# MINI-PROJECT 6

## PLASTIC INJECTION MOLDING


ME 270: *Design for Manufacturability*

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**AB5_3**

# PRODUCT

The product we have chosen is a mechanical pencil. Although it seems like an extremely simple product, this specific mechanical pencil has 6 injected molded pieces. 3 of the pieces in this product were too hard to remove from the main frame of the product so we only have two separate injected molded pieces depicted. The third injection molded piece that we will analyze is the clear frame of the pencil.

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The product and parts depicted above are mostly made from plastic. Because of unorthodox and complex frame, and the necessity for the product to be durable and withstand high forces from humans, this product and its parts must have been injection molded. In order for this product to be aesthetic as well as functional, there were a multitude of plastics used in this part based on their stiffness, hardness, color and weight and a few of these parts will be outlined below.

Two of the three parts, the front end where lead is dispensed from and the main frame of the product are both made from the same material. Because it is made from a hard plastic, is very stiff, and is part of a very low cost product, this leads me to believe that it is made from clear colored Polystyrene. The blue button that is depicted, is of similar hardness, but is less stiff and a lot lighter than the other piece. From this information it is safe to remove HDPE, LDPE, and PVC as candidates and Polystyrene because it is not the same material as the previous parts. This part is most likely made from a Polyester plastic composite.

# COMMODITY PLASTICS[1]

### ISOTACTIC POLYPROPYLENE (PP)[2]

The polymer Polypropylene can be made from a monomer with a fitting name: propylene. Polypropylene can exist both as a fiber and a plastic, but as this project is concerned only with plastics, this plastic exists in many places, but most commonly as food-containers that are dishwasher safe. Polypropylene has a very high melting point of 320℉ which allows for its multitude of uses. The isotactic prefix of the polymer signifies that the polymer will have a crystalline structure, so Isotactic Polypropylene is a semi-crystalline polymer.

### LOW DENSITY POLYETHYLENE (LDPE, LLPDE)[3]

Low density Polyethylene is a thermoplastic that can be made from the monomer ethylene. According to numerous sources, Polyethylene is the most popular commercial plastic as it exists in almost all plastic materials such as bottles, Saran wrap, and grocery bags. Although this product can be used in a multitude of ways, it has a very simple chemical composition. It is just a string of carbon atoms, with two hydrogen atoms bonded to it. Specifically to low density polyethylene, this polymer is branched where instead of a hydrogen atom, there will be another chain of polyethylene. Because of its branched structure, it is extremely easy and cheap to produce which is why it is used in so many different products. The entire polyethylene family is amorphous, so from this we can conclude that Low density polyethylene is amorphous.

### POLYVINYL CHLORIDE (PVC)[4]

Polyvinyl chloride is a plastic made from the monomer vinyl chloride. PVC is a very well-known commercial plastic that exists in many places. Its most common form is PVC pipes which as used anywhere from household plumbing to dispensing medicine from IV bags. Polyvinyl chloride is used in many places because it is both fire and water resistant. The structure of PVC is extremely similar to the structure of LDPE and HDPE, but on every other carbon backbone, one of the hydrogen atoms is replaced with a chlorine atom. The chlorine atom is the key for the fire-resistant quality of PVC because

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[1] http://polymerdatabase.com/polymer%20classes/Thermoplastics.html
[2] https://pslc.ws/macrog/pp.htm
[3] https://www.pslc.ws/macrog/pe.htm
[4] https://pslc.ws/macrog/pvc.htm

it stops combustion. Like the polyethylene family, PVC has a primarily hydrocarbon structure and is amorphous.

## HIGH DENSITY POLYETHYLENE (HDPE)[5]

High density Polyethylene is a thermoplastic that can be made from the monomer ethylene. According to numerous sources, Polyethylene is the most popular commercial plastic as it exists in almost all plastic materials such as bottles, Saran wrap, and grocery bags. Although this product can be used in a multitude of ways, it has a very simple chemical composition. It is just a string of carbon atoms, with two hydrogen atoms bonded to it. Specifically to high density polyethylene, the chain is linear and is extremely rigid. Linear polyethylene can be used to create fibers that they rival Kevlar and can even replace the ice in skating rinks. HDPE can also be found in household cutting boards due to its usually high coefficient of friction. Like its relative low density polyethylene, high density polyethylene is amorphous.

