

**AC 2005-545: DEVELOPMENT OF A PLASTIC INJECTION MOLDING  
PROCESSING LABORATORY FOR FRESHMAN MECHANICAL ENGINEERING  
TECHNOLOGY STUDENTS**

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**Development of a Plastic Injection Molding  
Processing Laboratory for Freshman Mechanical  
Engineering Technology Students**

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**Introduction**

As is the case with many educational institutions that offer a MET degree, an introductory course in manufacturing materials and processes is required. At Penn State Erie, The Behrend College, we offer first-year Mechanical Engineering Technology (MET) students the introductory manufacturing materials and processes course. The course has both a lecture and laboratory segment. During the lab segment of the course, students have the opportunity to experience: material testing, plant tours, manufacturing processes, statistical process control, and inspection/measurement techniques.

With 10 PIM machines, 3 extrusion lines, 2 thermoforming machines, and 2 blow molding machines, Penn State Behrend has the largest educational plastic injection molding (PIM) laboratory in the country. Collaborative efforts were initiated between the Mechanical Engineering Technology and Plastics Engineering Technology departments to enhance the learning experience.

Resulting from the collaboration a decision was made to add a PIM laboratory to emphasize the lecture on plastic materials and processes. The PIM laboratory was developed to give the student an introduction to the PIM process, machine, mold and the effects of processing variables on the parts. Also, students would gain knowledge regarding the effects of part design on the process. Prior to the implementation of this lab, the students went on plant tours or were shown videos of the PIM process.

**Learning Objectives**

The Manufacturing Materials and Processes course exposes first-year MET students to common manufacturing processes and engineering materials. The PIM lab helps the students understand the relationship between processing parameters and part geometry. In the past, students were taken on tours of plastics facilities to show that technology. A cooperative agreement was made to use the Plastic Engineering Technology facilities for this lab thus enabling the replacement of

plant tours and videos. This gave the students a hands-on opportunity to experience and participate in the PIM process. Also, the students gained more insight into the PIM process. The following learning objectives were established:

- student properly describes the major workings of the PIM machine,
- student properly describes the major workings of the plastic injection mold,
- student correctly identifies processing variables that have an effect on the part quality,
- student correctly identifies key processing variables,
- student correctly identifies basic plastic part design principles.

First, a lecture was used to present the PIM information needed for the students to understand the process. Next, the PIM lab was conducted by dividing the lab into two parts. The students were presented a handout one week before the lab with the expectation that they were to read the handout before attending the lab.

During lecture we first presented an overview of the PIM machine including: the flow of the plastic material from entry to ejection, the energy sources of the machine, and the mechanical workings of the machine. The mechanical workings of the screw and the clamp mechanism were reviewed. A simplified explanation, of plastic materials and how they behave during processing and in the solid state was given, setting the stage for an understanding of the need for this lab. An explanation of the different mold types, along with examples, was given to the students. Students were then exposed to different types of plastic injection molds and were able to view a two-plate, cold runner, PIM mold in operation. Processing problems such as short shots, jetting, flash, air traps, and weld lines were explained to the students while example parts were molded. Also, the effects of the processing variables on part quality were discussed.

The students used general rules of thumb to calculate the clamp tonnage needed for the parts produced in the lab. They plotted the change in part dimension, as well as part weight, with each change to process variables (melt temperature, pack pressure, and cool time). These exercises were intended to reinforce the lecture portion held at the beginning of the lab.

The experience in the laboratory setting allowed students to gain extensive knowledge of the basic components and variables of the PIM machines, molds, and process. From a pedagogical viewpoint, this was an effective laboratory to introduce the student to a complex and quite extensive PIM manufacturing process. The only substitutes would have been a video or a plant tour, and neither would have provided the same level of understanding of the PIM machines, mold, or process.

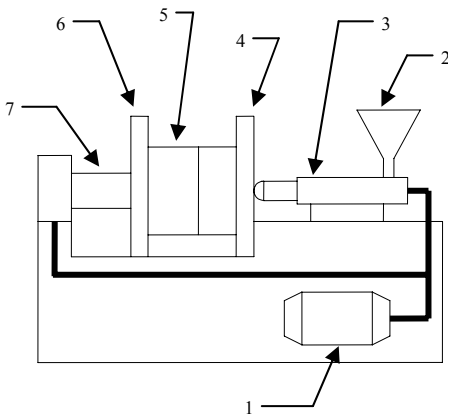
### **Laboratory Objectives**

Well designed plastic parts are dependent on good processing. Graduates of Plastics Engineering and Engineering Technology programs are trained in the processing and design of plastic parts. There are far more jobs available in the plastics industry than there are Plastics Engineers to fill those jobs and mechanical engineers and engineering technologists are used to fill these positions. Mechanical engineers tend to design plastic parts with some of the rules they would use for metal parts, usually resulting in product failure. For example, one of the cardinal rules of

plastic part design is nominal wall thickness which is not always important for the design of metallic parts. A nominal wall thickness allows the polymer to flow more uniformly in the part. When the part shrinks, a nominal wall helps the part to shrink more uniformly. To make a typical metal part, metal needs to be removed. A nominal wall metal part would be more expensive and time consuming to make. A plastic part that is designed with nominal wall does not always guarantee a good part and a poorly processed plastic part could turn a well designed part into one that is dimensionally inaccurate. Poor processing could also negatively affect the visual aspects/requirements of the part.

