Experiment 3: Thermoplastic Injection Molding with Morgan Press

Objectives:

- Compare the shrinkage and warpage of semi-crystalline and amorphous polymers.
- Identify and explore how fillers affect the shrinkage and warpage of injection-molded parts.
- Explore effects of cycle time variations on shrinkage and warpage.
- Explore Pressure-Volume-Temperature (PVT) behavior of unfilled polypropylene.

Background:

In injection molding of thermoplastics, molten polymer is forced into a colder mold cavity, where it cools and solidifies to take the shape of the mold cavity. All polymeric materials will shrink when cooled from melt state to a solid state, which can be described on PVT diagrams. Non-uniform cooling and non-uniform pressure distribution in the mold cavity cause non-uniform shrinkage, which leads to warpage.

Amorphous polymers shrink much less than semi-crystalline materials.

The injection molding cycle consists of the following stages: plasticizing, injection, cooling, and ejection or de-molding.

Plasticizing is the conversion of the polymer material from its normal, hard granular form at room temperature, to the liquid consistency necessary for injection at its correct melt temperature.

Injection is the stage during which this melt is introduced into a mold to completely fill a cavity or cavities.

Cooling is the process in which heat is removed from the melt to convert it from a liquid consistency back to its original rigid state.

Ejection is the removal of the cooled molded part from the mold cavity and from any cores or inserts.

Experimental Guide:

The independent variables are polymer crystallinity, filler, temperature, injection pressure and the cycle times. The dependent variables are the warpage and shrinkage of the molded part.

- You should test each of the first two independent variables using at least two different cycle times, temperatures, and pressures.
- You must include in your final report your experiment design and a rationale for the experimental conditions you selected.
- You should explain your testing methods for both the shrinkage and warpage in the final report.
- You should calculate the percent shrinkage (mold filled) and warpage using the given equations. Sample calculations are required in the "Calculations and Assumptions" section.

Materials:

Polycrystalline polymer:
- polypropylene

Amorphous polymer
- polystyrene

Filled polymer
- 30 wt% talc filled polypropylene
- 30 wt% glass filled polypropylene

Equipment:

Morgan Press (injection molding machine)
Aluminum mold cavity with nozzle adapter
Vernier caliper
Metal bars (4 total) and variance measurer for determining sample warpage
Vacuum Oven

Morgan Press Operation:

1. Switch on the electrical power for heaters. This is on the top left hand corner of the Morgan Press as you stand in front of the machine.
2. Switch on the pneumatic power to the machine by selecting the injection speed control/ram pressure on the injection pressure regulator on the back of the machine. The suggested value is between 6000 to 8000 psi. Injection pressures higher than these cannot be achieved due to limited line pressure (from the EB Utilities) available at the present time.

3. Using the chart on the front of the machine, find the approximate barrel and nozzle temperatures for the material that you are running. The temperatures

obtained are a first approximation and may not be the optimal processing temperature.

4. Set the temperatures identified in step 3 by pushing the up/down arrows on the Watlow Process Controller (the panel on the upper left hand side of the press, as you stand in front of it).
5. Once the barrel and nozzle zone temperatures reach the desired set points, spray some silicone mold release on the inside of the mold.
6. Assemble the mold by tightening the 4 allen screws on the mold and tightening the spru ensuring that the spru is flushed with the top of the mold.
7. Place the mold on the center of the table in the Morgan Press.
8. Place a small plastic cup with some aluminum foil under it, at the top of the mold -- directly under the nozzle to catch any polymer overflow.
9. Charging the polymer
    a) Load the polymer through the material loading chute on the side of the press.
    b) Push the polymer charge down the barrel using the "L" shaped aluminum strip tool.
    c) Close the orange cage guarding the chute.
    d) Remove excess air from this charge by depressing the injection control valve knob (the round black knob on the extreme right of the bottom panel of the machine as you stand in front of machine) for a short time (2 to 6 seconds); make sure that the orange grilled gate guarding the feed chute is closed.
    e) Release the injection control valve knob.
    f) Repeat steps a-e until the barrel is full.

