).
4 Pour mixed resin and hardener into mold until desired level is reached.
5 Stop here and clean up.
6 Place in oven for 30 minutes at 150 degrees, let cool to room temperature.
7 Remove from mold and clean.
8 Sand smooth any rough spots with number 600 abrasive paper, sand in one direction.
9 Buff until desired gloss is achieved.
10 Turn in for grade.

Slush Molding Procedure Sheet

PROCESS TYPE: Casting, Molding
TITLE: Slush Molding
MACHINE (S): Oven
MATERIALS REQ'D: Silicone mold release, Mold(s), Vinyl plastisol #90, Gloves, and Xacto knife.

PROCEDURE: SLUSH MOLDING

1 Pre-heat oven to 350°F.
2 Choose desired aluminum slush mold to be utilized.
3 Check to be sure that the mold is clean.
4 Spray mold slightly with silicone mold release.
5 Place prepared mold in oven for 15 minutes.
6 Remove mold from oven.
7 Fill slush mold to within 1/4" from the top of the mold with vinyl plastisol #90. NOTE: Paste vinyl pigment is used to color the vinyl.
8 Place cover (asbestos) over filled slush mold.
9 Place mold back in 350°F oven for 3 to 10 minutes. Ex. 3 to 5 minutes for the doorstop and 8 to 10 minutes for the football-kicking tee.
10 After 3 to 10 minutes remove the mold from the oven, and remove cover from the mold.
11 Pour out excess vinyl into appropriate trash container.
12 Place mold back into oven at 350°F for 20 minutes. NOTE: Do not put cover back on the mold.
13 Remove mold from the oven and place under cold tap water for 3 to 5 minutes. Remove product from mold.
14 Trim edges of the product while the product is still in a flexible state. NOTE: It will require approximately 10 to 15 minutes for the product to become rigid.
15 Product may be trimmed on the disc sander after it has become rigid.
16 Replace all materials and tools.
17 Turn in finished product in for grading.

PROBLEM

1a. Product tears and/or rips when released from the mold.

2a. Excess vinyl will not pour out.

3a. Product does not release from mold.

SOLUTION

1b. Oven not up to temperature. Mold not pre-heated long enough. Product not cured long enough.
2b. Be sure to cover back of mold during initial 3 to 10 minutes of curing time.
3b. Be sure to spray mold with silicone mold release prior to utilization.

Vacuum forming procedure sheet

PROCESS TYPE: Forming TITLE: Vacuum Forming MACHINE (S): Vacuum Forming Press MATERIALS REQ'D: Thermoplastic Sheet, Mold, Paint, and Scissors/X-acto knife.

PROCEDURE: VACUUM FORMING

1 If signs are to be produced, use polystyrene sheets, size 14" x 20" x .020 to .040 thick.
2 If casting molds are to be produced, use polyethylene sheets, size 10" x 14" x 1/16" thick.
3 Layout desired sign components or molds on lined platen. NOTE: Platen has one 1/32" hole per square inch to allow vacuum process.
4 When sign components or molds are laid out, insert either polystyrene or polyethylene sheets into heating unit holder of machine. NOTE: Polystyrene sheets must be inserted so that the dull side of the sheet is facing upward. NOTE: Layout components or molds so that as many holes as possible are exposed.
5 Check to be sure that the rest of the platen is clean.
6 Turn on heat unit. NOTE: Watch plastic sheets so that overheating does not occur. Use heat gun to heat all corners properly.
7 When sheets are properly heated, transfer sheets from heat unit to vacuum unit and immediately start vacuum motor.
8 Hold vacuum motor unit on for 3 to 5 seconds.
9 Let vacuumed sheet cool for minimum of 5 minutes before removing from machine.
10 Use felt-tipped markers for coloring.
11 Replace all tools and materials. Turn in for grade.

PROBLEM

1a. Parts of the letters are not forming down completely.
2a. Finished product has wrinkles or extremely thin spots.
3a. Irregular finished surface.

SOLUTION

1b. Try to arrange letters with vacuum holes in all the closed areas.
2b. Heat is applied to polystyrene sheet for too long of a period of time.
3b. Platen not properly cleaned prior to forming.

Information on the Testing and Evaluation of Materials

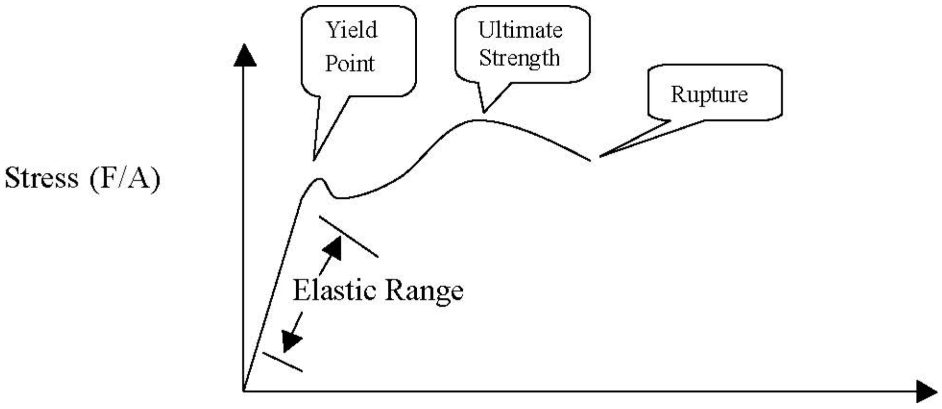
Introduction

The primary focus of these laboratory exercises is to help you develop knowledge and skills related to the design, conduct, and application of various testing methods. Testing data and results can then be applied to various real-world situations. This includes data on a material's chemical, physical, mechanical, and dimensional properties.

IMPORTANT: Individual safety is your foremost concern during any laboratory exercise. It is your responsibility to make sure all guards are in place and operating correctly; all shields are secure; all safety procedures have been followed; everyone is wearing proper protective equipment (including gloves, glasses, appropriate clothing and shoes, etc.); and that everyone is aware that you will be conducting a test. Use common sense. During testing, some materials will shatter and some will not. When materials do shatter, pieces will fly in all directions, possibly causing personal injury if that person is unaware of the danger. MAKE SURE YOU CHECK THE MACHINE FOR PROPER OPERATION AND HAVE CHECKED THE EQUIPMENT THOROUGHLY. FOLLOW ALL SAFETY PROCEDURES. Make sure you know how to interrupt and stop a machine before proceeding with the test. The time to stop a test is before someone gets hurt.

Mechanical Properties

Among the primary concerns we will be looking at are the mechanical properties of materials. These include: tensile strength, yield strength, ductility, toughness, and hardness, among others. These properties are commonly investigated and are among the most important properties used in design. Data concerning a material's strength can be collected in any number of ways; the more common is the tensile test. It provides a wide range of indicators concerning how a material will function under a variety of loads. Other important tests include: compression tests, flexural or bending tests, impact tests, hardness tests, creep tests (temperature over time), and fatigue tests (low loads repeated a large number of cycles). The strength exhibited by various materials may depend on the axis of loading or direction in which the property or properties are measured. One should be sure that the types of loading and appropriate steps to insure axial loading are confirmed. Stress-strain curves illustrate the correlation between applied stress and resultant strain a material exhibits under loading. The linear portion of the curve illustrates elastic deformation or the elastic region. The slope within this area of linearity is the modulus of elasticity. The greater the slope of this region, the stiffer the material is said to be. Typical moduli of elasticity run from 1.5 x 10^6 psi to 60 x 10^6 psi (10,000 to 410,000Mpa).



Strain (? L/L) There are several points on the stress-strain curve that are important to the fields of materials testing and engineering. These include the yield point and the yield strength. The yield strength of a material is easily determined based on an arbitrary offset value, expressed as a strain value percentage (0.1%, 0.2%, etc.). This value is known as the offset. The offset method for determining the yield point based percent yield involves drawing a line parallel to the elastic region of the material at the desired offset. With the stress applied, the point at which this line intersects the stress-strain curve is determined to be the yield point. The yield strength can be calculated from the data at the yield point.

Most materials can be classified into arbitrary classes: ductile or brittle. Ductile materials exhibit large plastic strains prior to failure. Brittle materials exhibit very little strain before fracturing.

