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Smart Compact At-Home Crusher to Promote Environmental Sustainability

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Abstract

Reducing plastic waste is seen as a grueling effort that takes too much time, but directly involving people in the process could encourage more recycling. We are designing an at-home water bottle and can crusher that addresses the problem of not having any small crushers on the market. Pre-existing products consist of manual can crushers, DIY crushers, and large industrial-size crushers impractical for many home or apartment residents. Our product aims to solve the problem that most existing competitors are experiencing. We would want to address a few issues: saving time, saving space, and having an easy-to-use product. We aim to address these issues by incorporating automated functionality. Research from other individuals who have done previous studies on this topic was also conducted to understand the nature of prior studies on sustainability and the historical trends in recycling plastic. Our group also analyzed several designs using their customer needs matrixes and FMEA analysis. The selected design is then justified based on the matrixes and customer needs. A stress analysis of the structure is simulated, and structural corrections are discussed. Our design has been finalized, and we have already begun manufacturing the product.

Keywords
Sustainability, practicality, waste reduction, automated manufacturing, senior design project, and capstone.

1. Introduction
Recycling sustainability has become an increasingly promoted topic for the betterment of the environment and society today. Reusing and recycling methods are continuously being implemented in our everyday lives, as seen in recreational areas, schools, offices, and parks. While the importance of recycling has been stressed in recent years,

many challenges and difficulties still prevent efficient sustainability. Plastic pollution is a growing concern that contaminates the environment, as less than 9% of plastic is recycled in the U.S. (California 2024). Although people are encouraged to recycle in public settings and at home, it can be difficult for some to follow through. Our idea is an at-home automated water bottle crusher that can also accommodate aluminum can crushing. Our automated water bottle/can crusher aims to motivate people to recycle more at home. It will provide an easier, faster, and more accessible way to collect recyclables, influencing people to go green. Aiming to promote sustainability on a much smaller scale will aid in the overall goal of keeping the environment clean.

1.1 Objectives

The project will have several objectives, including the capability to operate automatically and be its own bin with a compartment on the bottom that can be removed to dispose of the crushed drink containers. The crusher will also crush standard water bottles, standard soft drink cans, and other plastic water bottles up to 12 inches tall or less.

2. Literature Review

This literature review is crucial for our research on this topic because it will give us an idea of how to approach the project and provide us with background and knowledge of why it is essential. Gathering academic articles on this topic will give us more information on whether a similar idea exists, how we can improve our idea, and how it can appeal to the consumer better. Since our concept revolves around recycling, this research will help us identify the obstacles to recycling, which will help us improve and implement solutions into our project.The articles obtained seem to follow three themes, each of which falls under the same topic of recycling sustainability through at-home recycling crushers. To illustrate, the research article by Kin Sui (2020) has the theme of public sustainability and discusses how their research involving the public in designing recycling processes or procedures in their homes or housing complexes increases the likelihood that they will recycle, as they state,

Among the 97 interviewees, 36 residents, two cleaners, four scavengers, and three property management staff mentioned that this project facilitated their participation in household recycling. Twenty-two residents mentioned this project enhanced their motivation and changed their undesired behavior at the beginning. . .

Siu (2020) also remarks on how this positive attitude toward recycling changed since "their willingness to form sustainable behavior declined due to poor implementation and management." This research article illuminates how the public's attitude toward recycling can be positively changed if they are directly involved in the process and if the process is managed correctly. Since our idea aims to create a household-crushing machine, the individuals who purchase a home crusher will be directly involved and manage the process in their unique way (Siu 2020).

Though Siu details the importance of individual involvement in the recycling process, there is no clear description of recycling methods similar to our proposed project. What is explained in the article is the attitudes individuals have towards the concept of recycling based on their direct involvement in the process. This is still relevant information to the project because of its targeted domestic use. This can increase individuals' participation in recycling, increasing positive attitudes towards the subject.

The impact of recycling on the environment is the theme of the following two articles by Osama Lamma (2021) and Jefferson Hopewell (2009). Both articles focus on reusing recyclable materials rather than discarding them. However, they differ because Lamma's (2021) article focuses on preserving the environment through recycling. Figure 1 demonstrates how Lamma (2021) highlights the lack of plastic recycling in contrast to other recyclable materials. In comparison, Hopewell (2009) dives into the challenges and opportunities recycling presents to help the environment in different geographical areas. Figure 2 reveals the increase in plastic collected in the UK since they implemented curbside pickup for some residential regions. Hopewell (2009) discussed this in their article. This demonstrates the impact of making recycling convenient for people from the comfort of their homes or apartments, which can be translated to having a water bottle crusher for occupants to make the process even more convenient and save valuable space.