    Note: Close the orange gate guarding the chute. The machine will not operate if it is not closed properly or left open.
10. Allow 8-10 minutes for the charge to melt completely inside the barrel.
11. Set the clamp force to be approximately 10 tons using the round orange knob (second from left) on the bottom panel of the machine which regulates clamp force; the clamp force can be read on the clamp force gauge (red markers) on the left hand side.
12. Set the pilot valve pressure to be greater than 50 psi, but not more than 100 psi, using the black pilot valve pressure regulator (grooved black regulator, second from right hand side) on the bottom panel of the unit. The pilot valve pressure gauge (black markers) is on the top R.H.S. of the machine.
13. Remove the plastic cup (from step 9)
14. Lower the guard (orange wired cage with clear plastic shields) to sit firmly on the table platen so that the actuator pin on the back is fully seated in its hole. A “snap” is heard when this is done correctly.

15. Clamping the mold on the nozzle:
    a) Depress the orange clamp control valve knob (extreme left) on the bottom panel.
    b) The mold will automatically rise until the injection port and the nozzle come into contact with each other.
    c) Visually verify that the injection nozzle is in contact with the nozzle adapter on the top of the mold.
16. Depress the injection control valve knob (extreme R.H.S.) to have the ram inject the molten polymer into the mold.
17. Hold the injector control valve in until the allotted cycle time is complete (use a stopwatch to measure the cycle time).
18. Release the injector control valve.
19. Wait until the ram injection pressure is released and the injection control valve is fully retracted.
20. Release the clamp and raise the safety cage.
21. Remove the mold.
22. Cooling the mold:

    Allow the mold to sit in ambient air for sufficient time that the mold can be handled without the use of insulated gloves.
23. Disassemble the mold by removing the 4 allen screws.
24. Remove the molded part by removing the spru.
25. Some material may be stuck in the center gate. You will have to remove this with a razor blade, a scraper, or a drill. Ask the TA for assistance if you cannot remove it.

Notes:

- You need to purge the system if a different material is present in the barrel. If this is the case and the polymer will not inject, try raising the temperature until the polymer will inject.
- If the material does not flow into the mold when the button is pressed, make sure that the protective gate around the mold is completely down and that the orange gate on the feed chamber is snapped into place.

Theory and Analysis:

Shrinkage Analysis

The diameter of the mold must be measured. Then the final molded part should be measured. Assuming the mold is completely filled, the percent shrinkage can be calculated.

Warpage Analysis

The thickness should be measured for each sample using the vernier caliper provided. Also, devise a method for measuring warpage. For example, draw two diameters 90 degrees apart from one another through the center of the sample, and mark certain distances (e.g. 0.1 in. increments) through the diameters for measurements. The measurements will be done by placing two of the metal bars parallel to each other, with the molded sample in the middle, and put the third bar perpendicular to the other two bars (on top of the two bars). Use the third bar as a guide for the variance measuring [measures variances accurate up to mils (0.001 inches)].

PVT Analysis

Calculate the specific volume of the unfilled polypropylene disks at various temperatures and pressures. Use the PVT data provided (located in the library, and listed below in the references) to calculate what the specific volume of polypropylene should be for any given pressure and temperature. Compare these two values.

Discussion Questions

1. How do various ways of annealing each molded part affect the warpage and shrinkage of that part? (This is something to research and discuss)
2. How do variances in cycle time, temperature, and pressure (separately) affect the shrinkage and warpage for the molded disks (for each material)?
3. How close are the comparisons in the polypropylene PVT data (specifically, the differences in the experimental versus referenced specific volumes)? Why might there be differences between the specific volumes?
4. What could be surmised to be the “optimal” conditions for a certain material to be injection molded in the Morgan press and why?
5. If temperatures besides the ones listed on the machine were used, what was the rationale? For example, if the Morgan press lists the barrel and nozzle temperatures as being 320 and 340 degrees F, respectively, and you choose to do runs at 340/360, and 360/380, why was a twenty degree increase in each run chosen and used?

References

1. “Polymer Properties Test Report (Polypropylene, sample report),” C-Mold/AC Technology Polymer Laboratories, 1995.

2. Maier, C and Calafut, T. “Polypropylene: The Definitive User’s Guide and Databook” Plastics Design Library, Norwich, 1998, pp 151, 152, 171-173, 304.