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Recycling of Post-Consumer Resin (PCR) Plastics: A Capstone Project to Reduce Waste and Promote Future Recycling

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Abstract

While many plastics are recyclable, most single-use plastic products live out their end of life in the ocean, on the side of the road, or in landfills. This senior capstone project sought to create a simple process to reprocess single-use plastic waste. The process included methods for cleaning, sorting, and grinding plastic waste to make new injection molded products. Following extensive research on current plastic compositions and characteristics suitable for recycling, collection bins were placed throughout the cafeteria at the engineering college to gather used plastic utensils as well as pizza savers. Creative methods for cleaning food waste from collected items required design and fabrication of a new part for a donated dishwasher. This multidisciplinary senior design project pulled skills and experience from team members' undergraduate programs as well as student professional organizations such as the Society of Plastics Engineers. Using knowledge and techniques gained, the team developed an efficient process to create injection molded flying discs made out of 100% recycled polypropylene (PP) single-use plastic food items that students had previously simply thrown away. The injection molding cavities used had been developed in a previous senior capstone project that had created flying discs; these flying discs are now used by the college to interest visiting K-12 students in engineering and in the university. The end goal for this project was not only to divert a fair amount of the college's plastic waste from ending up in a landfill, but to create a process going forward to educate and excite students and guests about recycling.

Need and Goals for Project

Over the course of many years, multiple single-use plastic products have been discarded as trash by the general public. According to a 2018 *National Geographic* report [1], of the 8.3 billion metric tons of plastic produced as of 2018, 6.3 billion tons have been wasted. The vast majority of that – 79% – has ended up in landfills or in the natural environment. Only 9% has been recycled, although 12% has been converted from waste to energy. The fact that many plastic products spend their end of life cycle in the ocean, or in the stomach or orifices of sea creatures, is a cause for people to condemn plastic. It is vital that we address this crisis as plastics can take centuries to naturally decompose, leaving us with the choice to either recycle or reuse.

The truth is that many of these plastic products can be recycled or reused in some way; we just need to be more creative problem-solvers to accomplish this. This senior design project, Reprocessing of Post-Consumer Resin (PCR) Plastic Trash, was aimed at creating a transferable recycling process that helps reduce the amount of single-use plastic waste. Specifically, a process was created to handle secondary recycling of a university's cafeteria waste, such as plastic utensils and pizza savers, into a reprocessed material useful in the plastics teaching lab. Because the plastics lab is the site where potential college student visitors use injection molding to make flying discs, showing off our sustainability focus is a bonus. It is hoped that project results can be demonstrated to students or visitors coming on tour to educate them on more sustainable plastics manufacturing processes. We hope that this project will educate a younger generation and encourage them to recycle single-use plastic.

The criteria for the Recycling of Post-Consumer Resign (PCR) Waste project were as follows:

- Create a method for collection of used plastic cutlery and pizza savers in the cafeteria
- Research and apply information on recycling practices, existing plastics, compatibilizers, and other materials as needed
- Develop a system to effectively clean and separate plastic waste
- Upgrade, redesign, or build modifications to existing equipment as needed
- Ensure the system is environmentally friendly
- Create usable plastic material from co-mingled waste
- Injection mold flying discs using molds created by earlier capstone design group
- Test the resulting flying discs for quality; specifically, flatness, "fly-ability"
- Make recommendations for continuing development and ways to share recycling.

Background

Given that there are numerous advanced recycling techniques and different methods for each of them all available in the plastic recycling industry, researching helped the team to identify which technique or method was most suitable for this project. As there are various steps to reprocessing plastic wastes including different recycling processes, the team researched sorting and cleaning methods for single-use plastics, as well as compatibilizers. From the research findings, the team identified multiple methods and selected the appropriate techniques for creating the recycling process.

Types of Recycling

There are four main types of recycling for plastics. The first two are processes that involve mechanically recycling plastic, while the third and fourth types of recycling respectively deal with reverting the plastic back to a basic polymer chain or fuel, and creating energy by incinerating the plastics [2]. The focus of this project was to enable the plastics lab to practice the first two types of recycling.