The strength of many materials in increased with the addition of alloys. Typically, the strength of the material will rise with the rising percentage of the alloying element up to a given percentage. Low-strength materials are often used because of their low cost, workability, and ease of machinability. They are often chosen for other properties than strength. For example, formability, weight, strength-to-weight ratio, and corrosion resistance are certainly important criteria. To illustrate: would you want to form a hang glider out of lightweight aluminum or heavy, dense steel and why? Or why not?

Tensile Testing

Introduction

In tensile testing, the properties of interest include yield strength, tensile strength, ductility, and type of fracture. From the test data, one can calculate the modulus of elasticity and make some qualitative evaluations on stress-strain relations and other mechanical properties.

In tensile testing, the specimen is loaded so that the applied load tends to pull the two ends in opposite directions, away from each other. Typical test materials include: steel, metals, plastics, cable, rope, wire, adhesives, cord, string, fabric, and other materials and products for which data on tensile strength are required.

Specimens come in a variety of sizes and shapes. The more common include:

1. Flat specimens (0.5-inch maximum thickness).
2. Smooth and round-end specimens (0.375-0.875-inch diameter).
3. Threaded-end specimens (same as #2).
4. Bolts (0.5-inch diameter or less, typically).

Each of these requires test grippers, which are made for the type of specimen under consideration. Grippers are used to "grab" the ends of the specimens firmly without damage.

The primary objective of a tensile test is to determine the tensile strength of the material or specimen, by applying a tensile load and observing the effects on the specimen. Effects may include necking down, taking a permanent set, fracture, complete rupture, and other similar events. Ductile materials will neck down through the plastic region before rupture. Brittle materials fail sharply, without necking down significantly.

During the test, data should be recorded concerning the environment in which the test was conducted: humidity, temperature, and other such conditions. Information on the material itself might include the SAE/AISI number, the visual condition of the material, heat treatment condition, and other features. While actually testing, data on applied load and resultant deformation are collected.
Data on applied load are measured in pounds or kilograms while data on deformation are measured in thousandths of an inch or millimeters. Typical tests require at least en data points so that major events in the graph can be detected.

The original and final cross-sectional areas are calculated before and after the test, respectively. In addition, a gage length is established over which the change in length or deformation will be measured. The applied load divided by the cross-sectional area is the stress. The change in length divided by the original length is the strain developed. These two values will determine data points for the graph.

Tensile tests involving ductile materials will exhibit both elastic and plastic deformation. The elastic region is that portion of the curve where the material will return to its original condition after the load is removed. The plastic region includes that portion of the curve where the material will deform prior to failure. The point at which a material's behavior crosses from elastic to plastic (yet still within the elastic region) is called the elastic limit. The point at which a material's behavior enters the plastic range is termed the yield point. The material is said to have "yielded".

Required Equipment

Universal Testing Machine with appropriate grippers Test Specimen (ASTM standards) Gage-length indicating device (extensometer) Scale, rule, or appropriate measuring device Micrometer or calipers Safety glasses or face shield Data sheets

Procedure

1 Prior to applying the load to a specimen, measure its dimensions. Measure the cross-sectional area of the specimen. If elongation measurements are to be taken, scribe, or lay out, the gage length. On ductile specimens of ordinary size, this is done with a center punch, but on thin sheets or brittle materials make fine scratches. Care should be taken to avoid influencing the test with these marks. Typical gage lengths are 2 inches, but may be any convenient and appropriate length. Refer to the appropriate ASTM standard for the material under test.

2 Before operating a testing machine for the first time, you should familiarize yourself with the machine, its controls, its speed, the action of the weighing mechanism, and the value of the graduations on the scales. Before testing a specimen, check for zero-load indication, and adjust the machine, if necessary.

3 After placing the specimen in the machine, check for proper alignment of the grippers. Make sure all guards and shields are in place and that all safety features work properly. Place the specimen so that it is convenient to take gage length measurements.

4 When using the extensometer, determine the value of the divisions on the extensometer and the multiplication ratio before placing the extensometer on the specimen. Place it centrally on the specimen and align it properly. Place a small load on the specimen before resetting the extensometer to zero.

5 The speed of testing should not be greater that that at which load and other readings can be taken with the desired degree of accuracy and reliability. A common range for load application rate is from 0.01 to 0.05 inch per minute (0.003 to 0.015 mm per minute) of crosshead travel per minute. Refer to the appropriate ASTM standard for loading rates.

6 When using the extensometer, either apply the load in increments and read the load and deformation at the end of each increment or apply the load continuously at a slow rate and observe both the load and the deformation simultaneously. The latter is the preferred method.

7 Remove the extensometer after reaching the proportional limit.

8 Continue applying the load until the test specimen fails. After failure, remove the specimen from the machine: if elongation is to be determined, fit the broken ends of the specimen together and measure the distance between gage points with a scale, dividers, calipers or other appropriate device. The diameter of the smallest section is measured using calipers to determine the percent reduction in area.

9 Make a record of your observations regarding applied stress and stain and graph a stress versus strain diagram.

10 Determine the elongation--the increase in length over the gage length--expressed as a percentage of the original gage length. Report both the original length and the percent increase. If breakage occurred beyond the gage points, specifications often call for a retest.

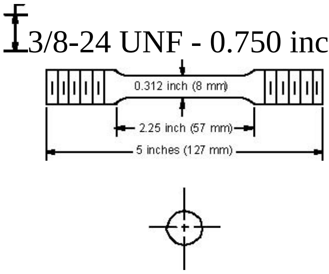
11 Determine the percent reduction in area by calculating the difference between the area of the smallest cross-section (at the break) and the original cross-section, expressed as a percentage.

12 Classify the fracture regarding form, texture, color, and other prominent features. Types of fractures often include cup-cone, flat, irregular, and ragged. These may be symmetrical or asymmetrical. Conditions of the fracture include silky, fine grain, coarse grain, granular, fibrous, splintery, crystalline, glassy, or dull.

Specimens

Typical specimens include: round-end, flat, threaded-end, and adhesive fixture.

3/8-24 UNF - 0.750 inch (19 mm)



0.505 inch (12.8 mm)

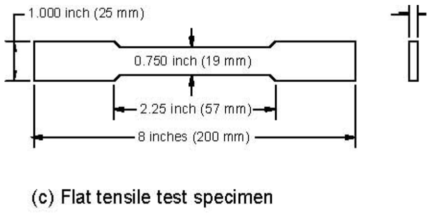
4 inches (100 mm)

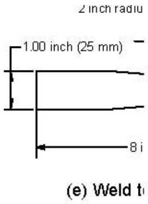
2.25 inch (57 mm)

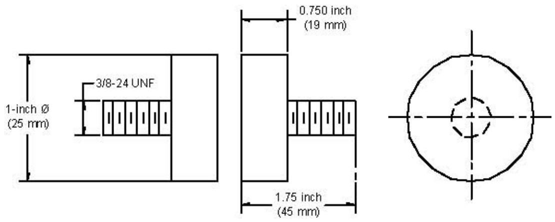
8 inches (200 mm)

5 inches (127 mm)

(a) Smooth-end round tensile test specimen (b) Threaded-end round tensile test specimen







(f) Fixture for tensile test of adhesives

Data

Sample data are given here as an example. This is only an example and should be used as a guide to developing your own test data sheet, which fits the particular test, test material, and conditions.

Sample Test Data (Title) In the results section, the data obtained and the stress-strain curve plotted are used to identify and calculate the yield point, yield strength, ultimate tensile strength, percent elongation, percent reduction in area, modulus of elasticity, and rupture strength of the material.

Material:	1020 Cold Drawn Steel	Date:
Original Diameter:	0.505 inch	Gage Length: 2.0000 in
Final Diameter:		Final Gage Length:

Reading	Applied Load (lbs)	Stress (lb/in2)	? length (in)	Strain (in/in)
1	1000	5000	0.0004	0.0002
2	2000	10,000	0.0008	0.0004
3	3000	15,000	0.0012	0.0006
4	4000	20,000	0.0014	0.0007

5	5000	25,000	0.0018	0.0009
6	7500	37,500	0.0029	0.0015
7	9500	47,500	0.0035	0.0018
8	10,500	52,500	0.0042	0.0021
9	11,500	55,000	0.0060	0.0030
10	12,500	62,500	0.0100	0.0050
11	12,800	64,000	0.0250	0.0013
12	11,300	56,500	0.0400	0.0200
Fracture				

Other Data Taken from Graph:

Yield Strength at 0.2% Offset: 52,000psi

Proportional Limit: 45,000psi
Ultimate Strength: 65,000psi
Rupture Strength: 56,500psi

Results

Yield strength is the stress at which a material exhibits a specified limiting permanent set.
Yield points are two critical points within the yield range for ductile materials, one upper and one lower, which are used to characterize the plastic range of a material.
Ultimate strength is the greatest stress that a material can withstand prior to failure.
Rupture or breaking strength is the stress applied at rupture.
Modulus of Elasticity (E), aka Young's Modulus, is calculated by finding the slope of the stress-strain curve for a given material within the range of elasticity, e.g. the range of linearity between stress and strain.

