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NICARAGUA BOTTLE UPCYCLING PRODUCT DESIGN AND MANUFACTURING

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ABSTRACT

Growing plastic waste streams are a critical issue around the world, particularly in developing nations such as Nicaragua, and there is a need for environmental and sustainable solutions to help reduce the amount waste. To assist ongoing initiatives to reduce plastic waste, RIT's Multidisciplinary Senior Design team 18433 worked to design a manufacturing process to upcycle used plastic bottles into a valuable commercial product. The manufacturing process is broken into three sections: shredding the recycled bottles into plastic chips, melting and forming the chips into a laminate sheet, and vacuum form the laminate sheet into an end product. The entire process is beneficial to local communities in developing nations because it can be used to help drive recycling and waste reduction efforts while also providing means for economic growth. Through a nine month period full of research, fabrication, and iteration, team 18433 has developed a melting and compression system to form the shredded plastic chips into a laminate sheet. The system receives a set amount of plastic and uses resistant heaters and a car jack to form a laminate sheet that can be turned into a variety of products. In conclusion, the team has recommended several improvements for future iterations that can be made in order to make the overall system more efficient and practical in actual implementation.

INTRODUCTION

Representatives from the 4 Walls Project and the Enlace Project, two organizations that provide aid to Nicaragua, have asked RIT's senior design team 18433 to help design a manufacturing process that can be used to upcycle plastic waste and help start a small business in the town of El Sauce, Nicaragua. El Sauce is currently facing an uphill battle as they struggle with an excessive amount of plastic bottle waste coupled with an inconsistent, low-paying job market. A clear understanding of the project goals and necessary requirements from the customer provided a direction for the team to design a feasible solution.

The team's primary objective was to develop a manufacturing process that will upcycle wasted plastic bottles in order to assist El Sauce with better waste management and recycling efforts, as well as build the framework to help create a small business that can sell useful products to the local community. In order to achieve this objective, the team needed to design and prototype a machine that melts and molds plastic chips into a feasible product. The final machine design utilized compression molding methods to create a versatile final product.

This project continues from MSD Team P17433, who went to El Sauce and conducted research on the bottle recycling systems currently in place. They developed an initial concept for a building block that was designed to increase ventilation, to be used as room dividers, and other functionality. Team P17433 was able to design and build a plastic shredder to turn the recycled bottles into chips. The key takeaway from this project was that we were able to start with valuable information about El Sauce and what their needs actually were. Additionally, as we began the project, we decided to not improve upon the shredder as it was not functional and would take up too many resources to get working and instead to focus on the next phase of the project instead.

Precious Plastics is an open source initiative that shares schematics and assembly instructions for home or small scale plastic recycling machines. Their plastic compression machine served as the primary benchmark and design source for the team's solution to the proposed problem [1]. It was their demonstrated success in the plastic forming field that provided the confidence that the team could be successful in their endeavor.