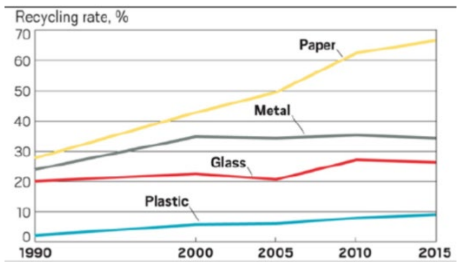

Figure 1. Recycling Rate Percentage (1990-2015)

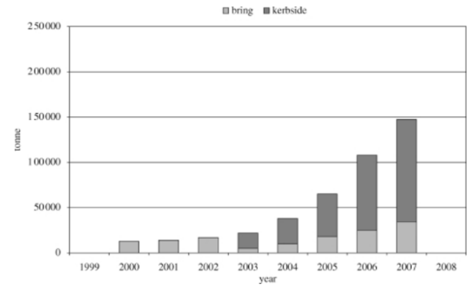

Figure 2. Growth in plastic collection from curbside pickup service in the UK after introduction

Like Sui's article, Lamma's and Hopewell's articles include relevant information about recycling and its impacts on the general environment but lack information directly related to the effects of domestic recycling processes. Though the impact of large-scale recycling is essential to consider while researching for and developing the proposed project, insight into small-scale recycling would be more beneficial to the overall purpose, given that the issue at hand is based on domestic recycling.

The last set of articles focuses on the theme of recycler crushers, with Agarwal's (2018) research focusing more on the design of a cost-effective recycling machine for the public, while Sawant's (2016) article centers on the mechanics and analysis of how a crusher crushes cans. The key findings in Sawant's (2016) research are that the more mass a crusher has, the easier it is to crush a can. Figure 3 demonstrates this study by showing how a can with different thicknesses affects the crushing force. While this may seem like common knowledge, minute details like the thickness of the crusher and the time it took to crush each can help refine the design of the at-home crusher and inform how robust the design will need to be.

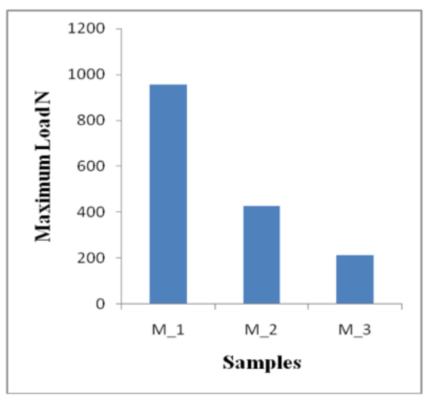

Figure 3. Crushing strength variation with the mass of the Crusher.

Sawant's research highlights critical factors to consider while developing the project, but a few gaps may need further research to perfect the solution. For example, Sawant does not mention the impact of speed or the mass of the crusher itself and how it can impact the crushing of a can. Another factor not explained is the impact that pre-bending may have on the effectiveness of a crusher. Agarwal's (2018) article explores potential machines that can aid in recycling, such as our proposed can crusher. However, differences in available resources and new technological innovations may create a gap between what is described in the article and what is possible to develop as our solution.
Considering the information provided by the above sources, it can be concluded that the current population lacks access to easy recycling methods despite community sustainability awareness. The market also lacks a feasible, convenient solution to this problem. Though Agarwal (2018) began to develop a solution to the problem, it can be improved in many ways with newer technologies.

The article by Anugrah (2020) discusses the design of a large gas—and electric-powered water bottle crusher meant for industrial use. The research highlights the efficiency and performance of both motors, with the electric motor producing a higher efficiency yield than the gas-driven motor (Anugrah 2020). This result was achieved after a cost analysis of the operating costs for both machines. The result for both crushing strength and motor efficiency was that the electric motor was 2.6 times more efficient than the gas motor (Anugrah 2020).