E = stress/strain at given point on curve within elastic region.

Percent elongation is the total percent strain that a specimen develops during testing.

%Elongation = (lf -lo)/lo x 100

Percent reduction in area is the difference between the original and final cross-sectional areas of a test piece, expressed as a percentage.

%Reduction = (Ao - Af)/Ao x 100

Items include in the results section are specifically:
1 Elastic limit
2 Proportional limit
3 Yield point
4 Yield strength at specified offset (typically, 0.2%)
5 Ultimate strength
6 Modulus of Elasticity
7 Percent elongation
8 Percent reduction in area
9 Nature and type of fracture

Other Tensile Tests Performed

Other tensile tests performed include those for wire and cable, welded test specimens, brazed and soldered specimens, plastics, and adhesives. One particular test that is often performed as a tensile test is a creep test. In creep testing, the specimen is generally tested under elevated temperatures and/or other environmental conditions. The creep test is a long-term test. The setup for creep testing is provided below.

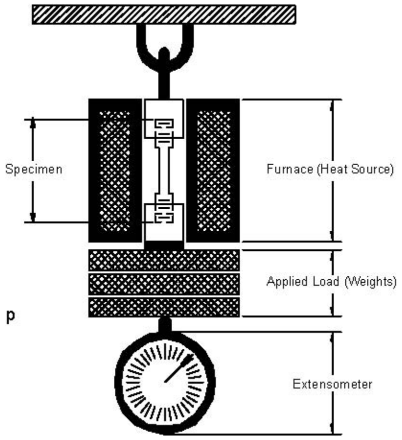


Illustration of Creep
Testing Principles

Compression Testing

Introduction

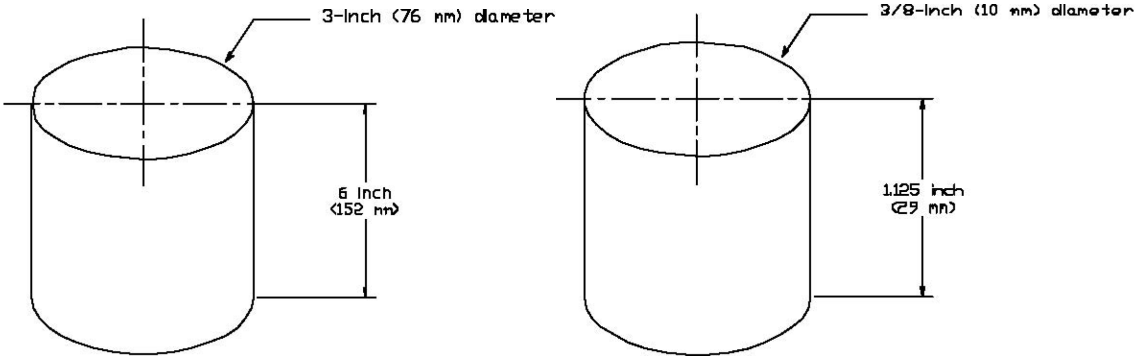
The compression test of a material, in theory, is the opposite of tensile testing. The following are some limitations to the compression test:

1 It is difficult to apply a truly concentric or axial load.
2 This type of loading is relatively unstable contrasted with tensile testing (due to buckling, column action, etc.)
3 Friction between the heads of the testing machine or bearing plates and the ends of the specimen due to lateral expansion of the specimen may affect test results.
4 A relatively larger cross-sectional are of the specimen is needed in order to obtain the proper degree of stability for the test piece. This larger piece results in the need for a larger-capacity machine; otherwise, specimens are so small and short that strain readings are difficult to obtain.
5 Specimens are kept relatively short to reduce column actio n and to test only compression effects in the specimen.

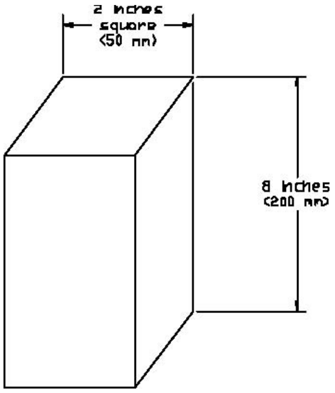
Procedure

1 Obtain a cylindrical material specimen approximately 1.5 times as long as the diameter. The selection of the ratio between length and diameter is a compromise between several undesirable conditions. As the length of the specimen is increased, there is a tendency toward necking of the piece, with subsequent nonuniform distribution of stress. As the length of the specimen is decreased, the effect of the frictional restraint at the ends becomes relatively important also, for lengths less than 1.5 times the diameter, the diagonal planes along which failure would take place in a longer section intersect the base, with the result that the apparent strength is increased.
2 Dimensions vary according to the material being tested. Concrete compression specimens are typically 6" x 12", but you need a machine of larger capacity to test to failure. Therefore, one can reduce the size while maintain the proportion, e.g., a 3" x 6" specimen would yield similar results on a smaller capacity machine. Wood is tested perpendicular to the grain and typically has a 2" x 2" x 8" clear specimen.
3 Typically, during compressive testing only the compressive strength is of concern. In brittle materials, the ultimate compressive strength can be determined. For materials where there is no clear fracture or other phenomenon to mark ultimate strength, arbitrary limits or deformation results are used to indicate failure.
4 In marking stress-strain determinations, three markings are placed 120° apart and the results averaged.
5 Observations include identification, dimensions, critical load, compressometer readings, and type of failure; sketches are made to illustrate test results.
6 The speed of testing is important in compression testing, as with most other static tests. The loading rate for a particular test can be found in the ASTM standards. However, a good general speed is approximately 2000 psi (13 Mpa) per minute.

Specimens



(b) Compression specimen for concrete (a) Compression specimen for metals



(c) Compression specimen for wood

Data

Data recorded during compression testing are typically load and deflection. This information is then used to calculate other figures of merit, and a stress-strain curve can be plotted.

Sample data are given here as an example. This is only an example and should be used as a guide to developing your own test data sheet, which fits the particular test, test material, and conditions.

Sample Test Data (Title)

Material: 0.375" x 0.75" round aluminum Date:
Original Area: 0.4418 square inches Gage Length:
Final Diameter: Final Gage Length:

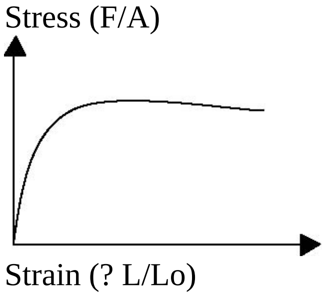
Reading	Applied Load (lbs)	Stress (lb/in2)	? length (in)	Strain (in/in)

1	500	1100	0.0015	0.0020
2	1000	2300	0.0025	0.0033
3	1500	3400	0.0035	0.0047
4	2000	4500	0.0050	0.0067
5	2500	5700	0.0090	0.0120
6	3000	6800	0.0150	0.0200
7	3500	8000	0.0270	0.0360
8	4000	9000	0.0620	0.0827
9	4200	9600	0.0710	0.0960
Rupture	4300			

Results

Discuss the effects loading may have had on test data. Explain the effects that loading rate, nonparallel load-bearing surfaces, and specimen preparation may have had on results. Finally, look for slippage or fractures and describe the type of features of these.

A typical compression curve looks similar to the graph below:



Other Compression Tests Performed

Compression tests are commonly performed on wood parallel to the grain, concrete, plastics, and brittle and ductile metals.

Shear Testing

Introduction

A shearing stress is a force that acts parallel to a plane, as distinguished from tensile or compressive stresses, which act normal to a plane. If a specimen is subjected to a tensile or compressive stress acting in only one direction, the shear stresses at 45° are one-half the magnitude of the applied direct stress. Generally, the maximum shear stress is equal to one-half the difference between the maximum and minimum principal stresses and act on planes inclined at 45° to these stresses. The strain that accompanies shear arises from the effort of thin parallel slices within the specimen to slide over one another. Two common types of shear tests are direct (single and double) and torsion.