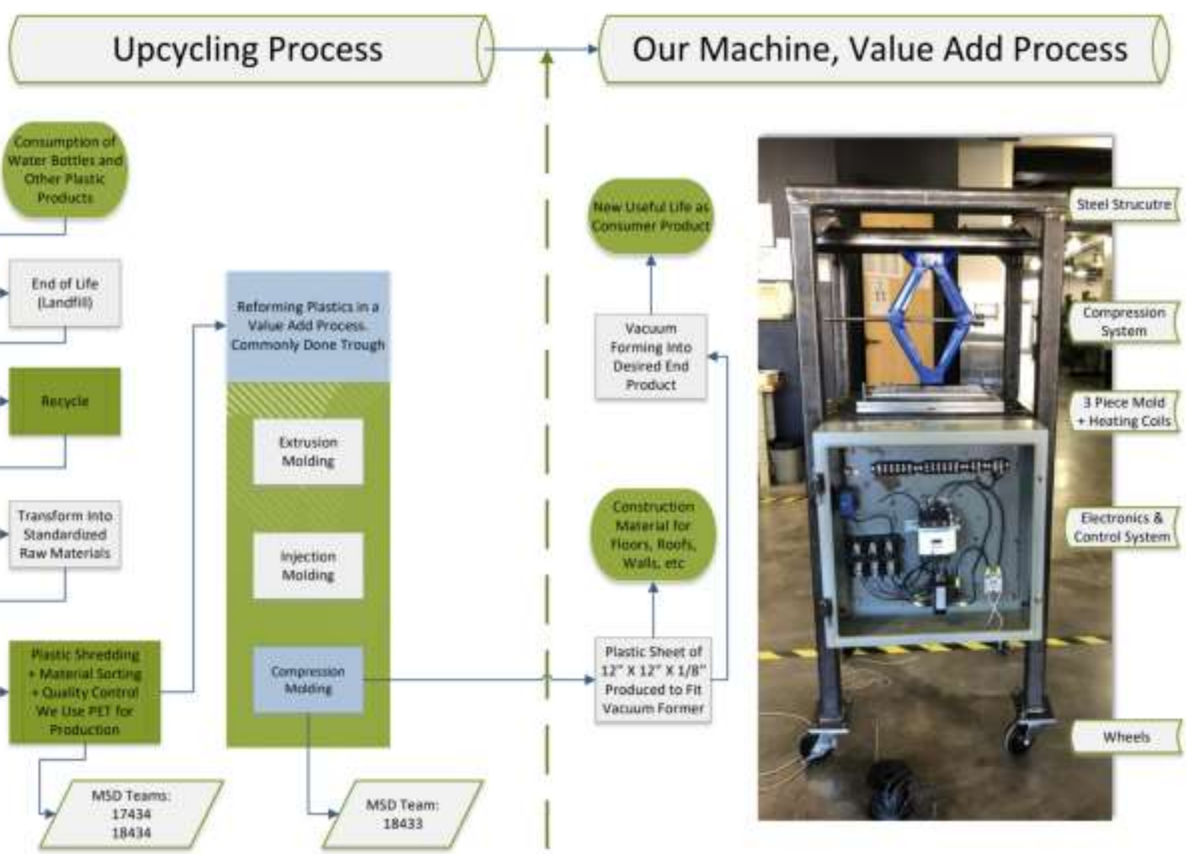

Figure 1: Upcycling Process Flowchart

PROCESS

Specifications & Engineering Requirements

The principal engineering requirements for this project are that the overall system should fit within a 1x1 meter footprint to ensure it can fit in a house in El Sauce, be able to reach a temperature range between 240 - 260 degrees Celsius to melt and not burn the plastic, and have no exposed hot surfaces or fumes for the safety of the workers. Additional constraints that the project faces include being restricted to 220-240 volts AC grid power, designing the manufacturing process for semi-skilled laborers to operate and be able to be maintained in El Sauce, having the end product be able to be manufactured in El Sauce, and being limited to an initial project budget of $500, which was increased to $1250. Lastly, the team was restricted to work with polyethylene terephthalate (PET) plastic as this is the material that plastic bottles are made of.

Engineering Requirement	Importance	Source	Aspect	Requirement	Unit of Measure	Acceptable Value	Target Value	Ideal Value
ERE1	9	CRE5, CRE11	Heating	Furnance temp range	C	240-260	250	250
ERE2	3	CRE6, CRE10	Production	Number of different Molds	Units	1	2	5
ERE3	9	CRE1, CRP5	Production	1 batch (of 4 product molds) per hour	Units/hr	0.5	1	>1
ERE5	3	CRE2, CRE4, CRE6, CRE7	Equipment	Machine size	m2	1x1	0.5x0.5	<0.5x0.5
ERE7	3	CRE1, CRE6, CRE7	Equipment	build time for the system with standard work instructions	hr	50	35	20
ERE9	3	CRE7, CRE9, CRE10	Compression	Pressure requirements for the molding process	Pa		tbd	tbd
ERE10	3	CRE5, CRE9	Safety	Outside temperature of the system	C	50	40	30
ERE11	9	CRE1	Production	Number of workers required to operate	Units	3	5	10
ERE12	3	CRE11	Equipment	Variable chip size acceptable	cm3	1	tbd	tbd
ERE13	3	CRE10	Equipment	Mold size acceptable	cm x cm x cm	38x38x38	38x38x2.5	38x38x2.5
ERE14	3	CRE7, CRE9	Heating	Lower heat loss rate	J		tbd	0
ERE15	3	CRE5	Safety	PPM of fumes produced, Polyethylene (low density) - Butane exposure	ppm	800	0	0
ERE16	3	CRE5, CRE9	Safety	Area of exposed hot surfaces	m2	0.25x0.25	0	0
ERE18	3	CRE2, CRE3	Safety	Force to tip over	N	500N	1000N	>1000N
ERE19	1	CRE2, CRE6, CRE10	Equipment	Low sub assembly weight (excluding frame)	kg	22	15	<15
ERE20	3	CRE2, CRE6, CRE10	Equipment	Small sub assembly	m3	1x1x1	0.5x0.5x0.5	0.25x0.25x0.25
ERE21	3	CRE7, CRE9	Heating	Power required from grid	V AC	250	220	120
ERE22	3	CRE5	Equipment	Surface roughness of the mold interior	µm		tbd	tbd
ERP1	3	CRE7, CRE11	Production	Weight of recycled plastic chip input per mold	kg	5	3	1
ERP2	3	CRE7, CRE9	Heating	Watts per unit of output	W/hr	120	<120	<120
ERP3	3	CRP4	Product Quality	End Product Weight	kg	0.7	0.6	0.5
ERP4	9	CRP2	Product Quality	Percent of product to fit together	%	95	100	100
ERP5	1	CRP4	Product Quality	Mass of water supported by gutter per meter of gutter	kg	15.6	tbd	tbd
ERP6	1	CRP4	Product Quality	Impact force to break the product	J			