The limitation of Anugrah's article is that our group is not designing a large crushing machine meant for industrial use. Their crusher's design was also different from our intended design, once again, since we aim to target homes and apartment residents. We are also not concerned with the use of a gas motor since it's not practical or safe for home use. Not every water bottle or soda can needs to end up in a landfill. An at-home water bottle crusher enables an individual or household to decrease its environmental footprint. An incalculable number of empty bottles and cans are generated daily, and having a recycler in the home drastically increases the likelihood of people recycling. Mindfulness towards recycling decreases with the amount of effort required. The environmental impact of beverage containers will be condensed by creating a crusher with enough mechanical strength to condense bottles and cans for more convenient recycling.

3. Methods

When it came to designing alternative concept designs, we had taken in mind that the crushing mechanism and the bin would be separate from each other. We began by designing various designs that focused on our crushing mechanism's housing, including how cans/bottles would be inserted and how they would be ejected. We designed the bin based on the specifications after coming up with possible housing designs for the crusher mechanism and selecting the best one that meets our needs.

The first alternative design seen in Figure 4 involved an intensive creative design process. The aim was to integrate extendable mounting brackets to fit trash compartments of various sizes. This would meet our customers' needs for flexible integration. The advantage, of course, would be that the customer would be able to use our product in any trash can that they desire to do so. The disadvantage of this design is that there must be enough clearance within the bracket for the shoot hatch to open, as seen in Figures 5 & 6. This would also create an issue when mounting into the trash compartment as an issue that may occur is for the crusher to tilt over on one side. This would occur due to the hatch being on roughly half of the crusher, thus requiring the mount to be placed near it so that it can open and dispose of the contents of the trash compartment. This means the crusher might only be mounted from half of its body, and the weight countering could cause it to tilt if no support is built on it.

