INJECTION MOLDING IN STUDIO

ENHANCING STUDENTS' CAPABILITIES WITH HANDS-ON INJECTION MOLDING PRODUCTION

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PAPER ABSTRACT: Desktop injection molding machines and stereolithographic printed molds make hands-on injection molding production possible in design studio classrooms and labs. Direct experience designing molds and parts for injection molding and producing the molds and parts is valuable, relevant experience for design students. This case study describes equipment, materials, projects and beneficial learning outcomes using in-studio injection molding in a university design studio class.

Keywords: Injection molding, SLA, 3D printing, polymer mold

1. INTRODUCTION

Industrial designers develop lots of plastic products. The limitless possibilities of shape, color and texture with plastics make creatively working with them both challenging and gratifying. The skilled creative space of plastic part and product design is a need area for designers to fulfill.

In the last decade, the ability to produce functional plastic parts and products has come to school design studios through fuse-deposition modelers (FDM). Desktop FDM printers have lowered barriers in cost, space needs and materials access for plastic product model-making. By applying thin-walls, interior features and assembly features in their work, current design students can produce more realistic parts and learn more through hands-on assessment (Page, 2018) than their predecessors could. Students now conceptualize and develop their designs with the intention of producing them through FDM or other additive manufacturing (AM) fabrication methods (Greenhalgh, 2016). Because of AM availability and students' design intentions to utilize these technologies, students can now be taught the skills of 'hybrid' designers, able to design interior as well as exterior product features, positioning them for bespoke design contracting and start-ups in addition to corporate and consultancy jobs (Campbell, 2003).

Whether students anticipate becoming hybrid designers – creating low-volume or bespoke 3D printed products – or more historic designers creating products for mass production, they do expect AM to be included in their design education. Some product design students arrive at college with their own 3D printers. Competitive design institutions have labs dedicated to AM. Additive manufacturing technology is accessible, interesting and positively impacts design learning. While it has only been in active use for approximately a decade in design education, today it is a standard component of design education (Adamczak, 2020).

The foundation of professional plastic part production is not additive manufacturing, however. Injection molding is the dominant fabrication method for plastic parts (Thompson, 2007). Fortunately, there are two developments in desktop production equipment that make injection molding in schools more practical and accessible. The first development is producing not parts, but molds through the AM process of stereolithography (SLA). While injection molding tools produced through AM have been experimented with for nearly 30 years (Sachs, 1992) (Kalami, 2019) (Böhme, 2021), new resin formulations for use with SLA desktop printers have the strength and thermal stability to be used for molds that can withstand the heat and pressure of injection molding (FormLabs, 2020). The print resolutions of SLA printers are fine enough for molds to come straight off the printer (Harris, 2002) (Walsh, 2021) without needing additional polishing. The total time it takes to produce a mold through SLA printing is a fraction of the time required to produce a traditional steel mold. The second development is in desktop injection molding. Injection molding machines with footprints similar to desktop FDM and SLA 3D printers are now available.

Coupling SLA printed molds with desktop injection molding machines provides students access to hands-on experience with the Design for Manufacturing (DFM) strategies learned in textbooks (Ulrich, 1995). Experiential learning through prototyping is a knowledge-acquiring process distinctive to product design studies. The act of prototyping provides the designer visual and physical stimuli about a product through the processes of making. The resultant parts and products created through prototyping are visual and physical stimuli for analysis (Gill, 2011) (Lee, 2020). Conceptualizing, actively experimenting with and making an injection molded part, and reflecting on the part and experience is a full cycle of Kolb's experiential learning model (Kolb, 1984). Students can understand injection-molded plastic product design more fully with the inclusion of hands-on injection molding experience than they can through textbook descriptions of injection molding processes, but lived experience with AM production.

This case study describes experimentation with and suggestions for straightforward production of injection molded parts in college-level design classes. Equipment and material recommendations are presented and examples from student productions are shown. The goal of these classes is to increase students' abilities and interests in designing injection molded plastic parts and products.