## POLYSTYRENE (PS, EPS)[6]

Polystyrene is a typically hard plastic that is made from the monomer styrene. Polystyrene is not seen very often in typical daily life, but can be used for the housing of older computers and other kitchen appliances. Unlike the previous plastics, polystyrene can exist as a plastic, foam, or rubber. Polystyrene foam is what is used in packaging and more famously in Styrofoam while the rubber, also called SBS rubber, is used in sealants and more commonly in rubber bands. Polystyrene has evolved over the years. The older form is called atactic polystyrene and its structure is similar to the previous plastics as the main backbone is a large hydrocarbon chain. In no particular order, any of the hydrogen atoms can be replaced by a phenyl group. The newer form of polystyrene is called syndiotactic polystyrene, and it has a very similar structure to atactic polystyrene, except the phenyl group is attached to alternating sides of the hydrocarbon chain. Syndiotactic polystyrene is preferred to atactic polystyrene because of its extremely high melting point of 270℃. Atactic polystyrene is extremely amorphous while Syndiotactic polystyrene is crystalline.

## POLYESTER (PET, PETE)

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[5] https://www.pslc.ws/macrog/pe.htm
[6] https://www.pslc.ws/macrog/styrene.htm

Polyester can exist as both a fiber and a plastic and is made from the monomer ester. Polyesters found in everyday life are usually composites and examples of these composites are plastic water bottles and water balloons. Polyethylene Terephthalate (PET) is what is used to make plastic water bottles and its structure is a large chain which contains ethylene groups and terephthalate groups, hence the name. PET, like polystyrene, can be both amorphous or semi-crystalline. If the PET is transparent, it is amorphous, but if it is white and opaque, it is semi-crystalline.

# ENGINEERING PLASTICS

### NYLON

Nylon is the first synthetic thermoplastic that has been made for commercial use. It has been applied to many different areas across household items to military gear. It can be found in the bristles of toothbrushes, parachute cords, and as tennis racket strings. Depending on the monomer it is blended with, nylon can be either amorphous or semi-crystalline.

### LEXAN

Lexan is a very durable plastic with high impact resistance and is extremely flexible. Lexan also has a very unique trait that is is resistant to ultraviolet light.Lexan can be used as a dielectric in capacitors and are often found as the lenses of eyewear. Lexan is unlike other solids as it does not have a crystal structure and is therefore amorphous.

### ACRYLONITRILE BUTADIENE STYRENE (ABS)

ABS is an extremely common thermoplastic that can be found in many places. Students in the MechSE department see ABS often as it can be used to 3D print with, but it is also found in other products such as Lego and recorders. ABS, like Lexan, is also amorphous.

### TEFLON

Teflon is a hydrophobic plastic that has a very high molecular weight and is one of the solids with the smallest coefficient of friction. It can be found in a variety of products such as catheters and teflon tape that is used on pneumatics. Teflon is also an amorphous plastic.

### ACETAL (POM)

Acetal is a plastic that is similar ABS for most qualities except for strength. Acetal is significantly stronger and can be found in a multitude of products across all industries. It can be found in insulators, insulin pens, and aerosol cans. Acetal, chemically known as polyoxymethylene, has a very high strength and hardness and is extremely crystalline.

