Molding Materials and Process Troubleshooting

LESSON 1: Plastic Material Properties

Lesson 1: Plastic Materials and Their Properties

The strength, hardness, clarity, and durability of each plastic resin are different. Every day, chemists and engineers are hard at work developing new resins with better properties and lower costs. In this lesson we will discuss some of the most common plastic resins you are likely to encounter.

Objectives of Lesson 1

1. Learn about the composition of plastics
2. Learn about commodity plastics
3. Learn about engineering plastics

Objective One

What is Plastic?

Plastic is a material manufactured from some of the earth's most basic elements. Some of the most common elements are carbon, hydrogen, oxygen, nitrogen, chlorine, fluorine, silicon, and sulfur. The properties of a plastic resin are determined by its elements and how they are arranged. Almost all plastics contain long chains of carbon. Plastic resins get their different properties from the other attached elements, and the structure of the chains.

All plastics are capable of being melted into a liquid and formed into shapes under pressure. Although molten plastic may look like a liquid, you should think of it as a collection of very long strings or chains. Some of these chains are connected to each other at the sides. Others are not connected at all, but intertwined. The length and structure of the chains determines how the plastic will behave after it is molded.

Monomers and Polymers

A monomer is a small organic molecule. In the plastics industry, monomers usually come from the by-products of oil or natural gas. Monomers are the building blocks of plastics. Chemists join monomers together in long chains called polymers. Figure 1 shows a monomer of Polyethylene.

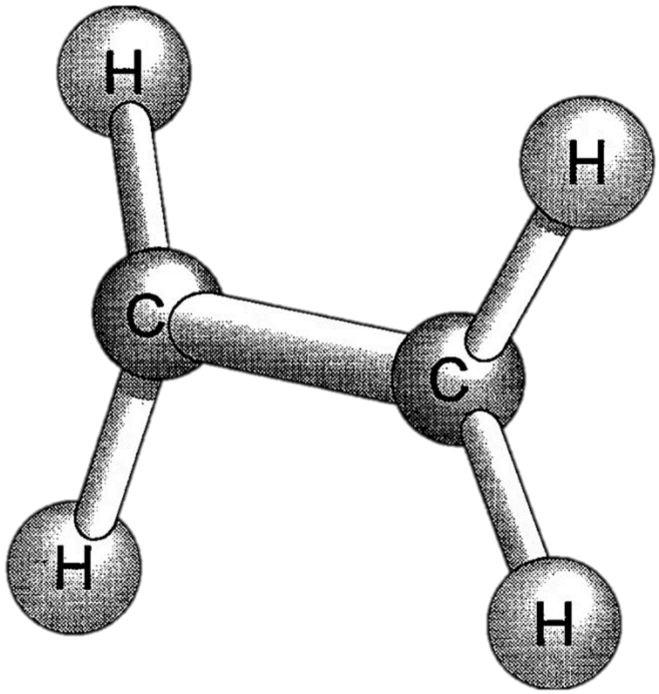

Figure 1 - PE Monomer

The typical polymer chain has between 1,000 and 10,000 monomer units. The length and structure of the chain determines the properties of the plastic. In general, the longer the chain, the stronger and tougher the plastic. Figure 2 shows a segment of a polyethylene polymer chain, which is a series of linked monomers.