Table 1: Detailed List of Engineering Requirements

Assumptions

While working through the design process, the team has made assumptions in order to create a realistic scope for the project as well as to help create our final design. From the start this project did not have a source of plastic to test the manufacturing process, so the team assumed that the input of plastic chips could be obtained either through shredding bottles or purchasing them. Additionally, the assumption was made that the input of plastic chips will be small, roughly uniform, and clean of debris before being utilized in the manufacturing process. Considering that the entire manufacturing process may not be able to be shipped to El Sauce, another important assumption was that there are similar resources (bandsaw, end mill, etc.) available in Nicaragua in order to reproduce the design. The last key assumption is that a vacuum forming machine, needed to create the end product, is available for use in Nicaragua or can be constructed by a future senior design team.

Concept Generation & Evaluation

When initially generating conceptual solutions to the proposed the three main plastic forming methods were investigated: compression, extrusion, and injection. In order to narrow down to one method, three primary criteria were considered: cost, maintenance, and ability to be produced during MSD. Injection and extrusion solutions were eliminated due to the designs requiring a lead screw, which would require a large monetary investment that would cripple the budget. Attempting to machine a lead screw was considered, but the resources available to the team were insufficient to create the thread and taper necessary for molding. Compression molding was chosen due to the relatively low initial cost, ease of manufacturing, and low maintenance requirement for potential implementation in Nicaragua.

Risks

While analyzing the project and working on the system, the team came across several key risks that influenced the design process and final manufacturing process. From the beginning, the team was unsure of how we would be able to test our final design because P17433's plastic bottle shredder does not function in its current state so there was no reliable source of plastic for us to test with. Another early risk that constrained the project was that the material cost to build our prototype design was larger than our initial budget so it seemed unlikely that we would be able to create a functional process. Specific to the actual design, the plastic heating and cooling cycle time is too long to be practical for implementation as well as the fact that the plastic may not melt uniformly due to the distribution of the heaters. There are also additional risks associated with the safety of the operator that include hot surfaces being exposed and the potential for the plastic to burn and release toxic fumes. The team has also had to face the risk that a team member may be unable to contribute to the project for an extended amount of time due to an unexpected event.

Feasibility Testing

In order to better understand how the system would work on a full scale, the team created a prototype mold to test melting the plastic into a scaled down sheet. The results from the tests gave a better understanding of the physical properties of melted plastic and the necessary requirements in order to properly melt and form the plastic.

Plastic Test 1 was a simple plastic melting test that used the acquired PET chips on an aluminum sheet resting on a hot plate to observe physical properties of plastic as it melted. The team learned that melted plastic was very viscous and did not flow as easily as expected. Only the plastic in direct contact with the aluminum properly melted, so the heat did not transfer well through the plastic. Results of Test 1 can be seen below in Figure 1. Based on the results from this test, the team decided that the melting method needed to utilize a larger surface area of heated metal to properly reshape all of the plastic.