Primary recycling

The first type of recycling is called primary recycling, which mainly deals with manufacturers that create products using plastics. Primary recycling involves grinding any plastics, such as scrap parts, gates, runners, etc., that are created during production and reusing them in addition to virgin material to create parts [2]. Using this type of recycling is beneficial to manufacturers as it is far cheaper to purchase reground or re-pelletized material than it is to purchase virgin material [3]. This type of recycling is currently available in the plastics lab as it basically only requires a grinder.

Secondary recycling

Secondary, or mechanical recycling, is the second type of recycling and is currently unavailable in the plastics lab due to lack of processes for cleaning and separating plastics. As secondary recycling deals with reprocessing post-consumer plastics, the mixture that is created will be heterogeneous in nature unless some sort of sorting is employed to pre-sort the plastic before it is ground. This type of recycling is considered more expensive than primary recycling, as additives, such as stabilizers, might be required in a secondary recycling process, as some plastics use and lose some additives during the molding process [2].

Sorting of Commingled Plastics

Sorting any incoming commingled plastic is imperative for many polymers. To avoid the consequences of processing polymers, recycling companies will sort them via different methods, including the sink-float method and manual sorting.

Sink-float sorting

Sink-float sorting utilizes the difference in the densities between similar plastics to separate them. A fluid is chosen for the sink-float method based on the material that is being sorted. It is necessary that the density of the fluid is between the densities of the two polymers, so that one plastic sink and the other floats. Water is commonly used as the fluid for this sorting method, as it has a density that falls in the middle of the commodity polymers [4].

Manual sorting

Manual sorting is one of the slower, cheaper sorting methods, and if done correctly can save time from any secondary sorting process. Just as it sounds, manual sorting involves sorting polymers by hand. West Michigan Compounding uses this method as an initial sorting method to remove dissimilar plastics and any assembly items such as metal clips [5]. Human error is the greatest downside to this type of sorting, which is mostly based on visual identification or the number on the recycling symbols on the plastics [4].

For our sorting process, it was decided to use manual sorting for its simplicity and low cost deemed appropriate for the scale of this project.

Cleaning Waste Plastics

Plastics that consumers recycle are often dirty and commingled. This means the plastics will need to be cleaned and sorted before they can be processed. Consumers are generally expected to clean the recycled products after they are used, but many people do not. This creates another step in the plastic recycling process. It appears that the most common method of cleaning plastic in industry combines cleaning and the sink-float method of separation. According to a video posted by Paul Vanderpool [6], dwell time in the detergent is critical, and he recommended a 25-minute dwell time to ensure the plastic is clean and contaminant free.

After doing extensive research on various cleaning processes, the team decided that using a dishwasher with dishwashing pods would be the cheapest and quickest way to clean the material. Finish dishwashing pods were selected from a low-cost range of dish soaps as a baseline dishwasher pod.

Compatibilizers

One of the downsides of processing commingled polymers is that some polymers do not bond well when they are processed. The resulting copolymer could have an increased chance of showing processing defects such as delamination, as well as reduced mechanical properties such as tensile, flexural, and impact strength. Compatibilizers help combat these unwanted side effects of processing copolymers.

There are many compatibilizers that could give processed commingled polymers better properties. If the group decided not to separate the plastics and process fully commingled recycled plastics, a polystyrene block copolymer or an ethylene-propylene copolymer would be the necessary compatibilizer. Since the plan was to sort the plastic to remove polyvinyl chloride (PVC), the compatibilizer that was chosen was poly(styrene-ethylene/butylene-styrene) block copolymer mixed with ethylene propylene rubber (SEBS/EPR), (trade name Kraton G). It is commonly used in polymer mixtures that contain polyethylene terephthalate (PET) to improve flexural and impact strength [2] [7]. The relatively high cost of the compatibilizer is offset by the low cost of post-consumer plastics, and low mass of the compatibilizer required to significantly increase the mechanical properties of the final product with as little as 4% compatibilizer increasing the impact strength up to 650% [8]. However, after having no issues processing the recycled materials, the compatibilizer donated by Kraton for research purposes was no longer needed; the unused compatibilizer material can be utilized to process commingled plastic for other design projects.