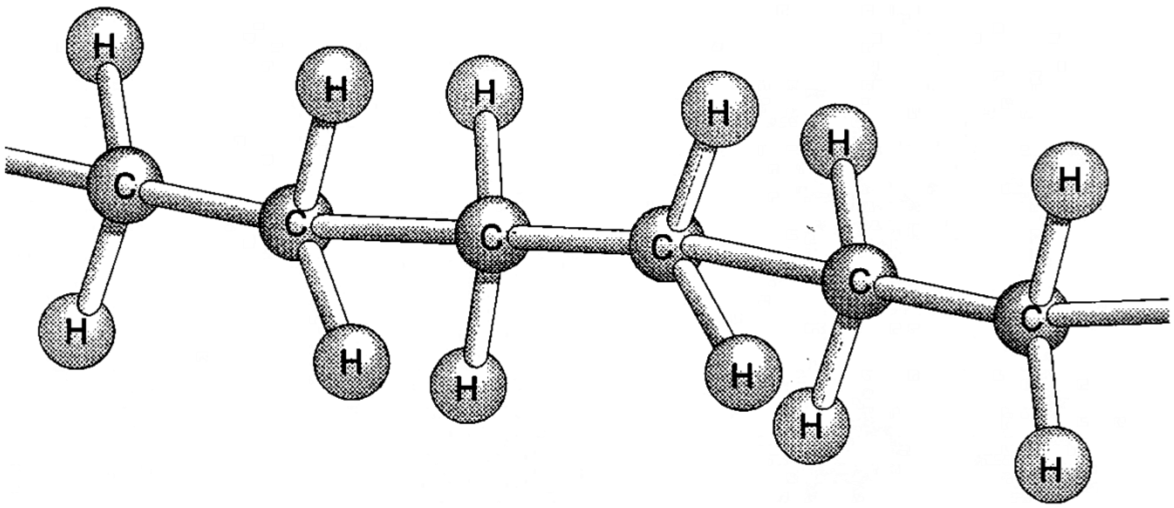

Figure 2 - PE Polymer Segment

Thermoplastics versus Thermosets

In general, plastics are divided into two families, thermoplastics and thermosets.

Thermoplastics are materials that can be melted and re-melted. Thermoplastics do not have connections between their chains of molecules.

Scrap parts made from thermoplastics can be re-melted and made into new parts. The majority of injection molded plastics are thermoplastics. A popular analogy is to think of thermoplastics as being like wax (Figure 3). Wax can be melted and shaped after cooling. If the shape is not right, the wax can be re-melted and formed into a different shape.

Figure 3 - Thermoplastics are like Wax

Thermosets are plastics that cannot be re-melted. Thermosets have strong connections between their chains of molecules. Heating and shaping a thermoset plastic resin creates a chemical reaction between the chains that cannot be reversed. Scrap parts made from thermosets cannot be re-melted, they must be discarded.

A popular analogy is to think of a thermoset plastic as a hard-boiled egg (Figure 4). Boiling an egg turns it into a solid shape farmed by the shell. A hardboiled egg cannot be re-melted.

Figure 4 - Thermosets are like Hard Boiled Eggs

Molecular Weight

Plastic resins are made of long chains of carbon, hydrogen, and other elements. The molecular weight of a plastic is largely a measure of the length of the chain. The number of elements in the monomer also contributes to the plastic's molecular weight.

Plastics are often rated and compared by their molecular weight. Most plastics are available in different grades, with different molecular weights. A plastic's molecular weight helps determine some of its properties. Longer molecules make stronger plastics.

In general, the higher the molecular weight, the higher the viscosity. So, a plastic made with longer chains, such as the first plastic in Figure 5, will not flow as easily as one with shorter chains, such as the second plastic in Figure 5.