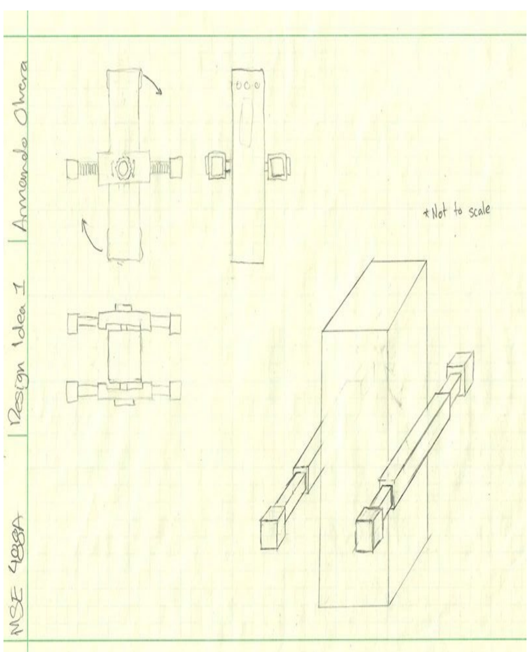

Figure 4. Concept Design 1

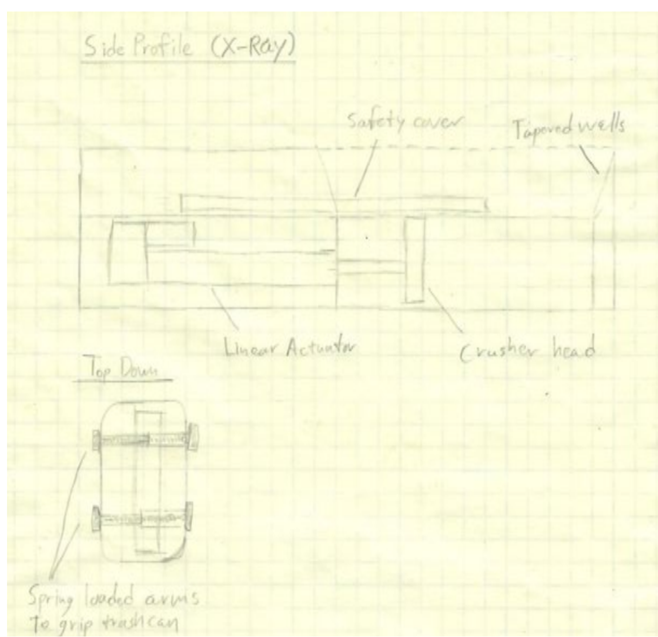

Figure 5. Crusher X-ray View

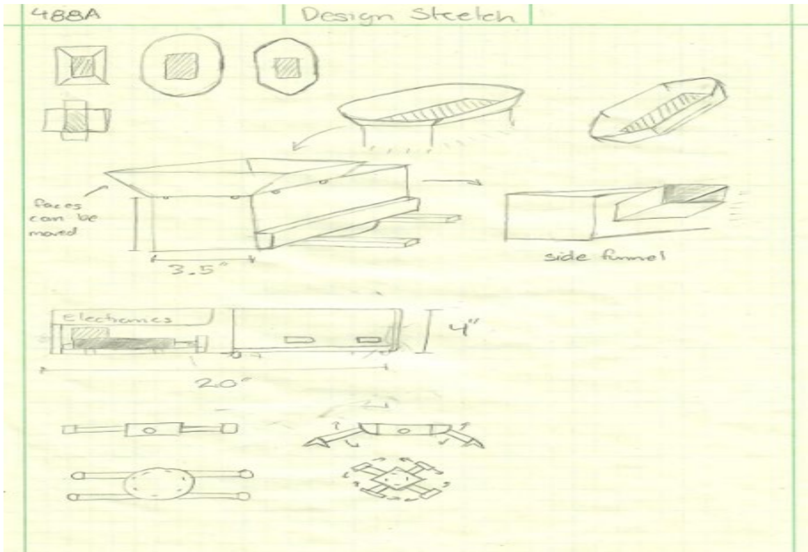

Figure 6. Design 1; Version 2 – Design includes funnel contraction to insert cans/bottles.

The second alternative design was designed with a different approach. This design consisted of a vertical standing crusher with the actuator and components built on the top half and the crushing mechanism below it, as seen in Figures 7 & 8. This design was designed with the idea of bottles and cans to be placed inside by opening the door compartment. The idea was that it would include an on/off switch or button, and while it's switched on, the crusher would work repeatedly if the door is closed, and once it's open, it would not function as this would when the bottles are placed inside. The bottles would then be disposed of from the bottom. The advantage of this design is that it would save space more efficiently since it is built vertically. One of the disadvantages of this design would be that there is room for failure in the disposal of the bottles and cans concerning the location of the shoot. This issue to be considered is that the crushing mechanism may cause damage to the shoot since it is placed where the final crushing form would be. Another disadvantage to this alternative design is that the user would constantly have to open and close the door while placing the bottles or cans. This would remove the automation of our customers' needs and would no longer meet the market or target design goals.

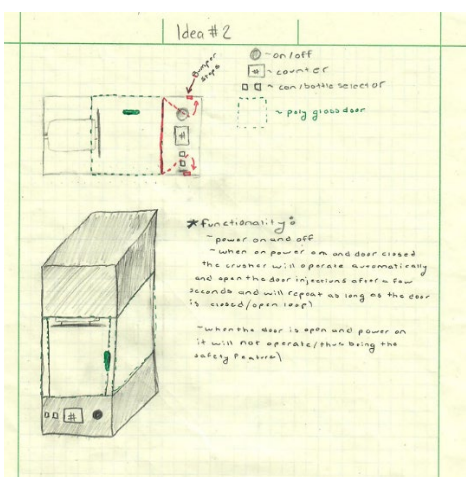

Figure 7. Concept Design 2

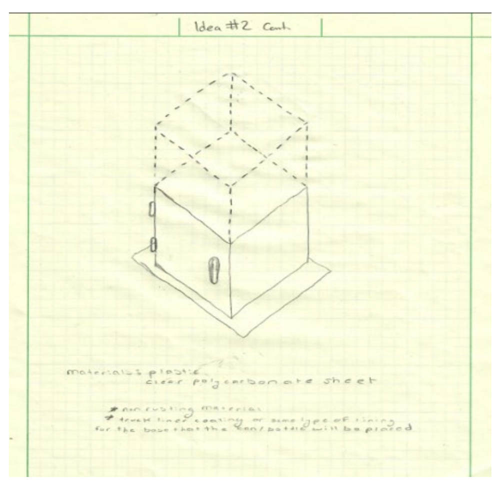

Figure 8. X-Ray View

The third alternative design differs from the rest as the crushing mechanism would consist of rollers, as seen in Figure 9. Some industrial-size crushers inspired this different approach in hopes of making a compact version, as there is currently none on the market. An advantage of this design was that rollers would speed up the process and allow for more simultaneous crushing. A disadvantage of this design was that it was challenging to finalize the concept design as it involved other factors that needed to be considered adequate. Another disadvantage was the noise level since the rollers being on and working would cause a lot of noise; therefore, the customers' needs were low. Noise levels would not be met. Another disadvantage was that it was difficult to decide where the bottles and vans would be disposed of if no compartment was built. If it were attachable, it would be an issue, and the mounting points and bracket would not allow it to be placed in any trash bin since the rollers would either be fairly long or short, depending on the final design.