Recycling and Processing Plastic Bags

It is a common sight to see plastic bags floating around on the side of the highway and in rivers. Even though plastic bags have a large role in today's society, many recycling companies refuse to accept them. This is largely because plastic bags can get caught in sorting mechanisms and end up in the recycling stream of other recyclables, as they are light, thin, and flimsy. To prevent the plastic bags from getting caught in moving pieces while being separated by material, they were hand sorted before any processing occurs.

Processing plastic film also presents a challenge due to its low density, which can cause issues when it is being reprocessed. To combat the issue of low-density and ensure a steady stream of material in the extruder, an agglomerator was used [9]. The agglomerator was a pot-type agglomerator, which uses a set of rapidly rotating knives to not only shred any incoming film, but to agglomerate it to increase its density. After the plastic film has been agglomerated, it can be cleaned and processed [10].

Methodology

The first step to recycling plastic was to set up collection bins to get a steady source of plastic waste. The group purchased recycling bins with lids and cut two holes in them to allow the plastic utensils from the engineering college's cafeteria to be deposited in. The hole was designed in a way that minimized the deposition of any contaminant trash. Pizza savers were also collected that come on the pizzas delivered from Little Caesars to the cafeteria.

Once collected, the pizza savers and utensils were cleaned in a modified dishwasher. A mesh basket made from stainless steel was designed and fabricated to allow for a higher volume of small parts to be cleaned at once. The mesh prevented utensils from falling to the bottom through the racks. Most of the parts were cleaned the first cycle; however, if too much was put in the basket, a second cycle was sometimes necessary. After the parts were cleaned and dried, they were ground into small chips.

In order to do small scale testing on an injection molding machine, maintenance was needed to get the Arburg injection molding press up and running again. After the water manifold was replaced, along with all the hoses and fittings parts, the machine was finally ready to be used. Parts were then made with virgin material to set a baseline process. Once the process was configured, the recycled material was introduced, and the process was tweaked until acceptable parts were produced.

Once good parts were created on the Arburg, the material was put in the Toshiba injection molding machine to create flying discs. The process settings were manually changed on the Toshiba to reduce the amount of flash that was appearing on the first few discs. Flash is defined as any excess plastic that does not fit the original mold. Once the process settings were acceptable, high-density polyethylene (HDPE) colorant was added to the reprocessed material to determine if colorant would affect the parts in any way.

Budget

The group was given no official budget, but since this project will benefit the school in terms of education and reducing plastic waste, differential tuition was used to purchase gloves for $7.84 and Finish dishwasher pods for $12.98 to clean the plastics in the dishwasher. For the project, the team used an old apartment-sized dishwasher obtained free of cost, and two 32-gallon sized bins purchased for $14.98 each for the collection. Stainless steel mesh was purchased for $188.20 to be used in creating a basket within the dishwasher to ensure the plastics wouldn't fall through the racks. The carbon brushes within the motor of the dishwasher broke and needed to be replaced, resulting in the team deciding to purchase a whole new motor for $150. The overall cost, supplemented by a great deal of hands-on work, was under $600.

The team did research on agglomerators, which shreds plastic film. This agglomerator research helped lay the groundwork for future senior design projects [11]. With the help from university financial staff, the team was able to determine a quality agglomerator from a reliable source overseas. The team then applied for a university-sponsored Student Sustainability Grant and was awarded $5,000 to help purchase the agglomerator. This agglomerator will be used to recycle plastic bags produced in the plastics lab, with the potential of also recycling grocery bags. It will also be added into the curriculum for teaching the Production Thermoplastic Processing class.