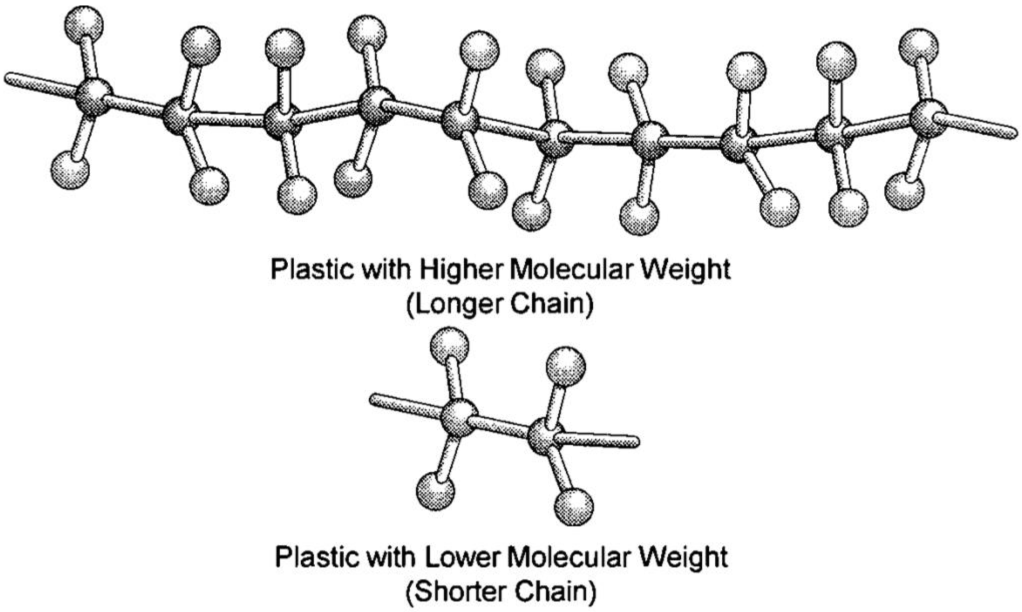

Figure 5 - Plastic Molecule Chains

Engineers choose plastics based on their viscosity and their molecular weight. For example, designers usually choose plastics with low molecular weight, and lower viscosity, for margarine tubs. Margarine tubs have thin walls that are hard to fill. It would be hard to get thicker, high viscosity plastic to flow well into the thin walls of a margarine tub. Plumbing pipes, however, can be made from high molecular weight plastic. Plumbing pipe is thick walled and easier to fill.

Copolymers

Sometimes monomers from two different plastics can be con-nected in the same chain. A chain made of links from two different monomers is called a copolymer. The copolymer plastic usually ends up with the combined properties of its constituent plastics.

The most common copolymer is ABS, Acrylonitrile Butadiene Styrene. ABS is actually a blend of three monomers. Technically, it is a terpolymer, meaning it is made from three monomers. The combination of properties from three different monomers makes ABS a very versatile plastic.

Alloys

Alloys are physical mixtures of two plastics. The plastic alloy usually inherits properties from both its constituents. Some common alloys blend two very different types of plastic to try to keep the best properties of both. One approach is to blend an amorphous plastic with a crystalline plastic. The result will be an alloy with the good chemical resistance of the crystalline plastic, combined with the impact resistance of the amorphous plastic.

Alloys often need special handling to keep them from breaking down into their separate components during processing.

Exercise One

Plastic Types

Find three types of plastic in your shop. Is it a thermoplastic or a thermoset? Is it a pure polymer, a copolymer, or an alloy?

Plastic	Polymer	Copolymer	Alloy

Instructor Date

Crystalline versus Amorphous Structure

As groups, crystalline and amorphous plastics have different properties. Crystalline plastics tend to form more structured chain patterns. The chains of molecules want to line up in patterns. Amorphous plastics have a random molecular structure.

Crystalline Plastic Properties

Cloudiness

The different layers of chain patterns tend to line up and block light. Crystalline plastics are not as transparent as amorphous plastics. In their natural color, crystalline plastics are cloudy and translucent or opaque.

Transparent means light goes through the plastic easily. You can clearly see through to the other side. Translucent means some light goes through the plastic, but you cannot see clearly through the plastic. Opaque means almost no light goes through the material at all. You cannot see through opaque plastic. Figure 6 shows transparent, translucent, and opaque plastics.