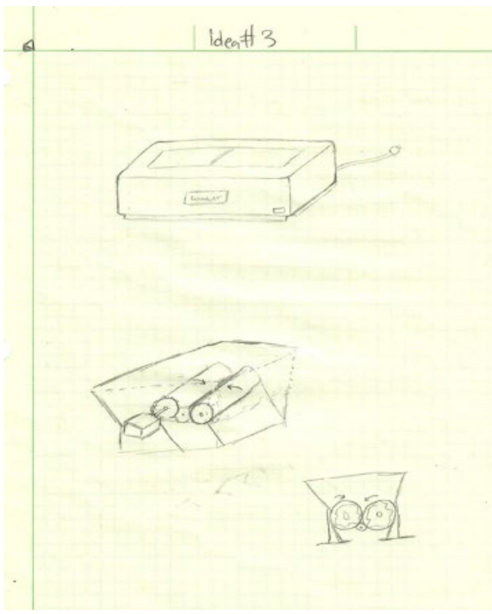

Figure 9. Design 3

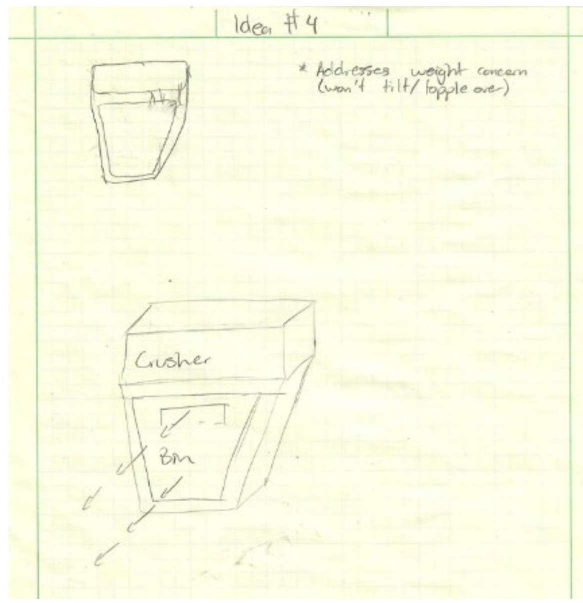

Figure 10. Design 4- Hand-drawn Sketch

The fourth alternative design was constructed to remove many concerns from the previous designs. We favored the landscape positioning of our first alternative; therefore, it was designed to remove the need for brackets and the issue of what bins might fit or not. Figure 10 more clearly illuminates the overall idea of the design, with a more understandable rendering presented in our CAD model, as seen in Figure 11. A disadvantage of this alternative design is that it would increase the overall size, meaning it is no longer as compact as the previous iterations, such as Figure 12.

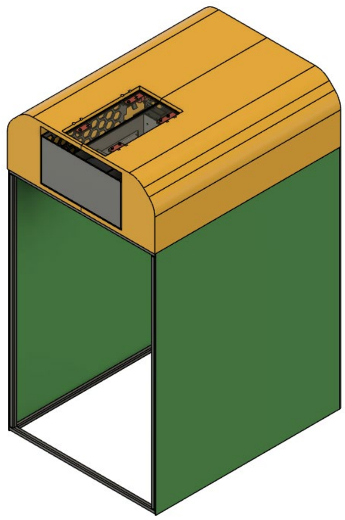

Figure 11. Design 4

Figure 12. Rough Final Design & Iteration 2

Overall, the decision of which design to choose came down to practicality, feasibility, and safety. Design 1 is feasible, but it lacks practicality in the sense that it doesn't take into consideration the actual size of the crusher and how the weight is distributed if it's attached to a trash can. The chance of the crusher toppling a trash bin is too high for us to consider this design idea, but it served as the backbone for how we came up with other iterations in terms of practicality. The conceptual design still served as the cornerstone of our crusher housing development and further determined the overall design of the other iterations, except design 3. Design 4 was the byproduct of considering safety, function, and feasibility. It ensures safety by housing the crushing mechanism and has bay doors that open for the user to drop a bottle inside. The overall idea is to have the crusher come with its own bin to make things more streamlined in terms of weight distribution and disposal of crushed containers. The bottom bin will have a removable compartment, like at-home paper shredders, that will help consumers bag and recycle their containers.