Figure 2: Preliminary Plastic Melt Testing

Plastic Test 2 utilized a scaled-down prototype mold set on a hot plate. The mold was heated up to 350 degrees Celsius and plastic chips were placed within the cavity. The plastic was left to melt within the mold for 45 minutes. A heat gun was used to apply heat to the top half of the mold and compression was provided by a weight placed on the mold. The system was then allowed to cool back down to room temperature to ensure that the plastic had completely rehardened. Once, the system was cool the mold was opened and the plastic sheet was extracted. Applying direct heat to only one side of the mold resulted in half of the plastic sheet melting and forming into the desired shape. The other half of the plastic sheet did not melt down and there were still loose chips after extraction. This test showed the importance of equal heating in the mold and the effects that this would have on the finished product. Images of the resulting plastic sheets can be seen in Figure 2.

Figure 3: Second Plastic Melt Test Results

Plastic Test 3 built upon the results of Plastic Test 2. Test 3 used the same scaled-down prototype mold set on a hot plate. The difference this time was that a heat gun was not used to heat the side of mold not touching the hot plate. Instead, the mold was flipped halfway through the melting process to simulate uniform heat being applied to both sides of the mold. After the mold cooled down back to ensure that plastic had rehardened. An issue arose when trying to open the mold and extracting the formed plastic because the plastic was sticking too much to the inside cavity of the mold. This caused the plastic product to break apart into small pieces when the prototype mold was opened, which is assumed to have occurred due to the amount of mold release that was used. Despite being unable to successfully remove the product, this test showed that the plastic indeed was able to properly melt on both sides and that the desired thickness could be achieved. This test validated that uniform heating to both sides of the mold is critical to being able to properly melt and form the plastic.

Test Plans

Test plans were created for the various aspects of the project, including simple observations, length measurements, weight measurements, temperature and heating, efficiency, compression, safety, and chip input tests. The observations tests detailed tests not requiring tools. The length measurements relate to the size of the subsystems and the system as a whole. Weight measurements detail the subassembly and end product weight of the system. Temperature and heating tests evaluate the effectiveness of the heating system implemented. The efficiency tests cover various aspects of efficiency of the device from number of products made per hour to energy used per product. The compression tests evaluate the effectiveness of the car jack as the force exerting device. The safety tests cover the fumes produced and the stability of the device. The last test on chip input size evaluates what size of chips work with the system.

RESULTS AND DISCUSSION

Final Design of Manufacturing Process

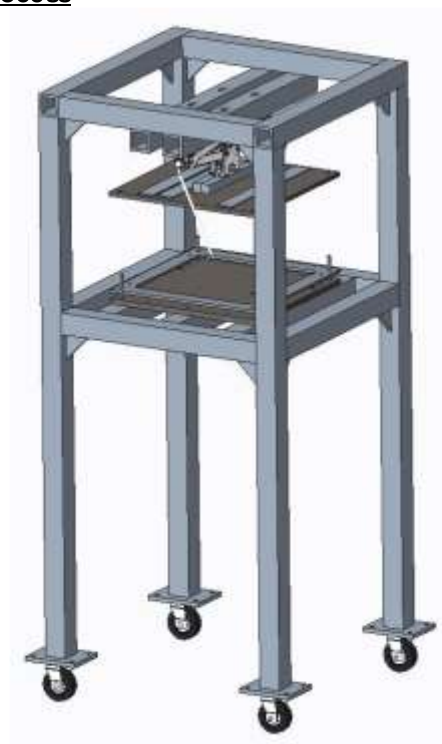

Figure 4: Final Assembly Model of Plastic Melting and Compression System

Figure 5: Final Assembly of Electrical System

Subsystem Breakdown

Structural Frame

The frame was built using A36 1/4" and 1/8" steel tubing and A36 1/4" plate steel for the gusset plates. Machining the tubing for the frame was not difficult, but assessing the proper location for our alignment features took us more than one try. The frame was initially tack welded in order to ensure that that mold and car jack would properly align before committing to the dimensions of our structure.

Mold

The mold was made with 2 plates of A36 1/2" steel and 1 aluminum plate. This 3 piece mold design is to help facilitate extraction of final plastic product. Care was taken when milling the mold surface to limit plastic sticking as well as care with the alignment pins installation into the mold.

Heating & Electrical

The heating system utilizes 6 strip heaters, with 3 attached directly to each side of the mold and positioned to optimize even heat distribution. The electrical system utilizes a temperature reading input, a desired set temperature, and various other components.

Insulation

Insulation is placed at locations for potential exposure to high temperature frame components. The insulation placed underneath the mold is to assist in retaining heat for efficiency and to protect the operator. The insulation is also attached around the vertical posts of the structure that will conduct heat from the mold support. The insulation we chose to use was 1.5" thick Ultra-High-Temperature Ceramic Fiber Insulation which was cut to appropriate lengths and attached with tape.