A shear test is performed by placing a suitable test specimen in the testing machine so that bending stresses are minimized across the plane along which the shearing load will be applied. In the punching shear test for flat stock, the amount of load required to push a punch through the material through the corresponding die is measured. The more accurate representation of shear strength is the torsion test. The torsion test can be performed on hollow or solid round shapes. It must be of sufficient length to attach a troptometer, which will measure the detrusion during the test. It also helps in determining the proportional limit, the yield strength, the shearing resilience, and stiffness. Stiffness is the angle of twist and applied load. The ductility of a material is determined by the amount of twist prior to rupture, the toughness is the amount of twist and the strength, and uniformity is indicated by the spacing, distribution, and appearance of lines of twist. Anyone who has ever twisted a bolt off has performed a torsional shear test to failure.

Procedure

Direct Shear Test

1 A bar is usually sheared in some device that clamps a portion of the specimen while the remaining portion is subjected to load by suitable dies. Specimens for ductile materials are cut from standards rods of suitable length to extend through the die.

2 In direct shear testing, the testing device should hold the specimen firmly and preserve good alignment through the test. The load should be applied evenly perpendicular to the axis of the specimen. The loading rate should not exceed 0.05 inches per minute (1.3mm per minute).

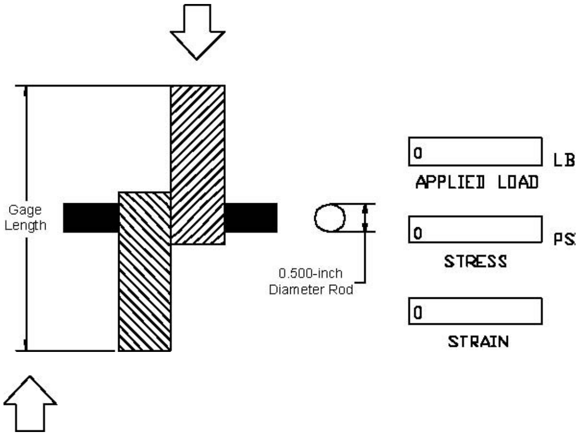
3 Also, the one critical value that can be observed is the maximum load applied. The area can be calculated and the stress determined. The shape, texture, and appearance of the fracture should be reported.

Torsion Test

1. Test specimen criteria include:
    a. The specimen should be of such size as to permit the desired strain measurements to be made with suitable accuracy and reliability.
    b. It should be large enough to eliminate the effect of stresses due to gripping the ends from that portion of the specimen on which measurements are made.

2. Actual specimen sizes are commonly chosen to suit both the size and type of testing machine available as well as the product to be tested.

Typical Setup



Typical Shear Test Setup

Data

Data generally include: material under test, original dimensions, maximum load, shear strength (calculated). Graph data include: reading number, applied load or torque, and deflection or detrusion.

Results

Results are typically reported as maximum shear stress developed. A stress-strain curve can be plotted based on data.

Torque = effort at a distance, e.g. T=f * d.

Flexure or Bend Testing

Introduction

If forces act on a piece of material in such as way to induce compressive stresses over one area of cross-section and tensile stresses over the remainder, the object is said to be bending. Bending may be accompanied by direct stress, transverse shear, or torsional shear. Bending action in beams is often referred to as flexure. This refers to transverse loading. The deflection of a beam is the displacement of a fixed-point reference on the neutral surface of a beam from its original position under the action of an applied load. The amount of deflection is an indication of the overall stiffness of the material.

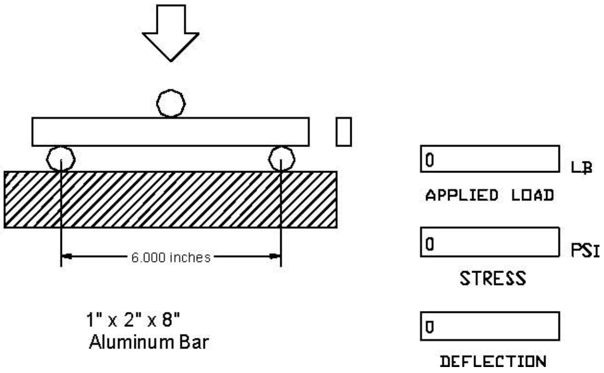
Procedure

1 The test specimen should be of such shape that it permits use of a definite and known length of span. In other words, it can be loaded properly in a machine of known dimensions.
2 The areas of contact with the material under test should be such that unduly high stress concentrations do not occur.
3 There should be provision for longitudinal adjustment of position of the supports to avoid longitudinal restraint of the test piece.
4 The arrangement of parts should be stable under load. Many flexure tests are conducted in universal testing machines, with the supports placed upon a platen or an extension thereof and with the loading block fastened to or placed under the moving head.
5 A load-versus-deflection curve should be plotted.
6 There should be provision for the lateral rotation of twisted beams and specimens from end to end, so that torsional stresses do not develop.
7 The loading rate is important and should not produce too rapid a failure. ASTM test standards should be referenced prior to starting the test.
8 Flexure and bend testing provide an indication of the ductility of the material being tested.

Typical Test Setup

Flexural Strength =

$$\frac{3\ F\ L}{2\ w\ h^2}$$



Hardness Testing

Introduction

Hardness, as a mechanical property, is the resistance of a material to surface penetration. Therefore, most hardness tests involve measuring the amount of force required to implant a specified indentation in the surface of a specimen OR the size of the indentation produced from applying a specified load. The indenter used varies with the test selected, but is generally a hardened steel ball or diamond brale.

Other types of hardness tests involve the rebound of a dynamic or impact load, such as the scleroscope. The amount of rebound that results is used as an indication of the surface hardness of the specimen.

Common hardness tests include the Rockwell and Brinell. Other test procedures used include the scleroscope, surface abrasion testing, Vickers, and Tukon-Knoop. Information on the Rockwell and Brinell will be presented.

Procedures

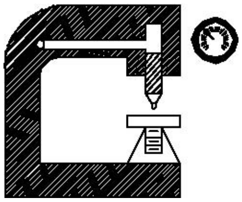
Brinell Test The Brinell hardness test is a static hardness test that involves pressing a hardened steel ball penetrator into a test specimen. It is customary to use a 10 mm, casehardened steel or tungsten carbide ball using a 3000 kg load for hard metals, a 1500 kg lo ad for intermediate hardness, and a 500 kg load for softer materials.

Various types of machines may be used for Brinell hardness tests. They vary according to 1) the method of applying the load (hydraulic, pneumatic, gear driven, or a system of levers, for example), 2) the method of operation (manual, automatic, computer-assisted), 3) the method of measuring the load (levers and weights, bourdon gauge, dynamometer), and 4) the size or capacity (portable, fixed). The Brinell test can be performed using almost any machine that can reliably deliver the specified load using the specified indenter, for example a universal testing machine could be used.

The test procedure involves placing the test specimen on the anvil and raising it by an elevating screw to contact the indenter. The load is then applied up to the specified load for the material. When the desired load is achieved, the load is maintained for approximately 30-60 seconds, depending on the material and condition of specimen. The diameter of the indentation is then either measured on the machine by measuring microscope with graduated scale, if the machine is so fitted, or removed to be measured remotely.
Once the indentation has been measured, a formula is used to calculate the Brinell Hardness Number (BHN).

$$= \frac{2\ L\ BHN}{pD\ (\ D\ -v(D^{2}\ -\ d^{2}))}$$

BHN = Brinell Hardness Number L = Applied Load D = diameter of ball penetrator D = diameter of indentation



Typical Brinell Test Setup

Rockwell Hardness Test

The Rockwell hardness test is similar to the Brinell in the fact that it relies on a specified load and the size of the indentation or penetration made to determine the hardness value. As in the Brinell, Rockwell hardness tests involve selecting the magnitude of the load to apply based on the suspected hardness of the specimen. Rockwell tests, however, use a variety of indenters, depending on the material and suspected hardness. The loads, indenters, and resultant indentations are generally smaller in the Rockwell tests than in Brinell tests.

The Rockwell hardness test provides more direct results. A specially designed testing machine is typically used and provides a dial reading for the Rockwell Hardness Number, so no special calculations or measurements are necessary.