2. OBJECTIVE

The objective of this case study is to encourage college-level design educators to include injection molding equipment in their labs, and teach injection molding in classes. The experimentation with materials and assignments presented will help educators anticipate and reduce barriers that are encountered with equipment, materials and class structures. Ultimately increasing the knowledge and experience that design students have with the injection-molding process will help them prepare for their successful careers in design.

3. METHODS

3.1 STUDENT DESIGN

Design education includes studio practice as a fundamental pedagogical method of instruction. This case study documents a lecture and studio class on DFM principles and practice. The applied design project is specified for injection molding. The volume of the parts to be designed, the final material of the product and the size envelope are constraints dictated by the existing studio lab equipment and practices. Overall part size maximum is a 30 mm diameter boundary for the x-y plane, and a nominal thickness of 3 mm. Each final product is to be made of two parts that fit together. The mold is to be a family mold, producing both parts of the product in the same mold. There is to be a distinct A-side mold with the cosmetic, or outside surfaces of both parts, and a distinct B-side mold with the interior details. The volume of a 2-part mold cavity, including two designed parts, sprue, runners and overflows, is to be approximately 6000 mm^3. To hit these constraints, the designed objects in this case are specified to be hollow, two-part duck charms for use on key fobs or as items of jewelry.

While assignments were developed for students to work in labs on both the 3D printing of their molds and the injection molding of their parts, the beginning of the Covid-19 pandemic occurred during the time of this case study and significantly reduced student access to lab facilities. Therefore, most of the mold printing and part injection molding presented herein was performed by lab technicians.

3.2 EQUIPMENT

The two main pieces of equipment are a Mini-Jector Model #45 and a FormLabs Form 3 SLA printer.

Figure1. From left to right, Mini-Jector Model #45 injection molding machine, Form3 SLA printer, Prusa Curing and Washing Machine and air compressor.

These are both desktop, or benchtop, sizes. The current Form 3+ printer has a starting cost of $3499.00 (FormLabs, 2022). The current Mini-Jector Model #45 does not have a listed price (Miniature Plastic

Molding, 2022) and is quoted at $21,635 (W. Beach, personal communication, June15, 2022). Additional equipment includes a washing and curing station for the SLA prints and an air compressor for the injection molder. The washing and curing station used is the Original Prusa Curing and Washing Machine, also benchtop size, which currently costs $749 (Prusa Research, 2022). The compressor used is a California Air Tools Ultra Quiet & Oil Free Air Compressor at $700 (California Air Tools, 2022). The total equipment investment, shown in Figure1, is $26,538.

3.3 MOLD PRODUCTION

The total production of a two-part SLA mold consists of five steps: CAD file set-up, printing, cleaning, curing and sanding. Setting up the CAD files includes quality-checking the files of the molds and orienting them for printing. In the Form3 printer, up to four two-part molds (eight mold halves) measuring 125 mm x 50 mm x 6 mm could be arranged within the print envelope at one time. Four molds took approximately fifteen hours to print. Printing is the longest step of the mold production, but requires little to no person-time. Cleaning the printed molds with alcohol solution to remove residue and support material is next. Then curing the molds in UV light. Two molds could easily be cured together in the Prusa station, and more could be added with the custom creation of clear acrylic support shelves placed in the machine. After curing, sanding removes residual bumps left at the junctures where support material held the mold in the printing process. The total time for one mold is comfortably estimated to be ten hours, with the caveat that multiple molds are processed at one time in the printing, washing and curing steps.

Experimentation with two types of 3D print resins showed FormLabs' Grey Pro resin to be preferable for these injection molding projects. Both Grey Pro resin and High Temp v2 resin were tested. Production time for the High Temp v2 resin molds was longer by one hour than the Grey Pro resin molds, due to an additional heat-cure step in an oven. The molds printed in Grey Pro were found to maintain their integrity under the heat and pressure of this system for one to ten shots, and had some physical flexibility so that the parts could be extracted from the molds without breaking the molds. The High Temp v2 resin molds were more brittle, occasionally shattering when molded parts were extracted.

