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School of Engineering

Glass Crusher Design for the SA1 Building

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has lead to the award of a degree.

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Abstract

This dissertation focuses on the design of a glass crusher to produce cullet which will be used to make a recycled glass desk for the main building in the University of Wales Trinity Saint Davids new SA1 Waterfront campus. Sustainability is an important part of the SA1 project and must be an important part of the design of the crusher. Sustainability and recycling have been researched to know what the current situation is in the world and the UK and also to know what goals are set to improve on what the current procedures are and the results they produce. Crushers are a large part of many industries and are researched to know what crusher is best for the demands of the crusher in this project. The current procedure for crushing glass has been critically appraised to see what improvements need to be made. The newly designed crusher will crush glass quicker and more precisely than what is currently done. Contamination of cullet will also be eradicated.

Table of Contents

1	Introduction.....	1
2	Sustainability	3
2.1	Sustainability in the UK	4
3	Recycling	5
3.1	UK Recycling.....	6
3.2	Recycling Glass	7
4	Crushers	9
4.1	Abrasion Crushers	9
4.1.1	Jaw Crusher	9
4.1.2	Cone Crusher.....	11
4.2	Impact Crushers	12
4.2.1	Hammer Mill	12
4.2.2	Vertical Shaft Impactor	14
5	Current Equipment and Procedure.....	16
5.1	Problems with Current Equipment and Procedure.....	17
5.1.1	Contamination.....	17
5.1.2	Production Rate	18
5.1.3	Feeding the Breaker Bar Crusher.....	18
6	New Design	19
6.1	Hammers	22
6.1.1	Hammer Design.....	22
6.1.2	Crushing Mechanism	23
6.2	Materials	26
6.3	Manufacture	27
7	Conclusion.....	28
8	Further Work	28

List of Figures

Figure 1: Concept Art for Reception	2
Figure 2: Energy and Air Pollution saving of Recycling(Recycling in General, 2012)	5
Figure 3: Bottle Bank in Town Centre (Nexus® 200 Plastic Bottle / Mixed Glass Recycling Bin, 2017) ..	8
Figure 4: Jaw Crusher (Afsar, 2012)	10
Figure 5: Cone Crusher (Afsar, 2012)	11
Figure 6: Hammer Mill Crusher (How Does a Hammer Mill Work?, 2014).....	13
Figure 7: Vertical Shaft Impactor (How a VSI Crusher Works, 2014).....	14
Figure 8: Current Crusher and Figure 9: Crushing Hammer Configuration (Oseng, 2009)	16
Figure 10: Contaminated Recycled Glass Tile (Oseng, 2009).....	17
Figure 11: Magnets on Steel Sheet and Figure 12: Contaminant Removed by Magnets (Oseng, 2009)	18
Figure 13: Crusher Body.....	20
Figure 14: Electronic Speed Controller (T.W.T Speed Controler, 2017)	21
Figure 15: Hammer	22
Figure 16: Stress Concentration (Fundamentals, stresses types and other considerations, 2017).....	22
Figure 17: Hammer Configuration 1	23
Figure 18: Hammer Configuration 2	24
Figure 19: Space Between Hammers	25
Figure 20: Shaft Collar (Ruland, 2017)	26

1 Introduction

The Swansea branch of the University of Wales Trinity Saint David is developing a multi-million pound SA1 Waterfront campus. It will include purpose built facilities for learning, teaching and research alongside social, leisure and recreational spaces. Sustainability is of significant importance to the entire project. There is an emphasis on using locally sourced materials in the building of this facility to create a visually pleasing environment which is as sustainable as possible keeping up with the universities established reputation in higher education sustainability. (SA1 Swansea Waterfront, 2016)

The desk of the main building is a project in of itself. With leadership from Dr Tyra Oseng-Rees and a team of students and others, a reception desk made from recycled glass is being designed and made. Glass must be crushed into small pieces to be able to be ready for recycling. These are known as cullet.