A properly designed plastic part must be designed for manufacturing from the beginning. Details such as gate location, parting line, and ejection must be considered as the part is being designed. Because of process in orientation and part filling concerns, the gate location is important. Processed in orientation can cause warpage and changing the direction of orientation can result in warpage reduction. Plastic will take the path of least resistance. Areas with thinner walls, which are close to the gate, will have problems filling. Weld lines are formed when the plastic flow front moves around a hole and connects again. Changing the gate location can move the weld line.

The following paragraphs illustrate additional lecture information that was shared with the students prior to the conducting the laboratory.



**Figure 1 - PIM Machine**

PIM machines are one of the most common types of plastic processing machines. They are used to create high tolerance, good surface finish, and complicated parts. A representation of a PIM machine can be seen in Figure 1. Most PIM machines are powered by hydraulic pumps (1). Some new machines are powered by DC servo motors. The process starts with 1/8 inch diameter pellets fed into a hopper (2). There is a reciprocating screw that rotates and augers the pellets from the hopper to the front of the barrel (3). As the material is augered forward, it pushes the screw backwards. When a predefined amount of material is in front of the screw, the screw stops rotating. When the mold (5) is empty, the screw pushes forward and fills the mold in two stages. The first stage is the filling and the second stage is compensation or packing. There is a non-return valve on the front of the screw to stop any flow of the material back into the screw. The mold is held by the stationary platen (4) and the moving platen (6). As the material is pushed into the mold it builds pressure and that pressure tries to push the mold halves open. The movable platen is moved by a hydraulic cylinder or mechanical linkage (7). Mechanical linkage machines have 10% to 20% faster movement than hydraulic machines [1]. Hydraulic clamps have more control on the movement.

The processing parameters discussed in this section are the important variables in the PIM process. The PIM process consists of three stages: injection of the plastic into the mold, packing of plastic to compensate for thermal shrinkage, and cooling of the plastic. In the injection phase, the plastic is pushed into the cavity in the mold through a sprue, runner system, and the gate.

The cavity is then filled to 98% of capacity as injection of the plastic is done under high velocity and would spike the pressure if the part were completely filled in the injection phase. The last 2% is filled in the compensation or packing phase. As the material starts to cool in the mold, it starts to shrink. The packing of plastic into the mold cavity helps to compensate for this shrinkage. When the gate is completely solidified, the packing phase is complete. At this point there are still areas of the part that are not solid and the cooling phase allows the plastic to cool fully, allowing the parts to come out of the mold. The longer the parts stay in the mold, the better chance they will have of staying in spec. It is during this phase that processors try to reduce the cycle time, sometimes with drastic results.

There are a few important variables that can be observed during the injection phase: melt temperature, injection velocity, and mold temperature. The melt temperature has an influence on the viscosity of the plastic; increases in melt temperature lower the viscosity of the material. There is a maximum melt temperature that cannot be exceeded because it will start to degrade the material. To assist in preventing this, a temperature profile is used on the barrel to aid in the melting of the material. The temperature in the feed section is usually set 11°C to 17°C below the melt temperature [2], helping to convey and melt the material. The injection velocity also affects the viscosity of the plastic. When the molten plastic enters the mold cavity, it forms a frozen wall. Because there are velocity gradients between the frozen layer and the center section of plastic, frictional shear heating occurs. As the material undergoes additional shearing, the viscosity is lowered. If the material is put in too slowly, it could allow the frozen layer to get thicker, having the effect of reducing the flow channel thickness and increasing the pressure needed to fill the part. The last variable in the injection phase is mold temperature. It really has no effect on the materials viscosity or frozen layer development in the injection phase, but does, however, affect the surface finish of the part. Warmer mold temperatures allow the surface to appear glossier.

During the packing phase, the important variables are packing pressure, packing time, and mold temperature. The higher the pressure used to pack the parts puts more plastic in the mold and makes for good compensation for the shrinkage. There is a point where the pressure could be too high and cause problems resulting in the parts being ejected out of the mold. Some of the plastic could still be under pressure and stick in the mold. High pressures could also overcome the clamp force needed to hold the mold halves together and create an opening where plastic would spill out at the parting line. If the pressure is too low, the last 2% of the part may not get filled. Packing time is critical because it determines how much plastic is pushed into the mold. When the gate solidifies, no more plastic can be pushed into the mold. If the gate is not solidified when the packing pressure is removed, the pressurized plastic in the mold cavity will push some plastic back out of the gate into the runner system. This reduces the amount of compensation around the gate region. Mold temperature, also a factor in the packing phase, determines how long the gate stays open to allow the plastic to flow into the part.