In the Rockwell hardness test, the specimen is loaded on a platen and raised with an elevating screw to contact the indenter, the indenter having been selected for the material and hardness being scrutinized and previously installed in the testing machine. The indenter may be a 1/16 inch hardened steel ball, a 1/8 inch hardened steel ball, or a 120 diamond cone ground to a point, called a brale. Once the specimen is loaded, the platen is raised to contact the indenter to a specified set point on the machine's readout. This point is used to indicate that the minor load has been applied. By raising the platen and specimen against the indenter, a small, minor load drove the indenter into the specimen to initially set the indenter into the specimen. The minor load is typically 10 kg.

The major load may now be released to drive the indenter further into the specimen. Major loads typically range from 60-100 kg when the steel ball is used and 150 kg when the brale is used. Once the major load has been released, sufficient time is allowed for the dial to come to rest, generally between 30 and 60 seconds, depending on the material. The major load is then removed and the Rockwell Hardness Number read directly from the readout on the machine with the minor load remaining. This provides a value based on the distance the indenter was driven into the specimen by the major load. Once the reading is taken, the elevating screw is used to release the minor load and the specimen may be removed.

Rockwell Scales Scale Indenter Applied Load (kg) ***A*** Brale 60 ***B***
1/16-inch ball 100 ***C*** Brale 150 ***D*** Brale 100 ***E*** 1/8-inch ball 100
F 1/16-inch ball 60***G*** 1/16-inch ball 150

Typical Test Setup

Impact Testing

Introduction

As the velocity of a moving body is changed, a transfer of energy must occur; work is performed on the parts receiving the blow. The mechanics of the impact involve not only the question of stresses induced, but also a consideration of energy transfer and of energy absorption and dissipation. The energy of the blow can be absorbed: through elastic deformation of the parts of the system, through plastic deformation of these parts, through friction between parts, or through inertia of moving parts.

In the design of structures and machines, attempts are made to provide for the absorption of as much energy as possible through elastic action, relying secondarily on some form of damping to dissipate some of the energy. In impact testing, the object is to use the energy of the blow to rupture the test specimen.

The property of a material that relates to the work required to cause rupture is called toughness. Toughness depends chiefly on the ductility and strength of a material. Impact testing is an adequate measure of a material's toughness.

In performing an impact test, the load can be applied in flexure, tension, compression, or torsion. Flexure loading is very common; tension less common; and torsion and compression very seldom used. The impact blow can be delivered through dropping weights, a swing pendulum, or rotating flywheel, depending on the load applied. Some tests involve rupturing the specimen in a single blow while others involve repeated blows until rupture. In tests involving repeated blows, some involve multiple blows of the same magnitude while others involve gradually increasing either the size of the weight or the height of the drop--generally terms incremental drop tests.

Perhaps the most common impact tests are the Charpy and Izod impact tests. Both employ a pendulum and are made on notched specimens in flexure. In the Charpy test, the specimen is supported as a single beam, whereas in the Izod test, the specimen is supported as a cantilever beam. In these tests, a large portion of the energy absorbed is taken up in a region immediately adjacent to the notch. A brittle type of failure is often induced.

For wood, the Hatt-Turner test is used. Although not described in detail, this test is a flexural-impact test of the incremental drop type. The height of drop at which failure occurs is taken as a measure of the toughness of the material. From the data obtained, the modulus of elasticity, the proportional limit, and the average elastic resilience can be calculated or obtained from the graph.

Procedure

Items that require standardization in impact testing include the foundation, anvil, specimen supports, specimen, striking mass, and the velocity of the striking mass. Principal features of a single-blow testing machine include:

1 A moving mass whose kinetic energy is great enough to cause the rupture of the test specimen placed in its path,
2 An anvil and a support on which the specimen is placed to receive the blow,
3 A means of measuring the residual energy of the moving mass after the specimen has been ruptured.

The kinetic energy is determined from and controlled by the mass of the pendulum and the height of free fall from the center of the mass. The pendulum should be supported to reduce or restrain the lateral play and friction that may be felt as it swings in an arc toward the test specimen. The release mechanism should be constructed to reduce any binding, acceleration, or vibratory effects. The anvil should be heavy enough in relation to the energy of the blow to help reduce the energy lost as a result of deformation or vibration. The specimen should be supported firmly and in the correct position throughout the test.

Charpy Test

A Charpy test machine generally has a capacity of 220 ft-lb or more for metals and 4 ft-lb or more for plastics (ASTM E 23). The pendulum consists of a relatively rigid rod or piece of channel, which has a heavy weight at the end of it. The pendulum swings between two upright supports and has a knife-edge blade that is centered on the striking mass in order to strike the specimen over its full depth at the time of impact.

The standard Charpy test specimen is 10 x 10 x 55 mm, notched on one side of center. Some tests require keyhole notches; others U-shaped notches. The specimen is supported between two anvils so that the knife strikes opposite the notch at the midswing point. The pendulum is lifted to horizontal and held in place by the release mechanism. To perform the test, the release mechanism is used to release the mass and the mass is allowed to free-fall. During the swing, the mass will strike and rupture the specimen and allowed to climb through its arc until it stops and returns through the arc. The initial and final angles in reference to the center point of the arc are measured or the energy required read directly from the machine.

Izod Test

The common Izod machine is produced with a 120 ft-lb or more capacity. The test is similar to the Charpy test, with the chief differences being specimen placement and specimen features. In the Izod test, the specimen is 10 x 10 x 75 mm, having a 45° notch cut 2 mm deep off center. The impact strength can be determined from the angle of rise after rupture.

Specimens

55 mm

10 mm

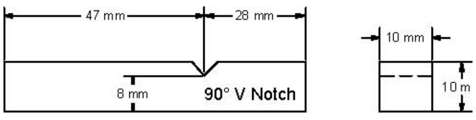
10 mm

R0.25 mm8 mm 10 mm27.5 mm

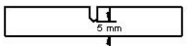
10 mm 10 mm

(a) V Notch

→← 2 mm



Typical Izod Metal Specimen

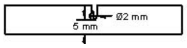


Hammer

10 mm

(b) U Notch

10 mm



Hammer

Typical specimen

10 mm

configuration for

(c) Keyhole Notch

Charpy test Typical Charpy Metal

Test Specimens

Typical specimen configuration for Izod test

Data

Data collected during an impact test include: the type and size of specimen, including the type of notch; the amount of energy absorbed and an estimate of the amount of energy lost for to friction and other effects; the shape, type, and texture of the fracture; and the number of specimens failing to break and proposed reasons for non-breakage.

Results

The energy required to rupture a specimen could be calculated using the following formula:

E = w*r(cosß - cosa) or E = m*g*r(cosß - cosa) [metric]

E = energy required to rupture the specimen in ft-lb or N-m w = weight of pendulum in pounds m = mass of pendulum in kilograms g = gravity - 9.8m/s^2 r = length of pendulum in feet or meters a = angle of fall (initial angle) ß = angle of rise (final angle)

Fatigue Testing

Introduction

Most structural assemblies are subject to variations in applied loads, causing fluctuations in the applied stresses in component parts. If these fluctuations are of sufficient magnitude, even though they may be considerably less that the static strength of the material, failure may occur when the stress is repeated enough times. The type of stress, frequency, and magnitude would all be factors.

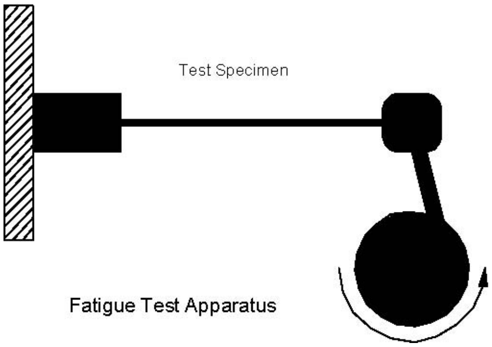
The stress required for fatigue failure should be designated by degree of stress variation and type of stress. The stresses may be axial, shearing, torsional, or flexural, typically. The stress at which a material fails by fatigue is called the fatigue strength. The limiting stress, below which a load can be repeated indefinitely without causing failure, is called the endurance limit.

Fatigue tests are long-term tests, over months or perhaps years. They are, therefore, generally not used for quality control or inspection because of the time involved and effort required to collect the necessary data.

Procedure

The general procedure for fatigue testing is to prepare several representative specimens. The first specimen is treated with a high amount of stress so that it rapidly fails. The second specimen is subjected to less stress, again until failure. This procedure continues with each additional specimen being subjected to less stress until the endurance limit is reached and the specimen does not fail. A plot can then be made, showing the maximum stress applied versus the time or number of cycles required to fail.