# TRANSITION TEMPERATURES[7]

**ISOTACTIC POLYPROPYLENE (PP)**
GLASS TEMPERATURE: 0℃
MAXIMUM SERVICE TEMPERATURE: 130℃

**LOW DENSITY POLYETHYLENE (LDPE, LLPDE)**
GLASS TEMPERATURE:  -110℃
MAXIMUM SERVICE TEMPERATURE: 100℃

**POLYVINYL CHLORIDE (PVC)**
GLASS TEMPERATURE: 80℃
MAXIMUM SERVICE TEMPERATURE: 80℃

**HIGH DENSITY POLYETHYLENE (HDPE)**
GLASS TEMPERATURE: -110℃
MAXIMUM SERVICE TEMPERATURE: 120℃

**POLYSTYRENE (PS, EPS)**
GLASS TEMPERATURE: 95℃
MAXIMUM SERVICE TEMPERATURE: 80 - 120℃

**POLYESTER (PET, PETE)**
GLASS TEMPERATURE: 70℃
MAXIMUM SERVICE TEMPERATURE: 140℃

# POISEUILLE FLOW AND PRESSURE[8]

$$\Delta p = \frac{12\mu}{t_{in}}\left(\frac{l}{d}\right)^2$$

$$\Delta p = \frac{12\times 36}{0.1}(85)^2$$

$$\Delta p = 31,212,000 \text{ Pa}$$

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[7] https://en.wikipedia.org/wiki/Glass_transition
[8] https://en.wikipedia.org/wiki/Hagen–Poiseuille_equation

# NEWTONIAN COOLING TIME

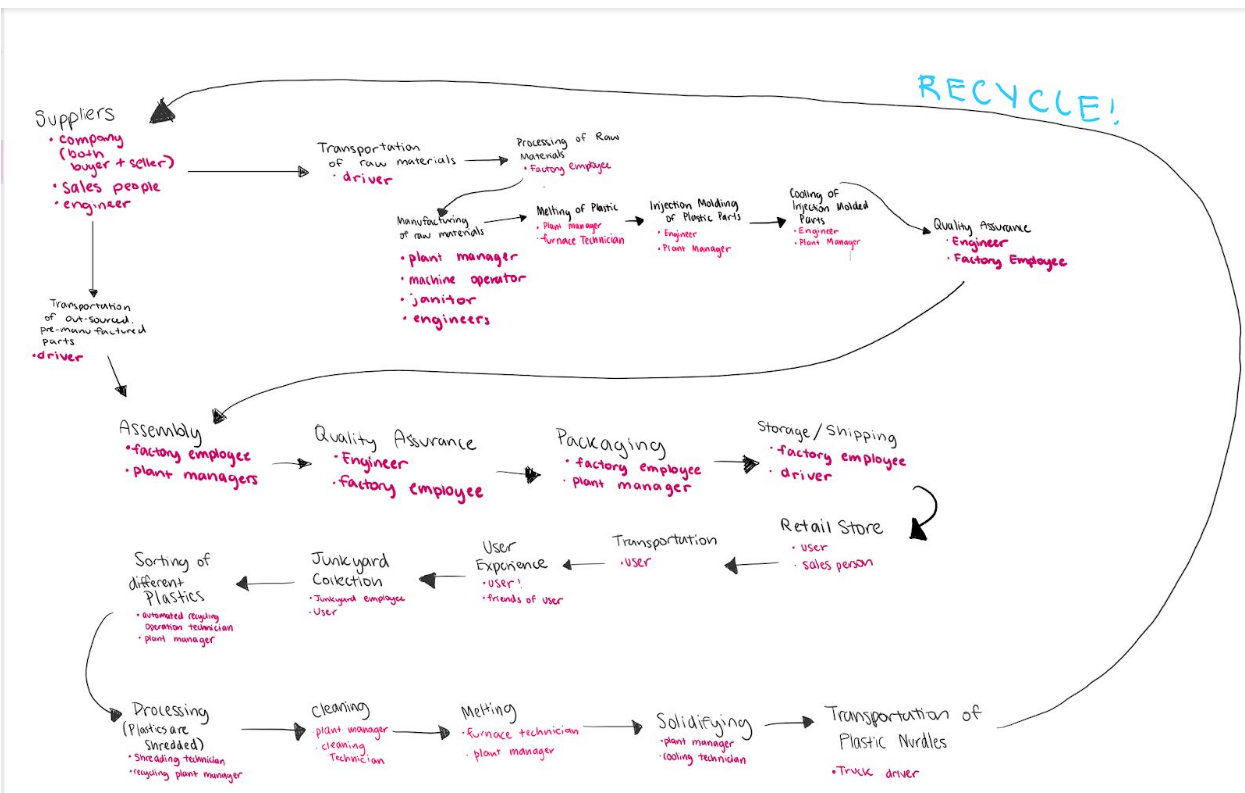
Phone cases are typically made from Polycarbonate, but more often than not, they can be made from Polypropylene. The thermal diffusivity, melt processing temperature, mold wall temperature, and eject temperature were the averages of the given values of the table for Polypropylene (PP). The thickness of the phone case is greater than two millimeters so we made an educated assumption by assigning the thickness values to three millimeters. If one doubles the thickness of the part, the cooling time will increase by a factor of four.