3.4 PART MATERIAL

The university polymer lab utilized for this class has two sustainability goals regarding PLA: using polylactic acid (PLA) for all FDM prints and recycling used PLA on site. To support this goal, maintain material consistency in the lab and enhance students' and technicians' common physical knowledge of this polymer, the material for the injection-molded charm products is specified to be PLA. Both NatureWorks 4043D and 3D850 PLA pellet were tried, and the 3D850, seen in Figure2, is recommended. The 3D850 material showed far less trapped air in the final parts than the 4043D. No other processing or part differences were significant between these two materials. The water-based Slide brand E/S Silicone spray was used as mold release on the mold inserts and is recommended, as it did not seem to interact negatively with the mold materials or the production part materials and was clearly helpful in releasing parts from their molds, as intended.

Figure2. NatureWorks 3D850 polylactic acid pellet with yellow colorant and view into the Mini-Jector hopper.

4. RESULTS

Students chose the CAD design tools of their preference, typically Rhinoceros or SolidWorks, to design the parts and molds. Initially, students were provided the external dimensions of the mold blanks to use in their mold designs. Through trial and error, it was found that providing CAD part files of the mold blanks, including sprue placement, ensured a precise fit of the molds in the injection molding machine.

Applied areas of learning that are presented with this project include: understanding of small parts, wall thicknesses, in-gate and overflow placement, knit line formation, application of draft angle and design for assembly. Starting with small part size, students learned to think about detailing on a product at this scale. Initial part designs commonly included elements that were visible in CAD models and renderings, but were too fine to be noticeable in the production parts. In project reviews, students remarked that concepts with interesting bounding shapes and comparatively large feature details resulted in stronger products, such as the example shown in Figure3 and Figure4.

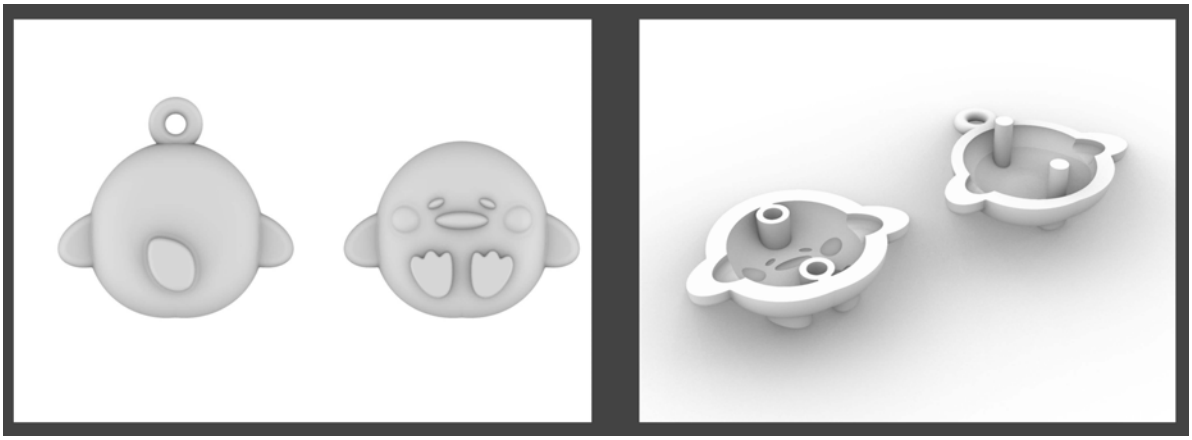

Figure3. Hollow duck charm part design. Design and image by Karina Amsden and Ayu Nguyen.

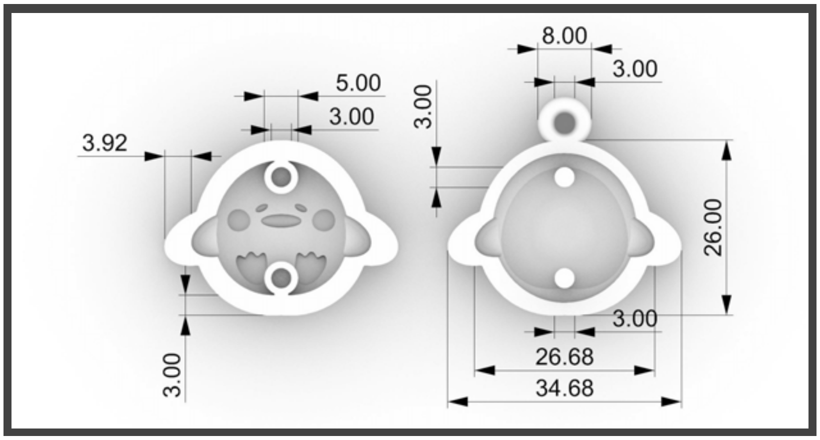

Figure4. Hollow duck charm part design dimensions. Design and image by Karina Amsden and Ayu Nguyen.