Typical Test Setup



Laboratory Reports, Homework, Research, and Projects

TED 226-PROJECT EVALUATION FORM

NAME___________________________________ DATE_____________________________________

PROJECT TITLE____
1 How closely do the final dimensions fit the original specifications? (10 pts) __________
Simply, how well you followed directions and completed the project as specified.
Comment:

2 Technical correctness of the processes used. (10 pts) __________
Missing items, poor skills development, obvious lack of understanding of the processes.
Comment:

3 How closely does the project fit the given instructions? (5 pts) __________
Comment:

4 Overall appearance. (5 pts) __________
Comment:

5 Laboratory report: completeness and correctness. (20 pts) __________

Lab report should include:

Introduction: Name, Class Info, Title, Date

Objective: What you expect to learn/teach with the project.

Procedure: Itemized step-by-step procedure for completing the project.

Drawing: Detailed, Descriptive, and Dimensioned so that anyone looking at the drawing can complete the project accurately and completely from the information provided.

Conclusion: Did you or did you not meet your objective and why or why not?

Comment:

Material Testing Laboratory Report

Don't forget to put your name on the report.

TITLE: Should be descriptive and refer to the material.

DATE: Date of test.

ORIGINAL DIMENSIONS: Values that are pertinent to the test.

OBJECTIVE: What was the purpose of doing the test? What skills are gaining by performing the test? How will you apply this to other materials and situations?

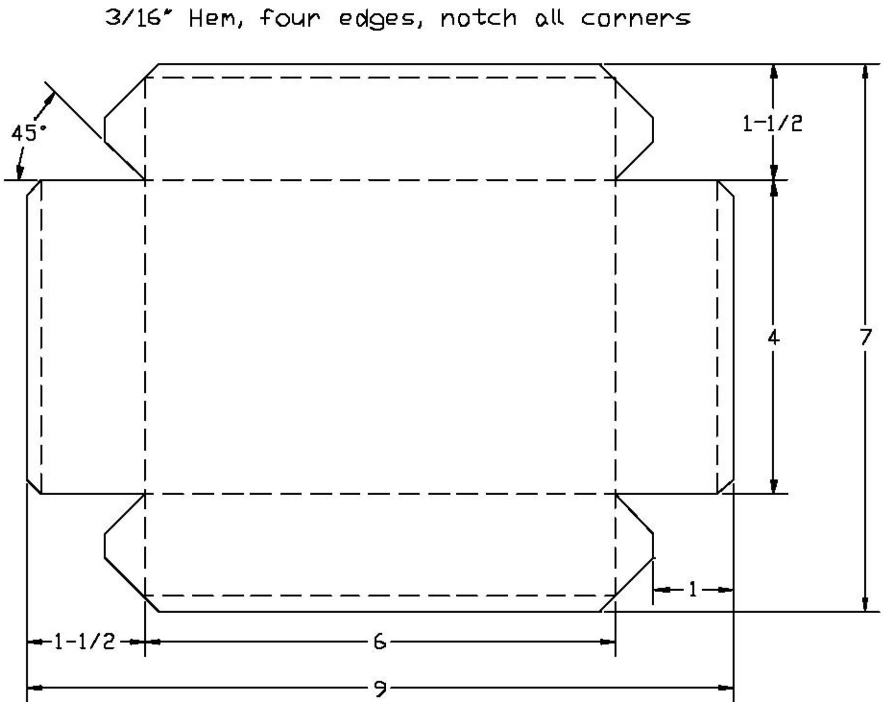
ASTM SPECIFICATION: Appropriate American Society for Testing and Materials Standard

REQUIRED EQUIPMENT: Machine, fixtures, instrumentation, tools, specimen, etc.

PROCEDURE:	List, in numerical order, alphabetical order, or flowchart, the steps required performing the test, including all inspection items, safety items, concerns, and cautions.
DATA:	Collected information from the test, including applied load, change in length, resultant values, quantifiable or measurable item.
RESULTS:	In graph and tabular forms, present the results of conducting the test, including recommended calculations. For the tensile test, these would include proportional limit, yield point, yield strength, ultimate strength, modulus of elasticity, and rupture strength. For compression, simply ultimate strength, rupture strength, and modulus. For flexure/bending, the ultimate strength and rupture strength. For impact and hardness, provide the value given. In addition, provide any conclusions you can draw from the test and data collected; typify the fracture according to type and condition; and troubleshoot any possible errors that might have occurred to alter the test conditions.

Projects

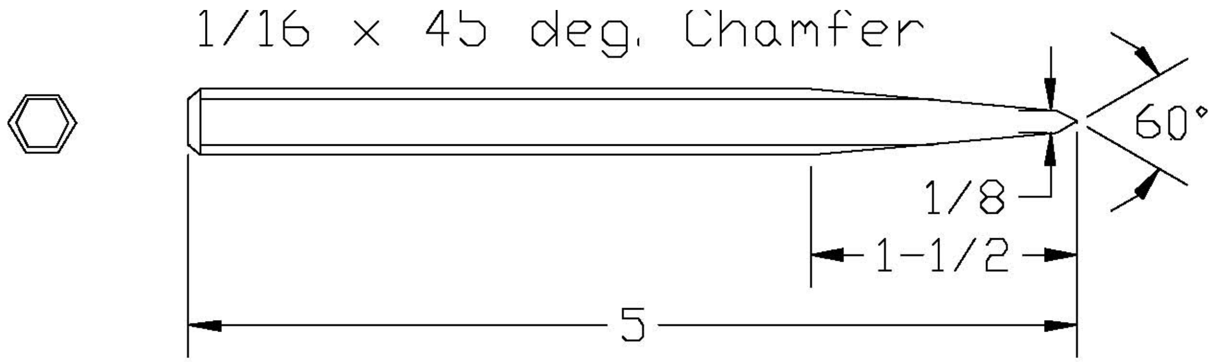
Utility Tray



Procedure:

1 Using a 7" x 9" blank cut using the squaring shears, lay out the project described above.
2 Cut on layout lines and notch all corners using snips.
3 Remove all burrs and rough edges with a file.
4 Hem all four sides using the bar folder at 3/16".
5 Bend the two shorter sides and tabs up to 90 degrees using the box and pan brake.
6 Bend the remaining two sides up, keeping the tabs on the outside.
7 Punch two 1/8" holes in any two corners using the tinner's hand punch.
8 In any order, install one "pop" rivet using the rivet gun, cold form one tinner's head rivet, spot weld one corner, and solder the remaining corner. [Four processes, four corners].
9 Clean the body of the utility tray using steel wool, soap and water.
10 Submit for grading along with lab report.

Chisel

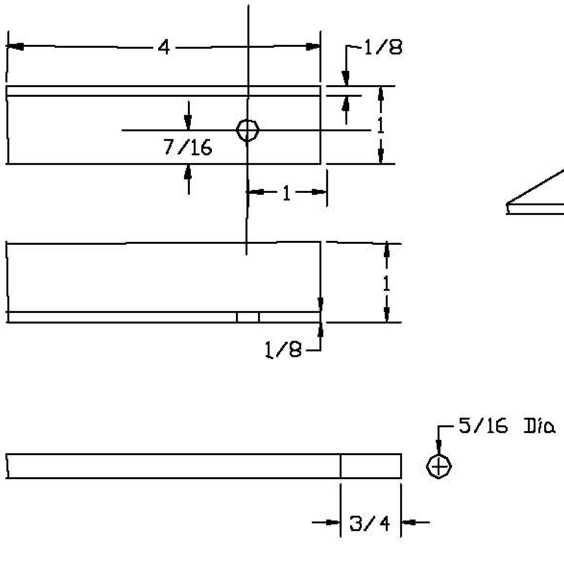


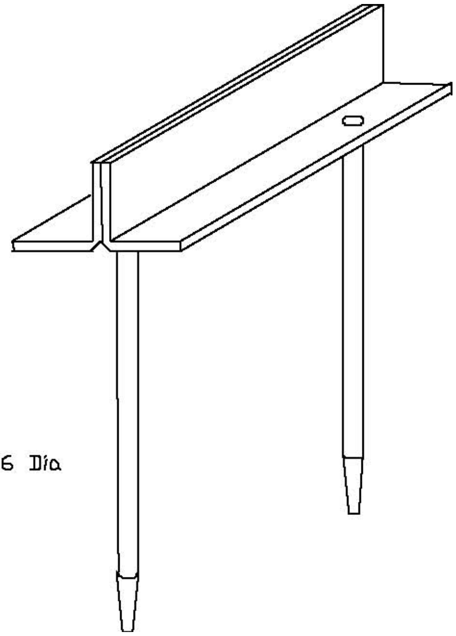
3/8" Hexagon Tool Steel
Blank Length - 4-3/4"