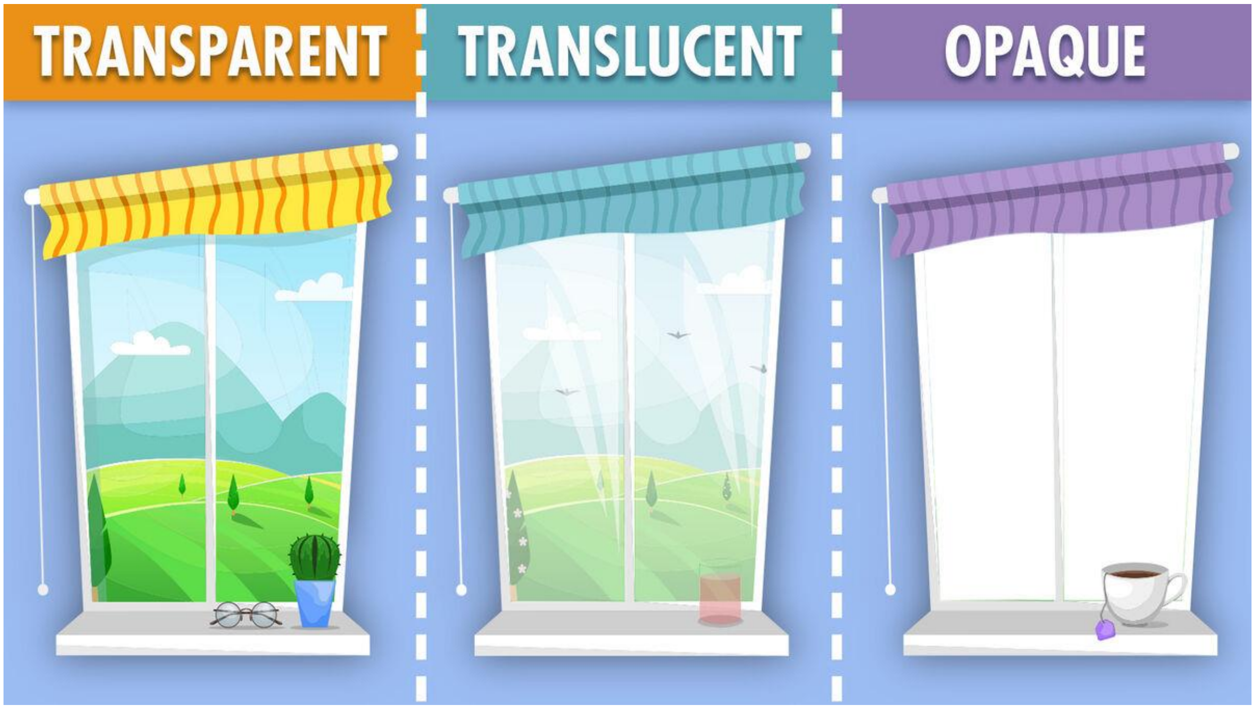

Figure 6 - Transparent - Translucent - Opaque

Narrow Melting Point

Crystalline plastics act much like metals. They go quickly from a solid state to a molten state very close to their melting point. Crystalline plastics also solidify quickly. A small change in temperature can radically change the plastic's resistance to flow. Therefore, it is more difficult to use viscosity to change the molding process when using crystalline plastics.

High Shrinkage

Melted crystalline plastics do not have the ordered pattern of long chains. When a crystalline plastic solidifies and cools in the mold, the chains try to go back to their more compact, ordered structure.

Crystalline plastic parts shrink a great deal in the mold. Most crystalline plastics shrink between .015 and .035 inches per inch. Crystalline parts are also more likely to warp as they shrink than amorphous plastics.

Good Chemical Resistance

The closer packing of the crystalline layers causes a greater attraction between the chains of molecules. This makes the plastic more resistance to chemical attack. Most under-the-hood car parts, such as the automobile battery in Figure 7, are made of crystalline plastics because of their resistance to oil and gasoline, and other chemicals like battery acid.