To do this a glass crusher must be used. The university does currently have this equipment but does not perform to the level that is wanted. A new crusher will therefore be designed which will be the focus of this report. To do this, numerous topics need to be researched. These will be sustainability, recycling, crushers and current equipment. The new crusher must meet various requirements. These include;

- Crush glass to size particles between 0-20mm
- Single phase electricity (Standard 220V, 13a power supply)
- Avoid contamination
- Safe - door interlock hazard free emptying
- Greatly increase rate of crushing (currently takes 96 minutes to crush 15kg of glass bottles)
- Portable
- Built in sieve



Reception
UWTSD FACE & Tech and Library Interiors

STRIDE TREGLOWN

Figure 1: Concept Art for Reception

2 Sustainability

Sustainability is becoming more important as the Worlds natural resources are depleting ever faster. This is not a problem for just a few countries, but for all countries worldwide. The most widespread programme for sustainability is a UN initiative, Transforming our world: the 2030 Agenda for Sustainable Development, also known as the Sustainable Development Goals (SDGs). (The Sustainable Development Agenda, 2016) This includes 17 Global Goals ranging from no poverty to climate action to peace, justice and strong institutions. The goals relating to this dissertation are;

- Industry, Innovation and Infrastructure – Ensure that efficient and environmentally sound facilities are produced from the ground up while still making sure performance is of a sufficient level.
- Responsible Consumption and Production – ‘Doing more and better with less’ is the simple thought behind this. Increasing economic growth and quality of product while reducing resources used and pollution produced during the entire lifecycle.
- Climate Action – Take necessary action to fight climate change and the impact it has on the world and us. Because of the scale and importance of this, the Paris Agreement was made with all countries agreeing to limit global temperature to rise to below 2°C but aim for 1.5°C (Sustainable Development Goals, 2016)

These goals are not just for rich or poor countries but for all countries to try and promote prosperity while protecting the planet. Although not legally binding, each country is expected to produce national frameworks to achieve these goals.

2.1 Sustainability in the UK

The UK has the same basic goals as the SDGs which they split into three sectors. These being economy, society and environment. (ukssd, n.d.) The government produce Sustainable Development Indicators (SDIs) to help measure the progress the country is making in the three sectors. In the environment sector there are sub divisions such as greenhouse gas emissions and natural resources used. With figures from the Department of Energy and Climate Change, greenhouse gas emissions have been reduced from 748.5 million tonnes carbon dioxide equivalent (MtCO₂e) in 1995 to 495.7 (MtCO₂e) in 2015 showing quite a large downward trend. This is opposed to a 50 percent increase in CO₂ emissions since 1990 worldwide so the UK is clearly trying and in the most part succeeding with making improvements. (2015 UK GREENHOUSE GAS EMISSION, FINAL FIGURES) Many more indicators like this show that work is being done to ensure the UK is getting more sustainable every year.

3 Recycling

Recycling is a very important part of sustainability which serves several purposes such avoiding/help reduce landfills, reducing pollution and reducing the amount of raw materials used. Energy saving is arguably the most attractive part of recycling in the modern world because the less energy needed, the lower the cost of production. To give an idea of how much energy is saved, recycling an aluminium can saves enough energy to run a television for three hours. (Importance of Recycling, n.d.) This shows the magnitude of how important recycling can be when considering it on an industrial scale. The table below shows how useful recycling can be.

Material	Energy Savings	Air Pollution Savings
Aluminium	95%	95%
Cardboard	24%	-
Glass	5-30%	20%
Paper	40%	73%
Plastics	70%	-
Steel	60%	-

Figure 2: Energy and Air Pollution saving of Recycling(Recycling in General, 2012)

On a global scale, recycling rates vary significantly. Overall, European countries have reasonably good recycling rates of around 40 percent or above. The best of which is Germany with a recycling rate of 65 percent making them world leaders (Which Countries Are Recycling Leaders?, 2016). Wales have become second in Europe with a recycling rate of 59 percent (The Record of Proceedings, 2016), overtaking Austria who have a 58 percent recycling rate. South Korea is another very good performer with 59 percent. The United States recycles 35 percent of its waste but as they are the largest producers of waste on the world this number must be improved (Which Countries Are Recycling Leaders?, 2016). Figures are not available for most developing countries because they do not have formal waste disposal programmes. However there is a lot of informal recycling in many of these countries. To sum up the significance of the recycling industry, it employs the second highest amount of people, only being outdone by the agricultural sector.