$$t_{cool} = \frac{d^2}{\pi^2 a}\left(\frac{\pi}{4} \times \frac{T_p - T_d}{T_e - T_d}\right)^2$$

$$t_{cool} = \frac{(0.003)^2}{\pi^2 \times 90E{-}9}\left(\frac{\pi}{4} \times \frac{250 - 60}{80 - 60}\right)^2$$

$$t_{cool} = 564.063\ \text{s}$$

# PROCESS FRAMEWORK



# PRODUCT FAILURES

We found a product same as what we displayed in the product column but is used for a longer time to observe how it wears out. After long time usage, the rubber handgrip was worn out and bubbles show up on the surface. When people are using this type of pencil their fingernails can damage the rubber part and in this case make a terrible looking pencil. Besides, when the pencil is exposed under strong light like flashlight or even normal sunlight, the scratches on the surface of pencil can be seen. This problem can be ignored if this is a normal pencil. However, mechanical pencil are designed to be used for a long time, so this defect will cause users' attention. The plastic parts are very stiff and do not have any sign of break or cracks for a long time usage. A stakeholder can be the designer of this pencil, which is someone at Pentel Co., Ltd which is the producer of this product. Also an experienced professional salesperson working in writing supplies area can also be the stakeholder.

# POTENTIAL DESIGN OPPORTUNITIES

Due to the fact that this pencil was not thrown away or discarded, the potential design ideas are not in correlation to why it is no longer used. Based off of the current use and the flaws from it already, only one issue has occurred: the grip tearing or wearing off of the pencil. This is probably caused by the repeated use and friction of the user in this specific spot. We would combat this by using a different material to make the grip or remove it altogether. By removing the grip, we would replace that spot with an ergonomic grip in the hard plastic of the pencil instead. This would reduce the cost of the pencil as well. We would talk to a Product Designer who would know ergonomic holds would be best to implement into the hard plastic part of the pencil.
Also, the metallic lead dispenser part on the tip can not be stored inside the product, which means it is like a pen without cap, and people can be hurt. We would make the tip of the pencil retractable to avoid injury. We would again talk to a Product designer on how to insert a spring retraction into the design of the pencil.

# DESIGN-FOR-MANUFACTURING AND ASSEMBLY

We would improve the actual design of the pencil and reducing the cost by incorporating an ergonomic hold into the hard plastic of the pencil. The stakeholders are the user and material supplier. By improving these two parts, the user would have a cheaper and more ergonomic pencil. To fix the grip, we decided to create a grip that had a flat side for the thumb and a small indent for the finger that rests on the other side of the pencil. On the grip itself, there would be small ridges that would increase traction.People usually grip their pencils in the manner shown below.  This would reduce the cost because it eliminates one part of the assembly as well as the use of another material. Besides, assembly time is also decreased by decreasing types of material. These design changes could easily be implemented by changing the injection mold for the hard plastic of the pencil. Admittedly, although replacing elastic rubber with plastic may cause a less comfortable feel, our purpose of design for manufacturing and assembly is to achieve a ideal balance between cost, function, and quality. For a normal-use targeted and low price product, quality is more important than function so we decided to sacrifice part of the function to achieve a long-lasting and cheaper product.