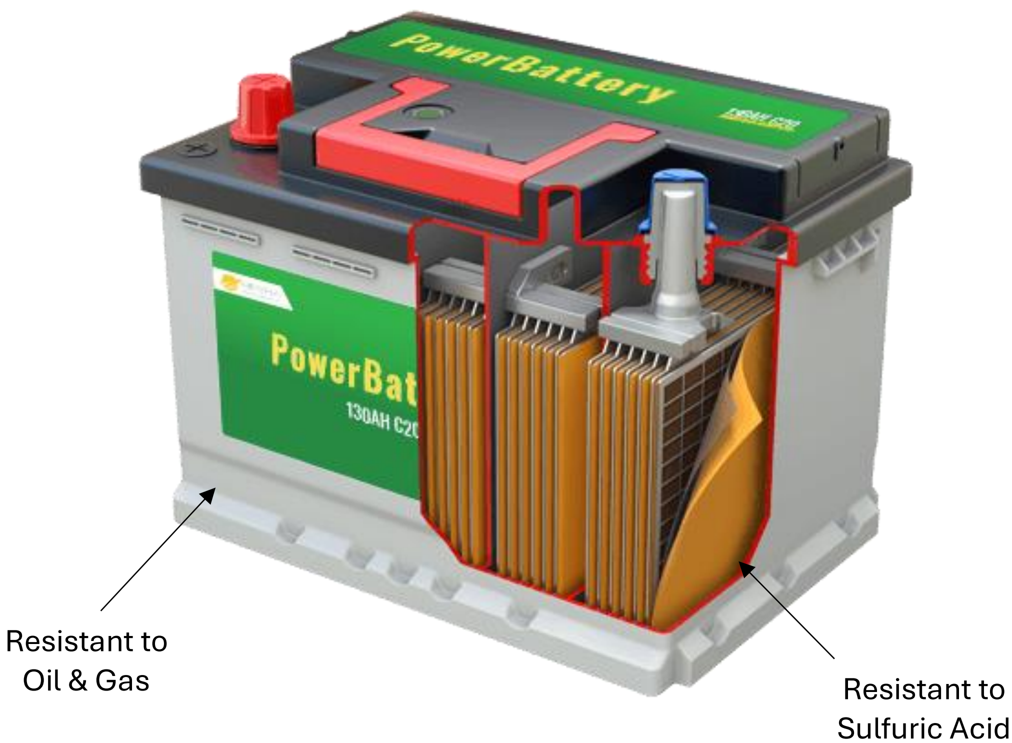

Figure 7 - Car Battery

Naturally Slippery Surface

Crystalline plastics have inherently low surface adhesion. This means the surface of a molded part is naturally slippery. Most plastic gears, bushings, and slides are made of crystalline plastics. The most common crystalline plastics are nylon, polypropylene, acetal, polyethylene, and polyesters.

Amorphous Plastic Properties

Transparency

With a loose, random structure, light can easily pass through amorphous plastics. Fillers, additives, and colorants usually make amorphous plastics opaque. In their natural state, most amorphous plastics are very transparent. Molded lenses and glasses are made from amorphous resins.

Low Shrinkage

Unlike crystalline plastics, the molten amorphous plastic does not have to reform ordered chains as it cools. Therefore, amorphous plastics tend to shrink very little as they cool. Amorphous plastics will generally shrink between .004 and .008 inches per inch.

Wide Melt Range

Amorphous plastics are inherently more viscous than crystalline plastics. Also, their viscosity changes over a much wider melt range than crystalline resins.

Therefore, it is easier to control the viscosity using only tempera-ture. This makes amorphous plastics more flexible to process. Figure 8 illustrates how anamorphous plastic's viscosity changes over a wider melt range than a crystalline plastic's viscosity. The most common amorphous plastics are polystyrene, polyvinyl chloride, polycarbonate, ABS and PPO.