There are however problems with recycling which must be taken into consideration when discussing if it's viable. Obviously there are materials which simply can't be recycled. Many of these being products with a lot of adhesive or coatings for example juice cartons which are internally lined with plastic (10 surprising things you cant recycle/, n.d.). There are many more products which can be recycled but is not cost effective to do so like bottle caps or ceramics. Contamination is big problem which means sorting may take a long time and if a contaminant does get through sorting, the recycled material is often rejected because its mechanical properties will be different than they should be or that the materials is aesthetically different (Rejected recyclable waste up 84% in England since 2011, data shows, 2016).

3.1 UK Recycling

In 2014, the UK produced 209 million tonnes of all waste across all sectors (the main of which are commercial & industrial, construction, demolition & excavation and household). (Waste and recycling statistics, 2013)43.6 percent of this was recycled or recovered. The rate of household recycling in the United Kingdom was 44.3 percent in 2015. This is around average for Europe. It is however lower than the previous year for the first time since it began in 2010 (Recycling in the UK, 2015). Wales did far better than this with a recycle rate of 59 percent (The Record of Proceedings, 2016), putting it amongst the world leaders and continuing its improvement on the year before. There is an EU target of at least 50 percent by 2020 (Recycling in the UK, 2015). The most resources are put towards recycling four main materials. These being plastic, paper, glass and metal cans. All of these are collected on a fortnightly schedule.

3.2 Recycling Glass

Glass is one of the most ideal materials to recycle. The vast majority of glass such as bottle and jars are 100 percent recyclable. Glass is practically infinitely recyclable because it keeps its quality and purity. This is different to many- materials such as paper, card and most plastics which lose quality, purity and strength after each cycle and cannot be recycled anymore after a certain number of cycles. (glass recycling facts, 2014)

Recycling glass starts with cleaning the glass to remove any labels or stains. It is then sorted into three colours. These being clear, green and brown. These are then crushed separately to form cullet, which is just the term used for crushed glass which is ready to be used in the manufacturing process of glass. The cullet can then be put into a furnace and shaped or can be added to raw materials as a substitute. (glass recycling facts, 2014)

There are many uses for recycled glass. These are wide ranging and cover many areas. The most common and best use of recycled glass, due to its basically never ending cycle, is bottle to bottle, also known as circular economy. From the time the bottles are taken away to be recycled, to being back on the shelves as new bottles can be as little as three weeks. If the cullet is not of the required standard to be made it to bottles or jars, for example it is of mixed colours, then it can be used in the production of many other products such as fibreglass, counter tops and bricks. Roads and pavements, often contain recycled glass. It is used for concrete and gravel along with other aggregates. Other uses include abrasive materials and landscaping. (Benefits of Glass Recycling: Why Recycle Glass?, 2016)

Not all glass can be recycled. Heat resistant or reinforced glass, including Pyrex and borosilicate glass which is used for things such as cooking appliances or scientific beakers would cause major issues if mixed with glass bottles to be recycled as it would change the viscosity of the molten glass in the furnace (Hickman, 2011).

The environmental and cost benefits of recycling glass are substantial. Manufacturing glass from glass cullet is considerably more energy efficient using around 2.5 to 3 percent less energy for every 10 percent cullet used (Glass is Infinitely Recyclable, 2017). A great deal of raw materials (lime, soda, sand etc.) are used in the manufacture of glass. Over a tonne of these natural resources are saved for every tonne of glass recycled (Glass Recycling Facts, 2015). This is obviously good for the environment but also good for hugely lowering the excavation cost. Greenhouse gas emissions are important during this time of global warming and any reduction is wanted. For every tonne of glass recycled and turned into bottles for example, CO₂ emissions are reduced by 670kg (Rademaekers, 2011).