Project Results Prove Feasibility of Recycling Post-Consumer Resin

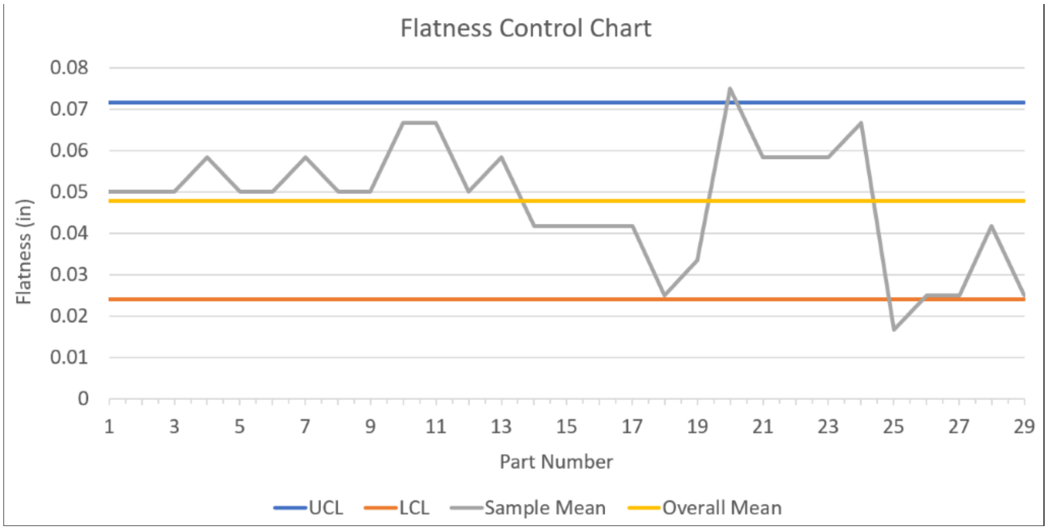
The team delivered a complete and fully documented recycling process system. The collected material was successfully used to create recycled flying discs. These recycled discs were compared to the quality standards of the current discs made with HDPE, to ensure that a quality part was made. These standards include flight stability, flatness, weight consistency, defects, how well the colorant takes to the material, and whether the material could be hot stamped.

Flight stability

Flight stability was checked by throwing the PCR discs and comparing them to the HDPE discs typically created in the plastics lab. The PCR disc showed good flight stability, as it flew straight until it landed. The HDPE discs, on the other hand, tended to veer towards the left.

