THE EFFECT OF ORIENTATION ON MECHANICHAL PROPERTIES OF RECYCLED PET

Angela D. Hasenbalg, Western Washington University

Abstract

The use of plastic products is becoming more prevalent in society. Scrap from plastics processing is reground and reused by plastics manufacturers. When the percentage of reground plastic becomes higher than 30% a decrease in mechanical properties is seen. No research has currently been found to encourage runner, vent, or gate modifications to enable manufactures to use a higher percentage of recycled material. The objective of this investigation determine if pin point, standard, or fan gates have an effect on the molecular orientation of virgin, 30%, and 80% recycled PET. Molecular orientation can be evaluated by performing mechanical property testing such as yield strength, tensile modulus, percent elongation, and hardness testing. Tensile bar inserts will be machined with pin point, standard, and fan gate styles. The resulting bars will be subjected to the mechanical tests of yield strength, tensile modulus, percent elongation, and hardness. By using a 2^k factorial designed experiment, the results will be analyzed to determine which, if any, gate causes the mechanical properties of the recycled plastic to be similar, within 10%, of the virgin material.

Background

Current public concern is being raised by the high amounts of visible waste being generated from the use of plastics in day-to-day living. Plastics manufacturers have a desire for increasing the amounts of recycled material that is used in their products. Defective parts and runners are scraps that the manufacturer must dispose of properly. Two common methods of dealing with scrap is to pay to have the parts shipped to a landfill, thereby detracting from the desirability of plastic in the public's opinion, or to regrind these parts and reuse the material in current production by their own or another's company. By increasing the amount of recycled plastic found in products, plastic manufacturers will be able to decrease the amount of virgin material that they are required to purchase, and increase positive public response to their product.

When plastic is reground the polymer molecules are broken into smaller molecules. These smaller molecules translate into a smaller molecular weight than the original polymer possessed. The mechanical properties of the polymer are directly related to the molecular weight of the polymer chain.(1) The higher the molecular weight, typically the higher the mechanical properties such as tensile strength and impact toughness. Polymers with longer chains entangle, or wrap around other polymer chains, with greater frequency than polymers with shorter chains. Once the polymers are highly entangled, the molecules resist separating from one another. Therefore, the polymers with high molecular weight are implied to have greater mechanical properties. With the decreased molecular weight, smaller molecules are more difficult to orient. As recycled polymers have had their molecular chains shortened when reground, products made with large amounts of recycled material typically have a marked decrease in their mechanical properties. The average amount of regrind currently used in the plastics industry is 20 – 30% by weight. This amount mixed with virgin plastic has no notable detrimental effect on the average application.(1)

Hypothesis

Various gating styles should have some effect on the molecular orientation of the PET polymer. Differing shear rate created by the gates should cause change in the molecular orientation of the recycled polymer. With molecular orientation changes come corresponding mechanical property changes. If the plastics industry is able to more closely match the mechanical properties of parts made with a high percentage of regrind to the properties of virgin plastic by modifying gate styles, then a larger percentage of recycled plastic can be used during processing.

Intent

This research will (if successful) show the effect that three different styles of gates have on the mechanical properties of virgin PET versus recycled PET. Mold makers would be able to modify gating styles to accommodate a customer's need for a mold that can accommodate an increased amount of recycled material to be successfully used during processing.

Research

Polymer Used:
Polyethylene Terephthalate was chosen for this project due to its high usage as a consumable plastic in pop, juice, and water bottles.[2] These are items that the public uses on a daily basis and have noted concerns about the increase of these items in landfills.[3] PET has relatively show crystallinity during processing and its molecules are easily oriented by mechanical means.[2] This ease toward orientation translates into better mechanical properties. With PET molecules being easy to orient, the effects of molecular orientation can be measured by tests on the mechanical properties. Mechanical properties are directly correlated to molecular orientation achieved during processing. The slow tendency of PET to crystallized will ensure that the majority of the mechanical properties will be due to the orientation effects and not to the crystallinity.[2]

Mold Modifications:
There are many ways to adjust the parameters of an injection molding machine with the intent to change the molecular orientation of the polymer being processed. However, no research can be found on tool modification for injection molding. Mold modification may enable the use of an increased amount of regrind material in place of virgin material.