Design 4 is the optimal choice for its features and overall functionality. It solved our weight distribution problems and safety hazards presented in the other design iterations. It also had the lowest FMEA score compared to the other designs and meets all customer needs.

After discussing and considering the manufacturing process for our prototype, the design of our product changed to reflect a more realistic and manageable product. As seen in Figure 12, the frame is no longer simply plastic but rather steel square tubing that we will outsource from a wholesale store. The side panels will also have 3D printed or ABS sheets to cover the product's internal bin/drawer compartment. The lid/cover of the internal mechanism is also going to be 3D printed. We made sure to emphasize the 3D printed parts of the product by having them be different colors than the other metal parts, as seen in Figure 11.

4. Data Collection

4.1 Material Selection

After further analyzing different types of metals, filaments, and materials, we concluded that the best selection for our product is polycarbonate, ABS filament, and 304 stainless steel. Polycarbonate is a transparent thermoplastic that has various beneficial structural integrities. we chose this material because it has a high impact strength, making it resistant to impact and fracture. Our goal is to create a better living environment where individuals can help make a change, so using polycarbonate will be beneficial. This is due to its being eco-friendly in terms of processing and recyclability. ABS filament is a common material used for 3D printing. ABS is strong, durable, and synthetic. One disadvantage of this is that it's less environmentally friendly than other filaments and is prone to warping during printing. There are various types of steel, but they all have different qualities that make them better than others. We chose 304 stainless steel because it is corrosion-resistant, has high durability, is easy to fabricate, and is crucial for us as we will need to be able to weld, and it is recyclable. The disadvantage is that it is on the higher end in terms of cost.

4.2 Manufacturing Process

The first step in our manufacturing process consisted of assembling all the electrical components of the crushing mechanism. This consists of wiring together the transformer, power distribution block, motor drivers, and Arduino to operate our actuators effectively. What proceeds next is programming the Arduino. We opted for outsourcing pre-cut stainless-steel panels and the base plate due to it requiring metal laser cutting. Our hammer, which does the crushing operation, is also outsourced. It is specifically designed for our product and requires professional machining as it will take most of the force when the can/bottle is crushed. This will be machined using a CNC mill through a trusted website, PCBway. What follows is all the parts, such as welding and assembling the metal pieces in our university lab.

Once we weld together the pieces necessary for housing the electrical components, we will focus on manufacturing the crusher's entire housing. This will consist of the lid and bin and the framing for it. The framing will also require welding metal tubing to ensure the whole bin is sturdy and does not tip over. To construct the lid and bin of the crusher, we plan on using a 3D printer in our lab. This would make it a lot more affordable and easier to manufacture. Other options we have considered are either buying a bin that fits the dimensions of our crusher or buying ABS panels to construct the bin. We also decided to print our actuator braces and hinge triggers in 3D.

5. Results and Discussion

The final design (design 4, seen in Figure 11) was selected as a culmination of fitting all the customer needs and objectives. As previously mentioned, the other iterations or designs had too many variables that we had to consider in terms of weight distribution, electrical component allocation, and structural integrity and function. For example, design one, seen in Figure 4, is a simple rectangular box that had the intended capability to fit any trash bin; however, when considering failure points, the main point of failure was that the weight of our product would be focused one side housing the electronics and therefore would lead to an increase chance of toppling when placed on top of smaller bins. Design 4, our final design, meets all customer needs and is a more convenient and complete package with bin housing that is already built in and readily available to use once acquired. It had fewer failure points that would lead to a total loss of functionality.

The final materials selected were polycarbonate, ABS filament, and 304 stainless steel. Polycarbonate serves to act as the doors in our design and is durable enough to withstand the multiple uses it will undergo when used. Having a clear doorway also allows the consumer to see the crushing mechanism in action and further adds visibility should something go wrong. ABS was selected since it is less moisture-absorbent than PLA despite being more costly. The material is also impact-resistant and will not degrade as quickly as any liquid splashing or sprayed onto it while the crushing mechanism is in motion. The 304 stainless steel was chosen due to its corrosive resistant nature, durability, handling, and high-strength material properties for parts like our [hammer] crushing head and anvil.