The theoretical DFM goal of consistent wall thickness or controlled wall thickness changes became physically apparent in relation to the overall size of the parts. Large changes in wall thicknesses, or adding large features to the exterior of a part and not shelling the features from the interior, produced significant sink. Students found palpable, visible sink in their physical parts to be undesirable and were motivated to modify their designs and minimize this defect.

In-gate and overflow placements were considered in relation to knit line formation. A requirement of the duck charms was to include a jump ring connector with a hole so that the charm could be attached to a chain, and the hole makes the formation of a knit line certain. Positioning the in-gate near the jump ring connector to ensure that it filled was typically weighed against positioning the in-gate on the opposite side of the part from this connector to ensure that the main part and internal details filled. The benefit of this problem is that it is a real-world conundrum often without a singular answer. Students had to make a choice for the mold design and wait to see what the results of that choice would be in the quality of the molded parts.

Another project requirement was poka-yoke assembly, so that the two halves of the product could only assemble in one orientation. Two bosses of different diameters or keyed bosses and pins were typical solutions to this problem, as shown in Figure5. The draft direction on individual features of parts became clear to the students with this detail. There were regular “aha” moments when students realized the taper of the negative, or interior, of a boss would fit with the taper of the positive pin form with the correct draft directions applied.

B-Side of charms B-Side of mold A-Side of mold B-Side of charms B-Side of mold A-Side of mold

Figure5. Injection-molded hollow duck charm parts and mold sides. Designs by Karina Amsden, Ayu Nguyen and Gemti Lowenstein.

As seen in Figure5, excessive flash was consistent in the injection molded parts. The target cavity size was set at the project outset so that the same shot volume, temperature and pressure could be set on the injection molding machine for all of the student projects. The shot size was set larger than the target volume of the mold cavities to ensure that short shots would be an issue of restricted part and mold design, rather than an issue with shot volume. The quantity of flash was considered unfortunate, but acceptable by the instructor and technicians.

5. CONCLUSIONS

Hands-on work in studios is one of the assets of product design education. The benefits of having students work hands-on with injection molding equipment, and hold and examine parts produced from their own designs was seen by the instructor and technicians as clearly beneficial to student learning. The moments of connection and understanding that students had with principles of Design for Manufacturing (DFM), such as consistent wall thickness and knit line prediction, and Design for Assembly (DFA), such as boss sizing and keying, that occur through this work are satisfying to observe. While most designers do not directly design injection molds in their careers, students beginning their professional design careers will more capable and confident of injection-molded product design having had this experiential learning.

Students commented that this experience was noticeably beneficial to their learning. They did not comment negatively about needing to design interior details that may be considered unnecessary considerations for a product designer. They found this work relevant to their design education. Student reviews included: “Thank you for giving us the opportunity to design and produce our own injection-molded parts! I appreciate the hands-on nature of this class, and getting to work with designs that could actually be manufactured,” and “…The learning materials were relevant in today's world of design. The assignments properly reflected this as well and made perfect sense for doing the step by step process we did….” In general, students would have preferred more direct and individual interaction with both the injection molding equipment and the stereolithography equipment, which will be possible as Covid-19 restrictions are rescinded.

While the benefits to students are the best driver for the inclusion of new techniques and technologies in education, there is an argument to be had that being a competitive educational institution in product design requires the inclusion of new prototyping technologies. The incorporation of additive manufacturing in design curriculum – at primary, secondary and university-level institutions – has been rapid. To provide students equipment that is advanced beyond their primary and secondary education experiences is an important consideration for design colleges and universities. Including desktop injection molding in studio is now an accessible option for an institution's new prototyping technologies.

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