Gates:
Gates are a design consideration that has been regarded as highly critical for the production of a successful tool due, in part, to the effect that gates have on molecular orientation.[1] When melt is pushed through a gate, the random coils of polymer molecules are stretched by the shearing forces created by the gates' opening. This stretching creates alignment of the backbone chains parallel to one another. Molecular orientation becomes more definite as the depth of the gate's channel decreases.[4] Many molecules align in the same direction because of the stress the polymer flow is exposed to. Research cannot be found to qualify or disqualify the use of different gate styles to allow for an increase in regrind material. For these reasons, gate style was chosen to see if different gating styles would show an effect on the mechanical properties of PET when parts were injection molded.

Alternatives:
Runners systems are designed to maximize the efficiency of raw material usage and minimize the energy consumption of the injection molding machine.[1] Runner size has been found to increase material shear heat, helping to maintain melt temperature and enhancing the polymer flow.[5] It could be possible that by changing the size or style of a runner, the polymer molecules could be caused to orient differently. With this method, there is the risk of degrading the resin due to the amount of time the resin is under shear stress. There are no reported effects of runner systems on the orientation of polymer molecules. Vents in mold cavities are designed to remove gases from the mold to prevent voids and weld lines in the final product. There has been no reported effect of vent placing on molecular orientation found.

Quantitative Analysis

Mechanical properties can be an indication of the molecular orientation that has occurred in a part produced by injection molding. The mechanical properties that will be tested on each part made from the different gate styles will be; yield strength, tensile modulus, percent elongation, and hardness.

Methodology

Three gate styles have been chosen for this experiment. Each of the gates has differing characteristics. A pinpoint gate will be used to see if the effect of forcing the PET through the gate's small opening will enable the molecules to orient better. With pinpoint gating care needs to be taken on determining the size of the gate. If the gate is made too small, burning of the plastic from the excessive shear can occur. The pinpoint gate will be noted as the small gate in this study. A standard direct gate will be used as

it is the most common style found in molds in the injection molding industry and should be included for that reason. This gate is in the average size range for gates. A fan gate will be used as the opposing factor to the pinpoint gate. Fan gates have fairly wide openings from the runner system into the cavity. This gate is in the larger size of gates. No warnings about the appropriate sizing of fan or standard gates can be found at this point. See appendix, Table 1.

The gates are ranked by the size of the opening that each gate will use, pinpoint gates being the smallest, standard gates being midsize, and fan gates having the largest opening into the part.

Proposed Solution

A full factorial designed experiment with one factor (the percentage of regrind) that has three settings (pinpoint, standard, and fan gate) will be used for this experiment. PET resin with 0%, 30% and 60% per weight recycled PET added will be used with each of the three styles of gates. Tensile bars from each of the gate styles will be produced using an insert mold in conjunction with an injection molding machine. The effect the orientation has on the mechanical properties will be evaluated by performing eh following tests; yield strength, tensile modulus, percent elongation, and hardness. Table 2 in the appendix shows an example of a data sheet to be used for this experiment.

For this project, tensile bars that both conform to the ASTM standards and that will fit on a 3 X 3 inch block insert needed to be found. A style V bar was the smallest tensile bar that can be made to ASTM standards.[6] This bar is only 2.5 inches long but, in order to fit on the insert with the appropriate runner system and gate, needs to be set at an angle to the insert edges. Two cavities will be machined into each insert as a runner system is necessary for the gates to be used on the tensile bars. For this investigation, insert molds for each gate style will be machined out of aluminum on the CNC machine in the machining lab. As these molds are strictly for use for the duration of this experiment and will not see production-style use, aluminum is an acceptable metal for the inserts.

Tensile bars will be made initially from 0% regrind (100% virgin PET). Using the virgin PET, the optimal settings will be found for running the PET on the Engel injection molding machine. Once the optimum settings have been found, several runs of tensile bars will be run. An estimated 40 lbs of PET will need to be run to ensure enough recycled PET is available for both the making of the tensile bars and for purging out the screw between percentage regrind changes.