Test Results

At the time of writing, all visual tests passed including machine accepts mold, machine is within desired footprint size, and one mold has been created for use. The more involved tests involving melting tests were not able to run yet as some subsystems are still being integrated, including the electrical and heating. In the time constraint of MSD, we were able to accomplish the physical tests of the system, along with some other plastic melting tests outside the system. From the length measurements that were able to be completed, the design satisfied these constraints initially proposed.

TEAM OPERATIONAL DECOMPOSITION

	Main Responsibilities	Other Responsibilities
Adam	Electronics and Controls, Research	Procurement, Documentation
Ignacio	Manufacturing, Mold Design, Project Leadership, Budgeting	Procurement, Documentation
Kyle	Electronics and Controls, Manufacturing, Research	Procurement, Documentation
Pierce	Structure Design, Insulation, Note Taker, Documentation	Calculation Models, Meeting Agenda
Vikas	Structure Design, Technical Drawings, Mold Design	Manufacturing, Documentation

Table 2: Responsibility Matrix

In Table 1 we see the operational decomposition for the team, each individual took over a series of main responsibilities revolving around subsystem design, assembly or manufacturing. These can be seen though this decomposition depicting how the team split responsibilities to bring the project to completion.

CONCLUSIONS AND RECOMMENDATIONS

When building this machine the team made a series of findings. One of the most important things that we learned through this process is that there are only 36 weeks to design, build, and document the entire process, for which there is going to be work than you can imagine. So KEEP IT SIMPLE and stick to the simplest idea that you will think will work.

In a more technical aspect, we faced many problems for which we had to find solutions or pivot our design. When it comes to plastic molding you must understand the vital phases of the process, which is as follows: introduction of raw plastic into the system, heating method, forming method (mainly injection, compression, or extrusion), system cooling method, plastic release system (i.e. how to release the plastic without breaking it), and the ejection system (i.e. extract the final form without breaking it). Through all of this, it is important that you keep safety in mind as the entire system will get extremely hot and you must handle with mold and car jack with care and thoughtfulness. Keep in mind that your budget will impose limitations that can more often than not be resolved with some ingenuity and manufacturing knowledge.

It will be vitally important that you budget well, which does not mean that you need to calculate the final number exactly at the start, but that you must be well within the ballpark. Raw materials are expensive and you will have to account for a series of purchases which will not have predefined price tags, such as metals. To help avoid issues, when you are trying to build a technical part make sure you acquire material that will neither deform nor be received in a state where it will not meet the functional requirements. We experienced this with our mold metals, which were bent and required a large amount of rework to utilize correctly. You might also consider switching your design to adapt to cheaper materials, which will require more time but might pay off monetarily.

In order to assist teams continuing on this project in the future, we have compiled a list of recommendations to improve upon our design and to help aid their own work. First, molds are highly expensive to design and manufacture so you should properly research the correct types of materials that should be used for a mold. To add to the design of the mold, it would be beneficial to grit blast the surfaces of the mold for a smoother surface and to aid the extraction of the formed plastic. However this task may need to be outsourced to another company as the current size of the mold is beyond the size capabilities of RIT ME Machine Shop. Second, design a cooling system to help the forming process and decrease the cycle time. Currently the heat up and cool down times for the system are impractical and so the addition of a cooling system may create a feasible manufacturing process. The current production times will lead to a poor quality laminate sheet that will in turn lower the value of the final consumer product. Relating to the quality of the formed plastic sheet, designing a proper ejection method will create consistent products. Also, design a simple vacuum former to be used in El Sauce to create the end product. There are currently two critical heat sinks in the mold, these are the middle beam and the carjack attachment to the mold, so it is highly recommended that you either insulate these or get rid of them. Lastly, design an end product that can be vacuum formed from the manufactured plastic laminate sheet and be sold as a value-add item in El Sauce. The team decided that a gutter would be a valuable final end product, but this idea should not limit future teams. The purpose of using the manufacturing process to create vacuum formable plastic laminate sheets is that it allows for the ability to have multiple end products by using different product molds.

REFERENCES

[1] "Compression Machine" [Online]. Available: https://preciousplastic.com/en/videos/build/compression.html. [Accessed: 26-Apr-2018].

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