Procedure:

1 Obtain blank stock.
2 Cut to 4-3/4” blank length.
3 Stamp initials in one end.
4 Mark the limit of the 1-1/2” tapered section using a prick punch.
5 Using the gas forge, heat the end of the chisel to be tapered to the forging temperature (bright red).
6 Begin the tapering process on the end opposite the stamped initials.
7 Forge the faces and edges alternately, keeping the edges parallel while the stock remains at the forging temperature. Do not work the material after the color has gone.
8 Taper until the stock is 1/8” thick at the tip.
9 Normalize the forged end of the product by heating it above the critical temperature (bright red) and permitting it to cool slowly by placing it in the sand pit.
10 Grind the edge and chamfer.
11 Heat approximately one-half of the chisel above the critical temperature (bright red) then rapidly quench in water or oil. This fully hardens the chisel.
12 Clean or shine the taper.
13 Re-heat the taper to 400-500 degrees or a light blue. As the color climbs up the taper, remove the chisel once the blue color has reached the top of the taper. Tempering improves the toughness of the chisel.
14 Test the chisel by cutting a piece of mild steel.
15 Leave the blue coloring, clean up, and submit for grading.

Boot Scraper

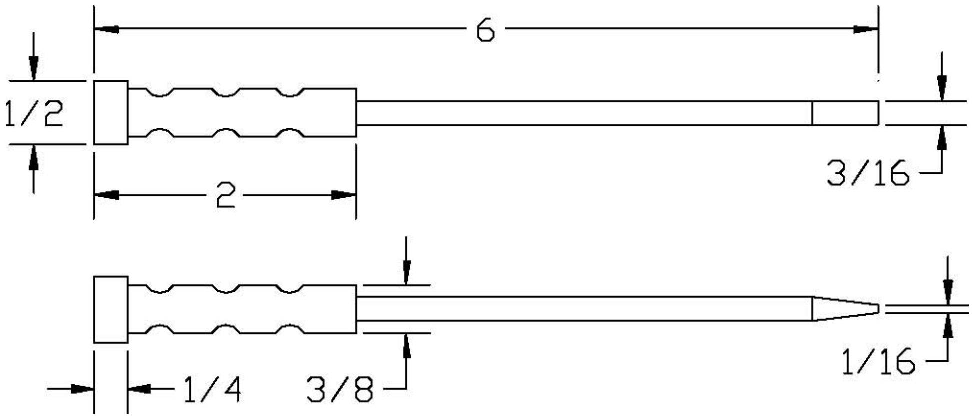




Procedure:

1 Obtain blank stock. 1” x 1” x 1/8” angle iron and 5/16” round legs.
2 Cut two pieces of angle iron, 4 inches long.
3 Cut two pieces of round stock, 5 inches long.
4 Remove all rough edges.
5 Grind two chamfers on the inside, mating edges of the angle iron pieces for welding clearance.
6 Drill two holes (9/32”), 1” from the end and 7/16” from the edge. One per angle iron piece.
7 Punch a mark ¾” from one end of each leg, marking the end of the taper.
8 Turn the taper of each leg on the engine lathe.
9 File a bevel on the other end of each leg so that it fits flush with the top of the hole drilled in the angle iron.
10 Place the upright faces of the angle iron together and clamp solidly together.
11 SMAW the two angle iron pieces together by filling in the clearance ground in the mating edges.
12 OAW the tops of the two angle iron pieces ¾” in from both ends.
13 Braze two legs in from the top of the two holes in the angle iron.
14 Clean all surfaces.
15 Submit for grading.

Screwdriver



Procedure:

1 Obtain blank stock (3/16”).
2 Cut stock to length, 6”.
3 By cold forming, taper one end of the shaft to 1/6” while maintaining parallel edges.
4 Flatten the other end so that the handle has something to grip.
5 Using pre-heated injection molder filled with polystyrene beads, place the shaft in the mold.
6 Once properly located in the machine, rapidly pull the handle of the machine to fill the mold cavity.
7 Hold the handle at the bottom of the stroke for 5 seconds.
8 Return the handle to the starting position.
9 Remove mold from machine.
10 Remove screwdriver from mold.
11 Clean flash from handle.
12 Submit for grading.

Research Questions

TED226- Dr. Larry Horath

I. Bio-technology

A. Select a bio-related technology and discuss the ethics associated with its development.
B. In the area of bio-medical research, discuss how technology has improved the quality of life.
C. Discuss the future applications of cloning and the reasons for pursuing or NOT pursuing them.
D. Discuss how technology has been used to enhance peoples' abilities.

II. Communication

A. Discuss the uses and abuses of the Internet.
B. Select an application of virtual reality and its possible future developments.
C. How has technology affected language and its use in communications?
D. Discuss how technology has and will be used to assist the visual, hearing, and speech-impaired.
E. Describe the impacts that communication technology has had on global economics.

III. Construction

A. Describe how and what you would use to construct a future space station to hold a colony of 500 people.
B. Given the limitations of aboveground construction, describe how you would develop underground cities.
C. Discuss how technology can be used to make structures less susceptible to earthquake damage.
D. Describe the applications of advanced technical materials, such as polymers, composites, and engineered lumber, in construction.
E. Discuss how technology is used to help ensure the safety of the worker.

IV. Manufacturing

A. Define the terms quality and value as they relate to manufactured goods and services.
B. Define manufacturing. Give three examples of the use of technology in manufacturing.
C. Does technology replace employees? Defend your answer.
D. Is the United States the world's manufacturing leader? Why or why not?
E. How has technology affected manufacturing in terms of quality, cost, production, and labor?

V. Transportation

A. Describe the pros and cons of current transportation systems under development, which use renewable energy sources.
B. Technology has increased the speed and reliability of personal transportation. What have been the effects of these advancements on society?
C. Discuss the advantages and disadvantages of public mass transportation systems.
D. Describe three methods of transportation and the effects technology has had on each.
E. What do you feel is currently the safest mode of transportation? Why?

Homework Assignment

NAME______________________________________

1 All atoms are made up of three basic components. Name them and describe their function.
2 Briefly define the term valence and how it relates to materials.
3 Name the three basic types of atomic bonding.
4 How does the type of bonding influence the properties of materials?
5 Define the terms stress, strain, elongation, yield and strength.
6 Explain the terms atom, compound, alloy, molecule and mixture. Give an example of each.
7 What is the name of the furnace that first made possible the smelting of iron in a molten state? What product is made in this type of furnace?
8 What three raw materials are used to produce pig iron?
9 Why is cast iron a poor material to use for making cutting tools such as knives?
10 What are the upper and lower limits of carbon content for steels?
11 Name three modern types of steel making furnaces.
12 What is the difference between elasticity and plasticity? Give an application, which requires each.
13 How can nonferrous metal alloys such as aluminum be hardened?
14 From what raw materials are most plastics derived?
15 What is the source of natural rubber?
16 What is the major difference between thermoplastic and thermosetting plastics?
17 Describe the common classification system used to identify alloys steels. Give an example.
18 List three common que nching media and give an advantage of each.
19 What are the alloying elements of stainless steel? What advantages do these provide?
20 Describe the process for refining pure copper from ore.
21 Which type of casting process requires melting the pattern to remove it?
22 How does molten metal get from the furnace to the mold?
23 Threads are often designated without tolerances. What is the meaning of the designation 1/4-20UNC? 1/4-24UNF?
24 What are three advantages and three disadvantages of using plastic materials over metals?
25 List three major methods of producing finished plastic parts. Give examples for each.
26 Describe the anodizing process.
27 Describe the galvanizing process.
28 List three different methods of applying paint finishes.
29 What are technical ceramics and what are three primary applications?
30 What are the major components of concrete? What are the primary applications of concrete materials?

Study Guide Questions

Materials - Introduction

List common properties that are important in selecting materials and the reasons you think these properties are important.

How does atomic bonding affect properties?

Describe five applications that owe their development to new materials.

List five applications where a traditional material has been replaced by a newer material or process. Provide the reason(s) you believe the material was replaced.