In the UK, glass is one the main materials to be recycled. The two main ways people dispose of their used glass to be recycled is by putting it in their green bags which are collected every fortnight by the local council or throw it into bottle banks which are located in many areas such as town centres and universities. In 2013, the UK consumed 2,399,000 tons of waste glass. 1,635,889 tons of this glass was recycled giving a percentage of 68 (UK glass recycling rate remains below EU average, 2015). These figures have been steady for the last several years previous. Although close to the EU target of 70 percent, it is far behind countries Belgium and Germany who in 2013 recycled 95 and 88 percent of their waste glass respectively (Glass recycling hits 73% in the EU, 2015).



Figure 3: Bottle Bank in Town Centre (Nexus® 200 Plastic Bottle / Mixed Glass Recycling Bin, 2017)

4 Crushers

Crushers are used in many areas and range from several tonne machines to the simple pestle and mortar. The two main types however are for reducing the size of large rocks to smaller rocks or gravels and to recycle waste materials. Crushers use two different ways to reduce the size of material. The first is by friction and compression. These are referred to as abrasion or attrition crushers. The second is the impact crusher. Abrasion crushers are predominantly used to process natural aggregates whereas impact crushers are used when the material to be processed is itself abrasive. This includes glass and hard rocks.

4.1 Abrasion Crushers

4.1.1 Jaw Crusher

Two jaws are opposite one another. One of them is fixed while the other moves in an eccentric motion due to the flywheel turning which opens and closes the gap between the jaws. This creates mechanical pressure which compress the rock/s and causes them to break. The movement of the jaw is small so several strokes are required to complete the crushing. The gap at the bottom of the two jaws can be adjusted to allow different sizes to get through. The two jaws are inclined, because of this there is a tendency for the ricks to slip upward. This is called slippage. The weight of the rock and friction between it and the jaws counteract this slippage. Therefore if very hard rocks, hard to break, and small rocks, low weight, have a higher tendency to slip upward so these are avoided with this crusher. Also anything which reduces friction such as water will increase the chances of slippage (Michaud, Jaw Crusher Working Principle, 2016).

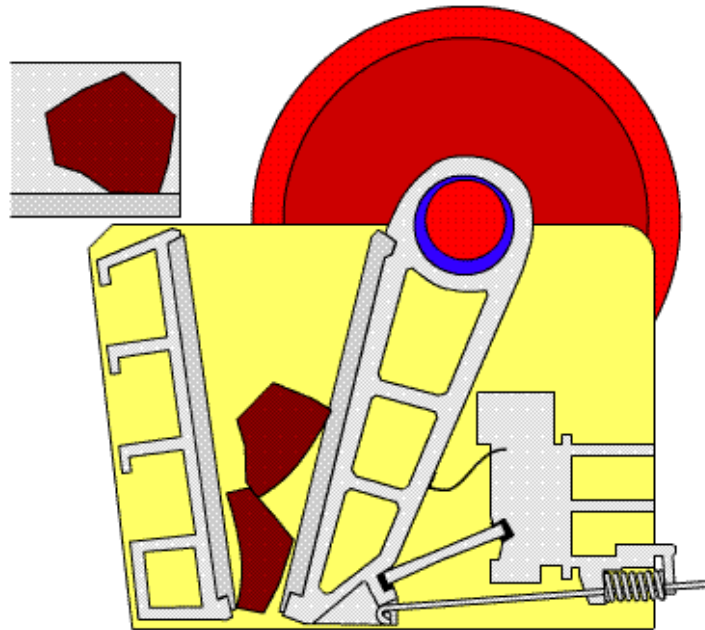


Figure 4: Jaw Crusher (Afsar, 2012)

Advantages and Disadvantages

Advantages;

- Large feed opening to allow large pieces of material to be fed in as they are instead of being pre crushed
- Large feed opening also makes it easier to load the machine and reduce feeding time
- Jaw crusher is easily adjusted to meet the required needs for example increasing the speed or reducing the exit gap
- Jaw liners can be reversible so when one side is worn, they can simply be turned over (Michaud, 2016)
- Can handle 'sticky' feed better than most abrasion crushers
- Maintenance and repairs are easily achieved (What Are the The Advantages of Jaw Crusher?, 2010).