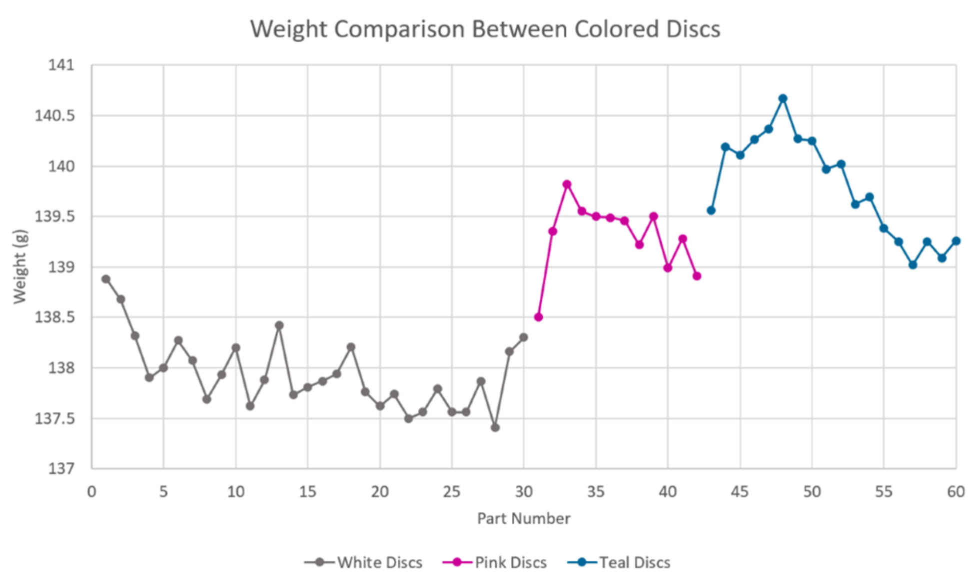
Flatness

Flatness was tested by placing the PCR disc on three blocks and placing a weight on the rim of the disc. This held the disc in place while the measurements were taken. A height gauge was zeroed out at the top of the three blocks, to ensure proper calibration. After the setup was complete and correct, a point was measured equidistant between two of the blocks. This gives a total of three points of measurement per disc. The data gathered from this test gave information as to whether the discs had any warpage. Warpage was a concern with the PCR that was used, as PP has a high tendency to warp. According to the data that was collected, the most warpage occurred in the discs that had colorant in them. While the warpage was under a tenth of an inch and within specifications, the data showed that the flatness was out of control. This is likely due to uneven shrinkage that occurred due to a poor distribution of colorant. The flatness of all the discs are shown in Appendix B in a control chart.



Weight consistency

Weight consistency is important to watch when starting a process, as a machine should produce parts that have a consistent weight. The weight of the discs was inconsistent once colorant was introduced. When colorant was added to the material, the weight increased a few grams compared to the material without colorant, then it started to fall back down, as the colorant was processed. The difference in weight based on color is shown in Appendix C.



Defects

There were only three major defects that occurred while processing the recycled material. The first was that there was some flash at the bottom of the rim of the disc. This was an odd spot for flash to occur, as it is typically found at the parting line of the mold. This flash may be caused by some defects in the mold. As for the second defect, there was one disc that had drool in it, due to the press running out of material while the discs were being molded. In the time it took the group to mix colorant into more material, the nozzle had produced drool without anyone realizing it, which made its way into a disc. The third defect was a short shot. The only time this defect was experienced was when the second molding session took place because a full shot was not built during the first shot.

Color

The colorant worked well with the PCR material. The colors mixed with the PCR came up a little lighter than they would with a virgin resin, as the PCR material was white instead of translucent. There were some instances where white spots showed up on the discs. This was possibly due to an uneven mixing of the colorant before it was loaded into the hopper.

Hot stamp

The last quality standard the PCR material should adhere to is the ability to be hot stamped. Hot stamping is the process of transferring a film image onto the surface of a part using heat and pressure. The film that is currently being used for the hot stamp does not form a complete university logo on discs made of PCR material. This is likely due to the adhesive layer of the film not being compatible with PP.

Conclusion

Over 20 kg (44 lbs) of single-use plastic was successfully diverted from the landfill over the course of a few months. This may not seem like much now, but it is the first step in creating a process to recycle multiple types of plastic waste, and if the collection continues, that 20 kg will continue growing. Expanding the collection area should increase the amount of plastic waste collected at the engineering college.

Recommendations

The initial goal of this project was to create a process that could recycle both used pizza savers and utensils, as well as plastic film. To complete the initial synopsis of this project, various recommendations should be considered.

- Develop a counterweight for the modified dishwasher to keep it from tipping over when the racks are fully extended out.
- Create a process using the agglomerator to recycle plastic film.
- Place multiple collection bins at every cafeteria or dining hall that uses plastic silverware at the university. This would increase the number of recycled utensils to be collected.

Future Projects and Progress toward Sustainability

In order to solve the problem of plastic waste and environmental issues, there needs to be education of the younger generation. The plastics lab hosts many school groups of all ages. They learn about plastic injection molding and learn how plastic pellets get turned into flying discs in a hands-on setting, and they take home with them a flying disc with the university logo that they made themselves. The success of this current project can help build even more interest and educate them on more sustainable plastics manufacturing processes. Eventually, we hope that as these students come for tours, they bring plastics waste that is collected at their own schools so that they can have a hands-on lesson in recycling. Continued effort to increase waste collection from future projects can help establish distribution of only 100% recycled flying discs to all future visitors and eliminate the need to purchase more plastic.

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