Provide a complete specification for a bookcase, particularly materials, hardware, manufacturing processes, coatings and finishes, and other such details.

Describe in your own words the differences between quality and value.

Ferrous Metals

List five applications that you encounter every day that use ferrous metals and the reason(s) why these metals were chosen for each application. Can you think of a better material for the application?

Select a common product made from cast iron, steel, or stainless steel and produce a flowchart that illustrates how that product was produced from raw material to finished goods.

Referring to the Iron-Carbon Phase Diagram, why do you think it is shaped the way it is? What factors influence the distinctive points on the diagram?

How do you think alloying affects the Phase Diagram for ferrous metals?

Again referring to the Phase Diagram, analyze the grain structure of the major formations. What influences do grain structure make on the properties of ferrous metals?

Why is the Time-Temperature Transformation Curve shaped the way it appears? What influences the shape of these curves?

Why is time important in the transformation of steels both in hardening and softening procedures?

Nonferrous Metals

What factors influence the selection of nonferrous metals?

In general, what advantages do nonferrous metals offer over other metals?

Select a product made from a nonferrous metal and flowchart how that product was produced from raw material to finished goods.

Explain the solution hardening of nonferrous metals. How does solution hardening influence the properties of the metal?

What other methods of heat treatment are available for nonferrous metals? Can you think of different methods of influencing nonferrous metal properties?

Glass and Ceramics

Is glass a liquid or a solid? Support your answer.

Can glass be alloyed? Why or why not?

List five applications of glass and provide the type most likely selected for each application.

What other materials are used as substitutes for glass?

How and why is glass tempered?

List five structural/industrial applications for ceramics. Why were these ceramics chosen for each of these applications?

What unique properties do ceramics have?

Select a product made from ceramics. Flowchart the process used to produce the finished product from raw materials.

What other materials can be substituted for ceramics?

Cement, Concrete, and Asphalt

List five applications of concrete that you encounter in everyday life.
What other materials may be substituted for concrete in these applications?
You are pouring a concrete pad for a 24' x 32' garage at a 4" depth. Determine the amount of concrete needed and fully specify the concrete batch to be delivered.
List an application for each type of Portland cement and the factors that go into your selection.
What factors do you think go into the selection of aggregates for concrete? How do you think these selection criteria influence the properties of the concrete product?
Why is concrete so prevalent as an engineering material?
What advantages and disadvantages do asphalt and its products present? How do these influence its selection as an engineering material?
Asphalt is commonly used as roofing and paving material. What substitutes can you recommend for these applications?

Plastics

List five common applications of plastic products.
What factors influenced the selection of the polymers used in these applications?
Take five common plastic products and describe the processes used to make these products.
The substitution of plastics for metals in traditional applications continues to grow. Name five recent applications where plastics have replaced metals.
What properties do plastics exhibit that are advantages and disadvantages to metals?
Do polymers have a crystalline structure? If so, how does this type of structure influence the plastics properties?
What applications are there for crystalline polymers?
Why are tires made of "rubber"? Are there substitutes that could be used? Why or why not?

Wood and Composites

List five common applications of composite materials.
Of these applications, how many are "new" applications and how many have used composites as a substitute for another material? What material was replaced in these applications?
What factors influence the decision to select a composite for an application?
Why is wood and lumber so widely used in the construction industry?
Are their substitutes for wood in construction? List these and provide advantages and disadvantages for each.

Adhesives and Coatings

Look around you and describe five applications each for adhesives and coatings.
Write a specification for plywood adhesive. Be as specific as possible.
Describe the difference between adhesion and cohesion.
Describe, in your own words, the purposes of paints and applied coatings.
Referring to your list of purposes, write a specification for the coating you described.
List five applications for inorganic coatings, such as platings, enamelings, oxides, and other such coatings.

Fuels and Lubricants

Describe three applications for each of the following: 1) solid fuels, 2) liquid fuels, and 3) gaseous fuels.
You are interested in locating fuel reserves for your investors. Describe the process by which you would locate 1) coal, 2) oil, and 3) natural gas reserves in the United States.
Describe three applications for each of the following: 1) oils, 2) greases, and 3) solid lubricants.
In each of these applications, describe the factors that influenced the selection of that particular lubricant, in terms of service conditions, viscosity, environment, and such factors.
Why do some fuels have higher heat values than others? What makes a better fuel?

Testing - Introduction

Take a common product or process that is measured (fuel, food product, time, speed, distance, etc.) and describe how the terms accuracy, reliability, and precision relate to their manufacture or performance.

Measure the length and width of a room using three different methods: 1) placing one foot in front of the other and stepping it off, 2) using a one-foot ruler, and 3) a tape measure. In terms of accuracy, reliability, and precision, describe how these factors were important to your measurements. How could you better plan and execute a measuring plan to reduce the errors in your measurements?

Products are generally tested according to a sampling plan: 1 out of 10, 5%, first three out of each new batch, and so forth. What questions or concerns would you have regarding the sampling plan involving: medical supplies and equipment, public transportation (aircraft, bus, subway, etc.), and other critical areas?

Write a sampling plan for a child safety seat. Defend you plan and describe the probability of an error passing through to the customer. What steps could be taken to prevent this from happening?

Often, physical and chemical properties are given numerical values for analysis. List five features, attributes, or characteristics that are important in material selection, but are not quantifiable or best not quantified.

Describe five applications where elasticity is a major factor.

Describe five applications where plasticity is a major concern.

Tensile Testing

Provide five applications each where an object is under: 1) tensile stress, 2) compressive stress, 3) direct shear stress, 4) torsional stress, and 5) flexural stress.

Describe three applications where tensile strength is the primary factor in material selection. What material would you select for that application and why?

What design considerations are important to applications involving tensile loading?

Describe the shape of a tensile stress-strain curve for: 1) a ductile material and 2) a brittle material.

Develop and describe your own tensile test procedure for testing shoelaces.

Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Creep Testing

Describe three applications where creep is the primary factor in material selection. What material would you select for that application and why?

What design considerations are important to applications involving creep?

Describe the expected creep rates for various materials. Which would you expect has the lowest creep rate? The highest?

Develop and describe your own creep test procedure for testing glass. Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Compression Testing

Describe three applications where compressive strength is the primary factor in the application. What material would you select for that application and why?

What design considerations are important to applications involving compression loading?

Describe the shape of a compressive stress-strain curve for: 1) a ductile material and 2) a brittle material.

Compare the similarities and differences between tensile and compressive testing.

Develop and describe your own compression test procedure for a tennis ball. Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Shear Testing

Describe three applications each where direct and torsional shear strength is the primary factor in the application. What materials would you select for these applications and why?

What design considerations are important in applications involving shear testing?

What efforts can be made to increase shear strength using the same material in an application?

Develop and describe your own direct shear test procedure for testing paper and cardboard. Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Bend or Flexure Testing

Describe three applications where flexure strength is the primary factor in the application. What material would you select for that application and why?

What design considerations are important in applications involving flexure loading?

Describe the shape of a flexural stress-strain curve for: 1) a ductile material and 2) a brittle material.

Develop and describe your own flexure test procedure for testing bookshelves. Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Hardness Testing

Describe three applications where hardness is the primary factor in material selection. What material would you select for that application and why?

What design considerations are important in applications relying on material hardness?

Develop and describe your own hardness test procedure for testing coins. Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Impact Testing

Describe three applications where impact strength is the primary factor in material selection. What material would you select for that application and why?

What design considerations are important in applications involving shock loading or impact strength?

Develop and describe your own impact test procedure for testing eyeglasses. Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Fatigue Testing

Describe three applications where fatigue strength is the primary factor in material selection. What material would you select for that application and why?

Describe the shape of the fatigue curve for: 1) a ductile material and 2) a brittle material. What would be your expectations in curve shapes for: a) plastics, b) ceramics, c) wood, and d) composites.

Develop and describe your own fatigue test procedure for testing metal wire. Describe the test setup, grippers, extensometer, loading concerns, data collection, and expected results.

Nondestructive Testing

List five applications where nondestructive testing is preferred or required.

Describe a testing application requiring each of the following: 1) X-rays, 2) acoustic waves, 3) magnetism, 4) liquid penetrant, and 5) visual inspection.

Develop and describe your own nondestructive test procedure for testing soda pop. The test should evaluate the fluid level, the pressure inside the can, and presence of foreign objects. Describe the test setup, grippers, equipment used, data collection, and expected results.