Disadvantages;

- Struggles to crush material into small sizes
- Crush rate is slow which reduces productivity
- Produces uneven particle sizes.

4.1.2 Cone Crusher

Similar to the jaw crusher, eccentric motion is used to crush aggregate against a stationary surface. With the cone crusher, the central cone turns eccentrically due to the flywheel. Rocks enter the crusher from the top and are crushed due to the compressive force between the cone and wall. The cone and wall are angled so there is a large gap at the top and narrows toward the bottom. With this design, larger rocks are broken towards the top, they then fall lower and are broken again and so on until the pieces are small enough to exit the narrow opening at the bottom. Slippage can occur for the same reason as for the jaw crusher (Michaud, Cone Crusher, 2016).

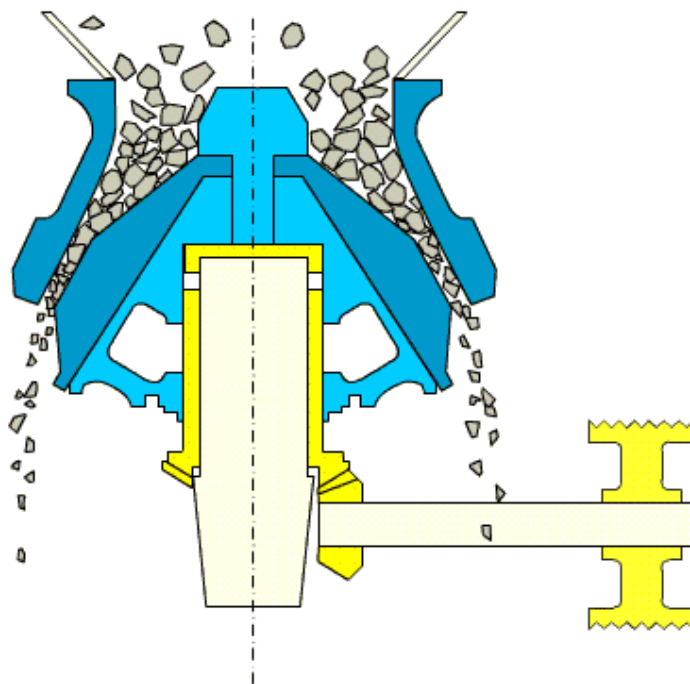


Figure 5: Cone Crusher (Afsar, 2012)

Advantages and Disadvantages

Advantages;

- Machine can be loaded from any direction
- Produces very regular and cubical final product
- High capacity ratings
- Lubrication is an economical option and this extends service life (The Advantages of Cone Crusher, 2010).

Disadvantages;

- Not suitable for crushing wet or 'sticky' materials
- Can't deal with soft materials and packing will occur in the crushing chamber
- Highest capital cost for installation (Michaud, Cone Crusher, 2016).

Abrasion crushers inevitably wear over time due to the way they crush and the forces involved, they are therefore used to predominately crush natural aggregates which tend to not be particularly abrasive as opposed to glass which is very abrasive. Wear resistant materials are used for the surfaces where crushing takes place. However these still need replacing after a certain amount of time. Abrasion crushers are not suitable for this project.

4.2 Impact Crushers

Due to the highly abrasive nature of glass, impact crushers are better suited to deal with this as glass will cause a great deal of wear on the equipment of abrasion crushers. All impact crushers work on the basic principle of things will crush/shatter when impacted. There are several types of impact crushers.