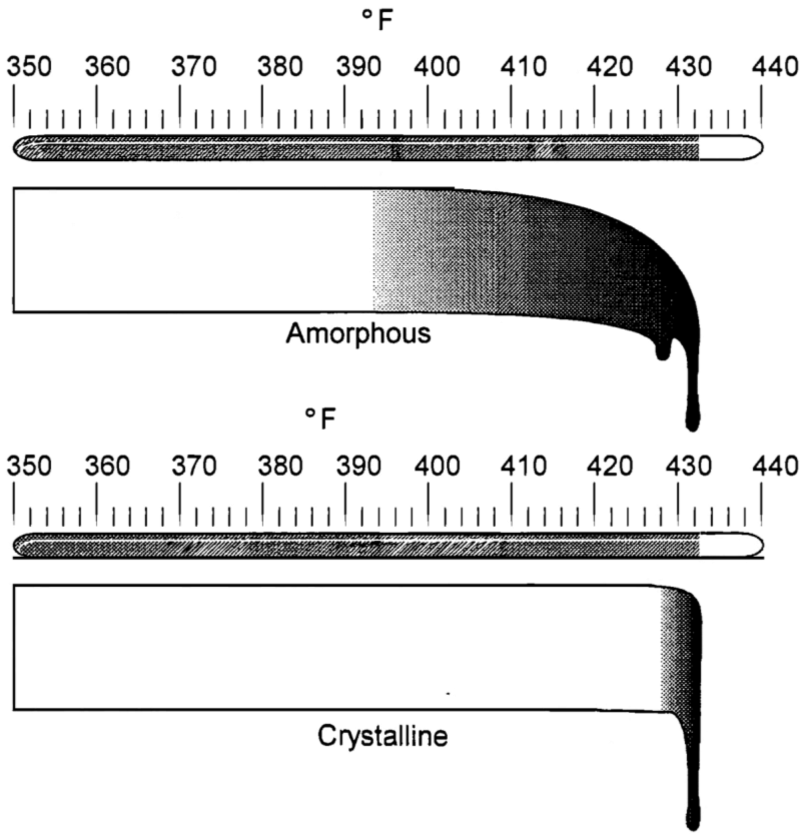

Figure 8 - Melt Ranges

Exercise Two

Polymer Properties

Identify a polymer in your shop. Use the box below to list its properties

Property	Description
Polymer Name	
Cloudiness	
Melting Point	
Shrinkage	
Chemical Resistance	
Heat Resistance	

Instructor   Date

Objective Two

Volume Plastics

Volume plastics are the least expensive group of plastics. They make up over seventy percent of the volume of all the plastics produced in the world. Generally, volume plastics are inexpen-sive, easy to process, and readily available in bulk forms.

Polypropylene

Polypropylene (PP) is a semi-crystalline plastic. It is often used to make battery cases, bottle caps (such as the one in Figure 9) and interior car parts. Polypropylene is harder and more heat resistant than polyethylene. It is highly resistant to chemical attack. Polypropylene is rigid and lightweight. It makes excellent integral hinges.

Figure 9 - Bottle Caps

Polyethylene

Polyethylene (PE), a semi-crystalline plastic, is one of the most common plastic resins used today. It comes in two major forms: high density and low density. High Density Polyethylene (HDPE) is often used to make bottles, food containers, milk crates, toys, and gasoline tanks. HDPE is a tough, chemically resistant resin. Low Density (LDPE) is often used to make squeeze bottles, jugs, such as the one in Figure 10, snap top lids, plastic wrap, and flying disks. LDPE is more flexible than HDPE. LDPE is tough, with a waxy surf ace feel.

Figure 10 - Low Density Polyethylene Jug

Polystyrene

Polystyrene is a clear, amorphous, hard, brittle resin. Crystal Polystyrene (PS) is most often used in boxes and model cars and airplanes, like that in Figure 11.

