INTRODUCTION

Plastics are so common in modern life that it's easy to forget they were developed recently. In 1950, the total plastics produced around the world amounted to 1.5 million metric tons per described demonstrations for extrusion, blow molding, compression molding, and vacuum forming[21]. Low cost 3D printers offer another way to introduce plastics manufacturing, but they print slowly which limits the opportunity for hands-on experiences by students in a lab class. Additionally 3D printing currently accounts for a small segment of industrially manufactured parts[22]. Injection molding, on the other hand, is one of the chief industrial manufacturing methods for thermoplastics. Herein can be found useful information for those interested in using an injection molding machine in a classroom, lab, or project.

A hobby scale injection molding machine (IMM) that costs around $2000 to $3000 offers a relatively inexpensive way to introduce students to plastics manufacturing. In recent years more manufacturers have started offering IMMs around this price point but the lack of off-the-shelf molds limits their usefulness. While it is relatively easy to make new plastic objects with a 3D printer, making a new plastic object with an IMM requires the creation of a new mold. There exists a large difference in skill requirement between operating an IMM compared to making a custom mold. Necessarily much of this article and the supplemental material is focused on the mold making aspect of plastics manufacturing due to the technical challenges associated with it.

Figure 1. A custom aluminum injection mold that creates a ball-and-stick model of polyethylene

Aside from making the mold, the actual process of injection molding is fast and easy to learn. The author's initial effort to introduce education in plastics manufacturing was done while teaching high school juniors and seniors. The students had no difficulty learning to use the IMM, and because it produces parts very quickly it could be incorporated into lessons without diverting much class time away from the learning objectives aligned with the mandated curriculum. For example, the author used a custom mold for a toy wheel to allow high school students to make their own balloon powered cars for studying momentum in a physics class[23]. For undergraduate engineering majors, a hobby scale IMM could be incorporated in a similar way, for example students could use it to make their own dogbone specimens for tensile strength testing. Alternatively, in a course such as materials science an IMM could be introduced as part of the main learning objectives as a low cost way to expand the plastics section of the course with hands-on activities. In the above cases, it would be desirable and/or necessary to have custom molds. In this article the process of designing a custom mold that makes a ball-and-stick model of polyethylene (Figure 1) is describe. Such a mold could be

The author used the IMM for classroom activities with 12 groups of students over two consecutive years. The IMM was so easy to operate that most students were able to run it after a 3-5 minute introduction.

and are usually not recyclable, that plastics are made from polymers, that different types of plastics have different physical and chemical properties and cannot normally be recycled together, they need to be cut or ground down in order to fit into the IMM. Assessment for recycling activities are similar to those described in the Classroom Use section.

With access to a plastics granulator, recycling activities could be expanded to include plastics from consumer products or other sources. Students could learn how pigments combine when different colored plastics are mixed and about challenges relating to color sorting. Students could also learn about the need for separating plastics by type, for example, separating the caps from water bottles. Currently hobby scale granulators are not widely available but a number of companies are developing them.

Hazards

At injection temperature, polypropylene release fumes which are a nuisance and can be

1) Visualize the part
2) Decide on parting line location, no overhangs, flat parting line
3) Consider milling tools before specifying dimensions
4) Pencil and paper sketch with key dimensions
5) CAD model of part
6) CAD model of gates, runners and pins
7) Boolean operations to make CAD models of molds
8) CAM milling tools setup
9) CAM workpiece setup
10) CAM toolpaths
11) CAM simulations
12) CAM post processing
13) G-Code editing
14) CNC Controller simulation
15) CNC setup (setting origin)
16) CNC milling
17) Polishing (optional; can remove machining marks)
18) Set Alignment Pins

While working on Box 1 steps 1-7, it is important to consider not only what can be made with the CAD program, but what can be made with the milling machine. Students should keep in mind the diameter of the end mill and avoid designing grooves and cavities that are too small to be machined. Box 1 Steps 8-11 require feed and speed values for the end mill; Table 1 lists data used by the author with the Taig CNC milling machine. These data are conservative; the author found milling slowly avoided broken end mills and was more cost effective than optimizing for rapid milling.

Figure 2. The asci-text G-code created by the Fusion360 post processor that needs to be edited in order to work with the MachIII software used by the Taig CNC mill.

Working together students can assemble a polymer long enough to visualize molecular scale phenomena such as entanglement of polymer chains and crystallinity. They can also demonstrated the relationship between random-walk, polymer structure, and entropy. By rotating each monomer unit the overall shape of the polymer can be changed and the backbone of the polymer resembles a random walk in 3-dimensions. Rotating the monomers to maximize the writing assignment, presentation or class discussion. The mold described here, for use in making a polyethylene ball-and-stick model, can be used to engage students in learning about plastics and to create demonstrations of polymer behavior.

Mold making requires more time and more advanced skills; it is most appropriate for a senior design project. The requirements for the senior design project can be based on custom molds needed for other courses or for local high schools interested in teaching students about injection molding. Making custom molds provides students with valuables skills and experience for their future engineering career.

As the manufacture of plastics continues to grow, it is important to include more opportunities to educate students, at all levels, about these amazing and relatively new materials. The low cost and abundance of plastic products, especially recyclable disposable products, leads many to undervalue its importance and global impact. Educational opportunities, such as those with an inexpensive hobby-scale IMM describe here, can help students better understand plastics and better appreciate the role plastics play in their lives.

SUPPLEMENTAL MATERAIL

Creating an Aluminum Injection Mold.pdf

DECLARATION OF CONFLICTING INTERESTS

The Author declares that there is no conflict of interest.

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