5.1 Numerical Results

5.1.1 Force Analysis:

The chosen design alternative was prototyping in the Autodesk Fusion software. Currently, we have a concept of the mechanism modeled to test how the mechanical components will fit together and to experiment with the dimensions of different components.

Based on the research we did at the beginning of the project, we selected two electric linear actuators capable of 1000N. Using this amount of force, simulations were run on the design's components that will be subjected to it. Three areas of the design will need to withstand the brunt of the forces: the Hammer, the motor mounts, and the Anvil. We are designing our components to have at least a safety factor of 3 when subjected to a 1000N load to ensure an acceptable degree of safety.

The actuators will be bolted to motor mounts at the back of the crusher, as seen in Figure 13. Each of the 4 mounts was subjected to a 1000N axial load, which pulled them away from the back wall to simulate the force of the actuators at full power. Simulation results report that the motor mounts have a safety factor of 12.37 as they are currently designed, which can also be seen in Figure 13. This is more than adequate and will be considered for future design revisions.

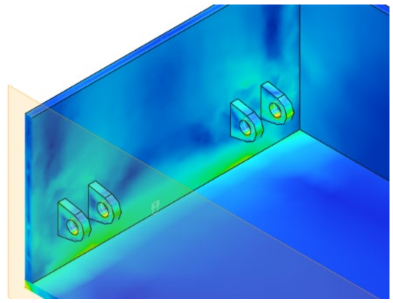

Figure 13. Motor Mount Stress

The crushing head (hammer) is attached to the ends of the linear actuators, pulled onto the bottle, and seen in Figures 14 & 15. Like most of the load-bearing components, it is designed out of a .25" thick steel plate to minimize component bending. The initial study of the part resulted in a minimum safety factor of 1.815, which is below the acceptable threshold seen in Figures 14 & 15. To raise it in increased rigidity, a rib was put across the back of the Hammer (Figure 16). Rerunning the simulation results in a new minimum safety factor of 3.027, which is within the acceptable range, as seen in Figure 17.

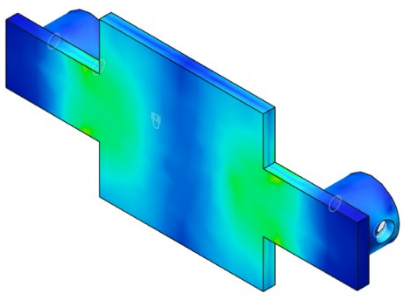

Figure 14. Hammer Stress

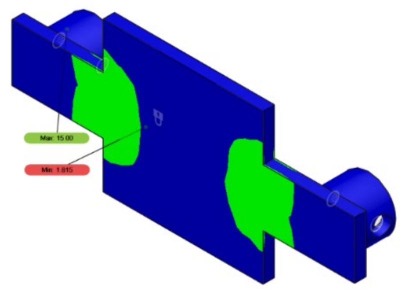

Figure 15. Safety Factor

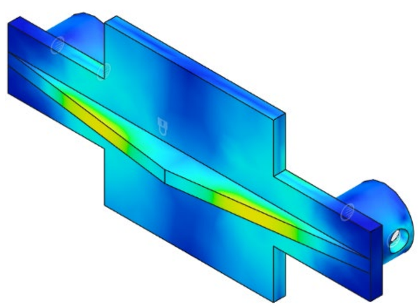

Figure 16. Reinforced Hammer Stress

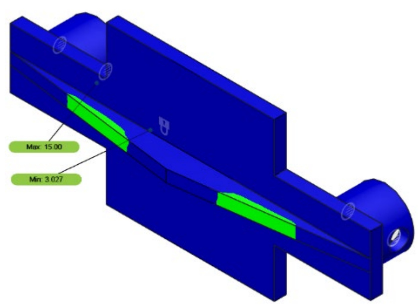

Figure 17. Safety Factor

The crusher's anvil, seen in Figure 18, will be anchored on the sides and bottom of the plate to improve rigidity. When subjected to the 2000N of force from the combined actuators, the anvil had a minimum safety factor of 10.06. This should prove more than adequate for our needs. There is also room behind the anvil should reinforcement need to be added in the future.