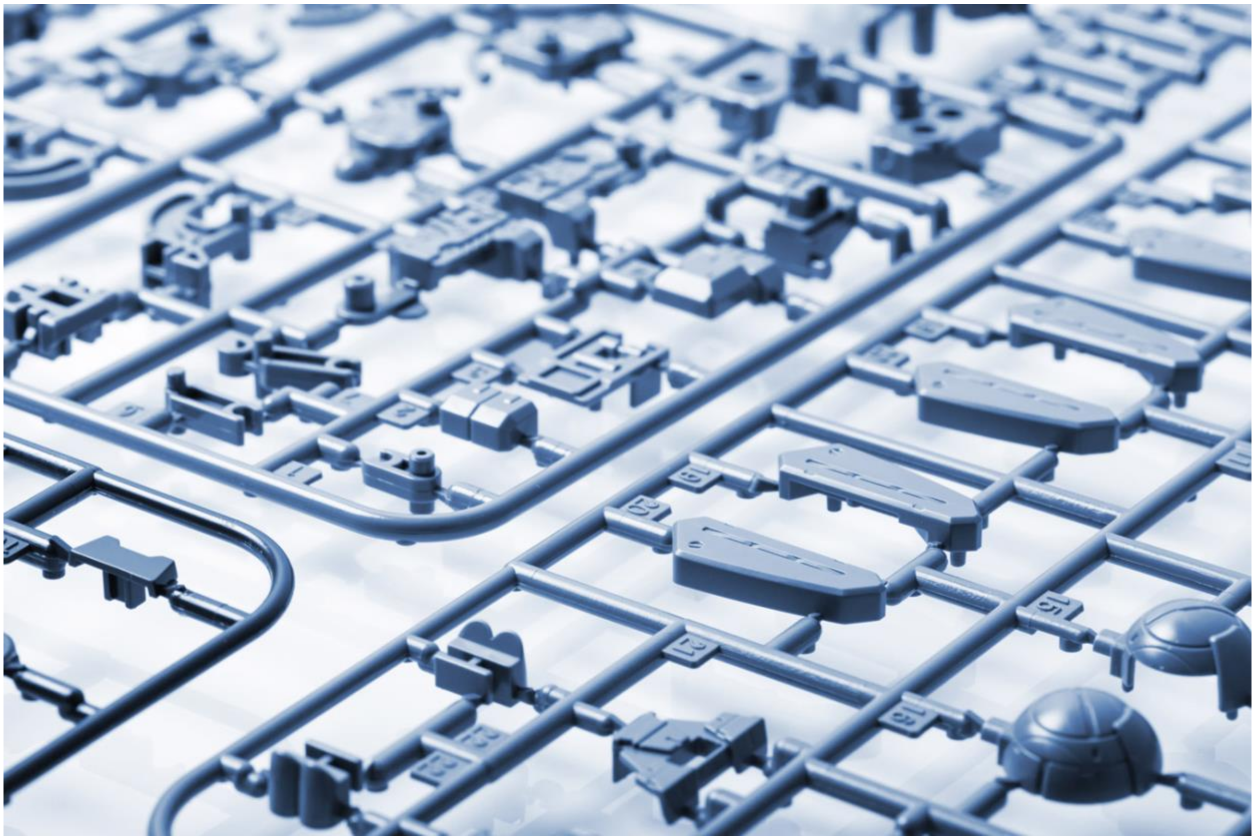

Figure 11 - Model Airplane Parts

Polystyrene is used for many disposable products because it is very inexpensive. Crystal polystyrene is hard, but not very tough. For a tougher resin, chemists add synthetic rubber to get High Impact Polystyrene [HIPS]. High Impact Polystyrene is often used in refrigerator liners and consumer products such as coolers and luggage.

Polyvinyl Chloride

Polyvinyl Chloride (PVC) is an amorphous resin. It is also one of the most versatile resins in use. It is available in rigid or flexible grades. For pipes, such as that in Figure 12, Polyvinyl Chloride has almost completely replaced copper in household and industrial plumbing. It is a strong, chemically resistant resin used for everything from automobile seats, to wire coating, to household siding.

Figure 12 - PVC Pipe Connectors

Exercise Three

Commodity Plastics

Find several different commodity plastic parts in your shop. In the space provided below, list the plastic from which each part is made, and describe the product's use.

Part Name	Plastic	Product Use

Instructor Date

Objective Three

Engineering Plastics

Engineering plastics are plastics that are known for their greater physical and mechanical properties. As a class, engineering plastics can make stronger, tougher, and durable parts than commodity plastics. Engineering plastics are used to make parts with more demanding engineering requirements, hence the name engineering resins.

Engineering plastics require more attention than commodity plastics. In general, the process windows of engineering plastics are narrower and the plastics are more expensive than commodity plastics.

Amorphous Types

Acrylic

Acrylic (PMMA) is a highly transparent resin used extensively in lenses, light fixtures, and outdoor advertising. It has relatively poor impact resistance. Figure 13 shows an automobile tail light made of acrylic resin.

Figure 13 - Acrylic Automobile Tail Light

Acrylonitrile Butadiene Styrene

Acrylonitrile Butadiene Styrene (ABS) is a tough, hard resin. ABS is one of the least expensive resins that combines toughness with hardness. ABS is often used to make luggage, automobile interior components and housings like the one in Figure 14.

Figure 14 - ABS Interior Component

Polycarbonate

Polycarbonate (PC) is one of the toughest of all resins. It is transparent and tough, making it ideal for safety glasses and goggles (Figure 15).

Figure 15 - PC Security Boxes

PC is often used in football helmets, power tool housings, and compact disks. PC has excellent heat resistance. PC is very difficult to bum. It is self-extinguishing, meaning its chemical nature extinguishes flame.

Polyphenylene Oxide

Polyphenylene Oxide (PPO) is a tough resin known primarily for its heat resistance and electrical insulation properties. It has a higher melting point than many other injection molded plastics.

Figure 16 - Coffee Maker

Polyphenylene oxide is most often used in electronic housings, battery cases, and other high heat or electrical applications, such as parts for the coffee maker shown in Figure 16.

Crystalline Types

Acetal

Acetal (POM) is one of the strongest of all plastics. It is very rigid, with good long term endurance and stability, even in water. Acetal is used in gears, bushings, plumbing parts, and automobile door handles.