During the cooling phase, the two notable variables are cooling time and mold temperature. As explained before, the parts will be more dimensionally stable if they stay in the mold longer. The mold acts as a cooling fixture to help lock in the part's dimensions. When the parts are out of the mold, they have unrestricted shrinkage. The mold temperature has the most effect in this stage. Typical cooling capacity requirements range from 70 to 200 Kcal/Kg/hour [3]. A cooler

mold will help to solidify the parts faster but may have adverse consequences, such as cooling the gate too quickly or affecting the surface appearance.

The last variable examined is clamp tonnage; this is not really a variable but a result of the injection or packing pressure built up during the cycle. These pressures are distributed along the cross sectional area of the parting line and create a force resisted by the moving platen. If the force is too high, it overcomes the moving platen and moves it away from the stationary platen, opening the mold and allowing the plastic to spill out of the mold cavity. Usually the pressure is higher during the injection phase, but at the end of fill it is zero. At the end of fill, the total force acting on this pressure will not be significant; therefore, the pressure at the gate has the most effect. In the packing phase, the pressure at the gate may be less than it would be during the injection phase. In this phase the mold cavity almost becomes hydrostatic. This creates more force from the areas around the end of fill. It is usually the packing phase that has the major effect on the clamp tonnage. If the clamp force is too high, it could put too much stress on the mold [4]. This usually happens when a small mold is put into a PIM machine that is too big for the mold.

Part shrinkage is another factor that affects the parts dimensions. Part shrinkage should not be measured within hours of molding, as some plastics will continue to shrink for days or weeks. The shrinkage within 1 hour after molding may only be 75% to 95% of the total shrinkage [5]. Also, some plastics like Nylon and Polycarbonate will absorb moisture from the air making them expand. After molding, the parts should be kept in a controlled environment.

The process set-up determines part surface finish and dimensions. Visual inspection of the part is done to find short shots, surface finish, and sink marks. Short shots are a result of not completely filling the mold cavity during filling and packing phases. The surface finish is determined by mold temperature. Sink marks are a result of a section of the part shrinking while the region around that section has some molten plastic. Since the region cannot get any more packing, the material will shrink more.

Measurements were used to demonstrate the changes in part dimension when there were changes in processing conditions. A region on the part, half way between two ribs, was selected for the measurements. This allowed for a good measurement of warpage.

### Student Feedback

After the lab was conducted, students were surveyed on the effectiveness of this new laboratory. Below are the questions and student responses to them.

Q: Did you find the hand-out helpful?

Yes	22
No	2

Q: Do you think that a video of the PIM process would be a better learning experience than the lab you just had?

Yes	2
No	22

Q: Was this lab a valuable learning experience?

Yes	23
No	1

Q: On a scale of 1 to 5 (1 being the least and 5 being the most), how valuable do you rate this lab compared to other labs?

Scale	Student's Ratings
1	0
2	1
3	2
4	15
5	6

Representative student comments regarding their learning experience after the lab was conducted are found below. Please note that these comments are verbatim and have not been edited for correct spelling, grammar, or punctuation.

- I thought that the lab hand out was very informative and also it did a very good job of clearly explaining every thing involved in the PIM process.
- The information in the hand out was helpful in visualizing the components of the Inejction Mold Machine and the mold itself. It was a clear representation to me, and each compent was easily identifyable by arrows.
- The lecture definitely helped. It covered the material in the handout, but was a lot easier to understand when I could see the process going on and having it described at the same time.
- It was much more stimulating to have the visual of the machine operating, and to have the ability to hold still hot parts in your hand; as apposed to a class room lecture with pictures in a book.
- A video might illustrate the process, but would not describe the steps entirely. Little things that wouldn't nesecarily be covered a video can lead to some interesting questions, or alternate avenues to explore.

## Conclusions

This lab was a valuable learning experience for the MET freshman. Before the implementation of this lab, plant tours and PIM videos were used to introduce the PIM manufacturing process to the students. Some of the issues that arose from the plant tours included:

- Students could not hear the tour guide's narration due to the operation of multiple machines.
- The tour guide understood the generalities of the machines, molds and parts but was not always technically inclined. There was a lack of the in-depth understanding needed to make this lab a valuable learning experience for college students.

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- Because of the travel time to and from the facility a great deal of time was lost that could have been spent on discussion of the PIM machine, mold and process resulting in student questions being left unanswered.
- Students were not afforded the time or needed tools for proper inspection of the parts.
- Process variables and their effects could not be studied because the machines were performing production runs.
- The ability of choosing machines, molds, and parts were for their educational value didn't exist as we were only able to observe what happened to be in operation at the time of the visit.
- Floor plans in the facilities that were visited did not allow students to position themselves where they could hear all portions of the discussion or observe the entire process.
- Students were not able to experience the total process, only segments of the process.

In addition to some of the above issues, many other issues resulted from showing videos of the PIM process. The videos did not captivate the student's attention or allow them hands-on experience. The laboratory setting allowed students to measure and observe parts as they were ejected from the machine, capturing their attention.

The in-house, hands-on lab overcame the difficulties associated with plant tours and videos. From student feedback received regarding the lab, it appears that the educational objectives we set were met. From an instructor's viewpoint, the lab was an efficient and effective vehicle for transferring knowledge to the student.

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