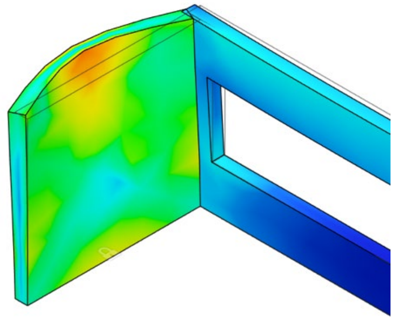

Figure 18. Anvil Stress

5.1.2 Energy Consumption:

We need to ensure that our product doesn't burden the user with being concerned about its energy use. For our energy consumption, we will use the widely accepted and used energy consumption formula:

$$E = P\left(\frac{t}{1000}\right)$$

E is the energy consumption in kWh, P is the wattage of our entire system (power draw), and t is the time (in hours) our machine will use.

To estimate the time our machine will be in use each year, we need to calculate an estimated value for water bottles the average family consumes, so we researched how much water the average family consumes and used that to determine the energy calculations. We then needed to find out how long it takes for our crusher to crush and reset after each use, while also considering its power draw while in use, which is set to 300W by design since we plan to have it run a 12V system with a 25A transformer.

The average family consumes roughly 26 gallons of water each year, not including other beverages (Recycling 2024). Using that information, we can estimate the rough bottle count from one family:

$$\left(\frac{26\,gal}{1\,yr}\right)\left(\frac{128\,oz}{1\,gal}\right)\left(\frac{1\,bottle}{17\,oz}\right) = 195.76 \approx 196\,\frac{bottles}{year}$$

So, one family uses an estimated 196 bottles of water each year. Using that estimation, we can gather other relevant data, such as the time it takes for the crusher to crush a bottle and reset fully. It's worth mentioning that the machine should not be using energy when it's not crushing anything; rather, it will be on standby mode.

The actuator we are using operates at 0.55 in/sec and has a full stroke length of 7.87 inches. To get the time it takes for our actuator to extend fully, we run the following calculation:

$$(7.87\,in)\left(\frac{1\,sec}{0.55\,in}\right) = 14.309\,sec$$

Multiply that value by 2 since we need to account for the time it takes for the crusher to reset, and we get roughly 30 seconds of use per bottle. When converted to hours, that number comes out to be 0.0083 hours of use per bottle.

Now that we have the operating time for the system to crush one bottle in hours and the estimated number of bottles a family uses, we can calculate the total time the crusher is in use per year:

$$\left(\frac{196\,bottles}{1\,yr}\right)\left(\frac{30\,sec}{1\,bottle}\right) = 5880\,\frac{sec}{yr}$$

Using this estimated value of operating time per year, we then convert this value into hours to get:

$$5880\ sec\left(\frac{1\ hr}{3600\ sec}\right) = 1.63\ hrs$$

We now have all the values we need to calculate the estimated energy consumption of our crusher per year:

$$E = 300\ W\ \left(\frac{1.63\ hr}{1000}\right) = 0.49\ kWh$$

From our estimations, our system uses roughly 0.49 kWh each year.

6. Conclusion

The importance of sustainability has seen a steady increase in recent years due to increased efforts to preserve the integrity of our planet. Plastic pollution is a main contributor to the increased pollution, so any new efforts to reduce this kind of pollution have the potential to have a large impact on the environment. Our product grants the public access to a much more convenient way of recycling, therefore creating a very innovative method of pollutant reduction.

The design and the product's mechanical functions highlight the objectives of versatility, ease of use, and practicality. The size allowances of the crusher provide versatility to the product because users can crush drink containers of multiple sizes, up to 12 inches, with the same result. Automated mechanics highlight the importance of ease of use within the product. It is crucial that the product can cater to a variety of audiences, despite mobility restrictions or other factors that may limit one's ability to operate machinery. Design components of the product, such as its size and the inclusion of housing and a disposal bin, present an element of practicality to the user as they do not have to worry about needing additional components to use the product.

Through proper implementation of this product and its technology, users are able to contribute to the continuing growth in sustainability awareness and pollutant reduction. Not only does this reduce the physical plastic that ends up in landfills, but it also reduces air pollution caused by the incineration of excess plastic material. Starting at home, this form of direct participation motivates users to continue to find other sustainable throughout their daily lives, further reducing the environmental impact that humans have on Earth.

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