Nylon

Nylon (PA) was developed by the DuPont Company, and introduced as a fabric to replace silk in women's stockings. Nylon is strong and tough, with good temperature resistance.

Nylon is one of the most used engineering resins today. Nylon has more processing requirements. It has a narrow melting range, and must be dried before molding. Nylon is the most popular choice for small industrial parts because of its great strength in small, thin walled sections. It is also used to make gears, drawer slides, fishing line, and carburetor housings as shown in Figure 17.

Figure 17 - Nylon Carburetor

Polyester

Polyester (PBT) is used to make hair dryers, electrical parts, pump housings, and automotive parts. It is a hard resin that is resistant to heat and chemicals.

High Temperature Plastics

Most of the high temperature plastics are low volume, high cost materials with continuous heat resistance up to 500° Fahrenheit. A few examples are:

- Polysulfone
- Polyphenylene Sulfide
- Polyether Imide
- Polyetheretherketone
- Liquid Crystal Polymer

Thermoset Plastics

Thermosets are plastics with strong cross links between their chains of molecules. Molding a thermoset plastic resin creates a chemical reaction between the chains that cannot be reversed. Scrap parts made from thermosets cannot be re-melted. They must be discarded. Thermoset plastics can be injection molded, but only on specially modified machinery. The two most common examples of injection molded thermosets are melamine and phenolic. Melamine is used to make dinnerware. Phenolic is used to make automotive distributors and heat resistant parts such as pot handles.

Exercise Four

Commodity and Engineering Plastics

Find a variety of plastics that are running in your shop. List what part is being made and classify each plastic as a commodity or an engineering plastic.

Part Name	Commodity	Engineering

Instructor Date

Self-Test

1. The most common copolymer is:
    a. Cellulose Acetate
    b. PVC
    c. ABS
    d. Polyethylene
2. A copolymer is a:
    a. Blend of two different plastics
    b. Polymer made up of two different monomers
    c. A polymer with the properties of more than one polymer
    d. a and b
    e. b and c
3. Crystalline plastics...
    a. Have a higher melting point than amorphous plastics
    b. Have a lower melting point than amorphous plastics
    c. Solidify over a narrower temperature range than amorphous plastics
    d. Shrink less than amorphous plastics

4. Amorphous plastics…
    a. Shrink more than crystalline plastics
    b. Are cloudier than crystalline plastics
    c. Are more transparent than crystalline plastics
    d. Are less viscous than crystalline plastics
5. Thermosets are:
    a. Plastics that can be re-melted and re-shaped as necessary
    b. Plastics with a wax like structure
    c. Plastics with an egg shape
    d. Plastics that cannot be re-melted after molding
6. Commodity plastics make up the bulk of all plastic products in the world:
    a. True
    b. False
7. Engineering plastics are:
    a. Used for engineering sample runs
    b. Require less attention than most commodity plastics
    c. Are generally less expensive than commodity plastics
    d. Used in parts with more demanding engineering requirements

8. Which of the following are commodity plastics?
    a. Acrylic, ABS and Nylon
    b. Polycarbonate, ABS and PPO
    c. Polyethylene, Polypropylene and Polystyrene
    d. Acetal
9. Which of the following are amorphous engineering plastics?
    a. Acetal and Nylon
    b. Polycarbonate
    c. Acrylic and ABS
    d. Polyester
10. ABS stands for:
    a. Acetal Butane Styrene
    b. Acrylic Butadiene Styrene
    c. Acrynylon Butane Styrene
    d. Acrylonitrile Butadiene Styrene

Glossary

Amorphous - without structure. Amorphous plastics do not form the uniform, compact, ordered chains of crystalline plastics.

Copolymer - an organic compound made from a series of different monomers.

Crystalline - a characteristic property of polymers that tend to form uniform, compact, and ordered chains.

Monomer - a small organic molecule that can be linked in chains to form a polymer.

Polymer - an organic compound made from a series of linked molecules called monomers.

Thermoplastic - a material that can be melted and re-melted.

Thermoset - a material that cannot be re-melted. Thermosets undergo an irreversible chemical reaction when heated.