Twenty bars of 0% regrind will be set aside for testing and the remaining bars will be reground. The regrind will then be mixed with the virgin PET by weight to gain the remaining percentages desired.

Using the same settings found for running optimal parts with virgin PET, the remaining 30% and 60% regrind PET will be run in the Engel. Care will need to be observed when purging the material from the machine when changing runs so that regrind of differing percentages doesn't contaminate the next run. All tensile bars run will need to be checked for processing defects and a minimum of 10 acceptable tensile bars from each percentage regrind will need to be found. These bars will be subjected to yield strength, tensile modulus, percent elongation, and hardness testing.

All machinery needed for testing the tensile bars is located within Western's Engineering Technology Department with the exception of the appropriately sized load cell. For tensile bars of the size being made for testing, a load cell with a range of around 130 lbs is necessary. An undergraduate research grant was applied for and granted with the purpose of purchasing a Sensortronics Model 60001-0221 with 25 – 300 lb capacity for $393.00. If the grant had been denied, a similar capacity load cell could have been used at a local company's testing site.

Once tested, the data will be entered into a table similar to table 2 in Excel. Using the statistics portion of Excel, the data will be analyzed and charted to determine which, if any, gate style has a positive effect on the mechanical properties. The tensile bars made with 0% recycled material will show what, if any, effects the gating alone has on the mechanical properties of the virgin PET. The tensile bars processed with the regrind material will then be compared with the virgin PET to decide if it can be shown that any of the gates will enable the reground material to have similar mechanical properties as the virgin PET.

Assumption for Final Draft

It is anticipated that the pinpoint gate will have the largest effect on mechanical properties due to its increased ability to orient the PET molecules due to its reduction of area from the runner system through the gate and into the cavity.

The research that this paper is presenting will take place during the winter quarter, January 7 through March 12, 2002. The final draft of the paper, with calculations, is to be finished by April 1, 2002. Photos and graphs of the parts tested will be included in the final draft of the paper. A rough draft of this paper, with data compiled to date, will be resubmitted by March 1, 2002.

Bibliography

1. Malley, R.A. (1994). Plastic Part Design for Injection Molding: An Introduction. Cincinnati, Ohio: Hanser/Gardner.

2. Strong, B.A. (2000). Plastics: Materials and Processing. Columbus, Ohio: Prentice Hall.

3. http://www/plasticrecycling.com

4. http://www.dow.com/engineeringplastics/tech/guide/display.htm?guide=gates.htm

5. http://www.dow.com/engineeringplastics/tech/guide/display.htm?guide=run.htm

6. Annual Book of ASTM Standards, Vol 08.01. (1984), Subcommittee D20.10 on Mechanical Properties, NY: ASTM

Appendix

Time Line

• CAD Drawings for inserts	Nov. 16, 2001
• Mold Inserts finished on CNC	Jan. 31, 2002
• Parts run for regrind	Feb. 8, 2002
• Parts w/regrind run	Feb. 22, 2002
• Finish testing (yield, hardness, etc)	March 1, 2002
• Calculations finished, graphed, & calculated	March 12, 2002
• Summary Report/poster finished	April 15,2002
• Present paper to ANTEC	May 5, 2002

GATES		
Pin Point	Standard	Fan
-	o	+

Gates Table 1

PET	Gate Style	Yield	% Elongation	Tensile Modulus	Hardness
0% Regrind	Pin Point				
	Standard				
	Fan				
30% Regrind	Pin Point				
	Standard				
	Fan				
80% Regrind	Pin Point				
	Standard				
	Fan				

Data Sheet Example Table 2

Product	Cost
Sensortronics Load Cell Model 60001-0221 w/ 25 – 300 lb capacity	$393.00
4 x 4 x 8 inch Aluminum Stock for Inserts	49.50
1/8 End Mill – 4 Flute	1.95
1/8 Ball End Mill	4.95
1/16 End Mill – 2 Flute	8.95
Total	**458.35**

Cost Analysis Table 3