4.2.1 Hammer Mill

Hammer mills are the most common impact crushers. Hammer mills consist of many free swinging hammers attached to pivots which are subsequently attached to a rotating shaft. This shaft rotates at a high speed. Glass is fed into the machine through the feed chute. The glass is then broken by the several ways. This includes repeated hammer blows, collisions with the walls and glass to glass impacts (How Does a Hammer Mill Work?, 2014). The pivots help the hammers transfer energy to the glass while minimizing wear on the hammers. The hammers being directly attached to the shaft would cause stress on the shaft and reduce the shaft speed (Types of Glass Crushing Equipment, 1996). This increases the life of the crusher because the engine doesn't need to work as hard and things such as bearings are exposed to less stress. The hammers must swing close to the inner walls to effectively crush the glass and not allow large pieces to get through. To achieve the desired cullet size a view things can be changed. These are the shaft speed, the quicker the rotation, the smaller the cullet, and

the number of hammers, the more hammers, the smaller the cullet (How Does a Hammer Mill Work?, 2014).

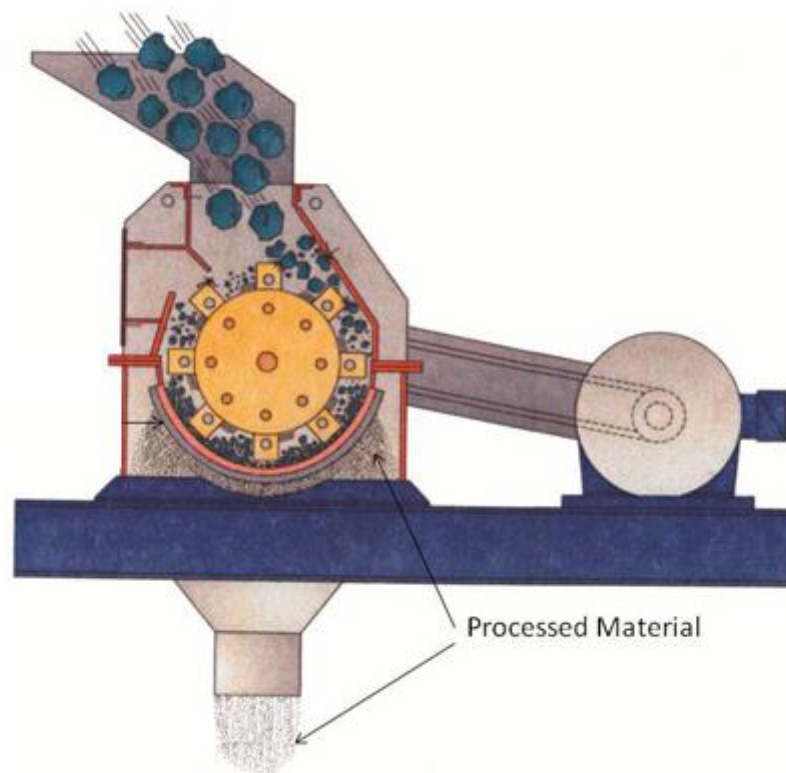


Figure 6: Hammer Mill Crusher (How Does a Hammer Mill Work?, 2014)

Advantages and Disadvantages

Advantages;

- Produce wide range of particle sizes depending on needs
- Initial investment is low compared to other crushers
- Easily change product by changing rpm or hammer configuration
- Produces very even, spherical particles
- Minimal maintenance is required
- Many hammer mills have parts which are easily changed such as the hammers or the screen (Kelly, 2012).

Disadvantages;

- Particle size variance is greater than other crushers
- Hammer mills are usually noisy
- Dust pollution (Kelly, 2012).

4.2.2 Vertical Shaft Impactor

Instead of directly striking the glass to crush it, the vertical shaft impactor throws the glass to achieve this. Glass is fed into the top of the machine and reaches the impeller table. This is rotating at a high speed and through centrifugal force, the glass is thrown against impact plates which surround the impeller and are made of very hard materials. There is very little wear throughout the machine especially on the rotating parts. The only parts which experience considerable wear are the impact plates. To alter the size of cullet produced the speed of rotation can be altered. Increased speed means a smaller cullet. The distance from impeller to impact plates also effects cullet size. The bigger the distance between the two, the bigger the cullet because the glass will be travel slower than if the impact plates were closer (Marcotte, 2015).

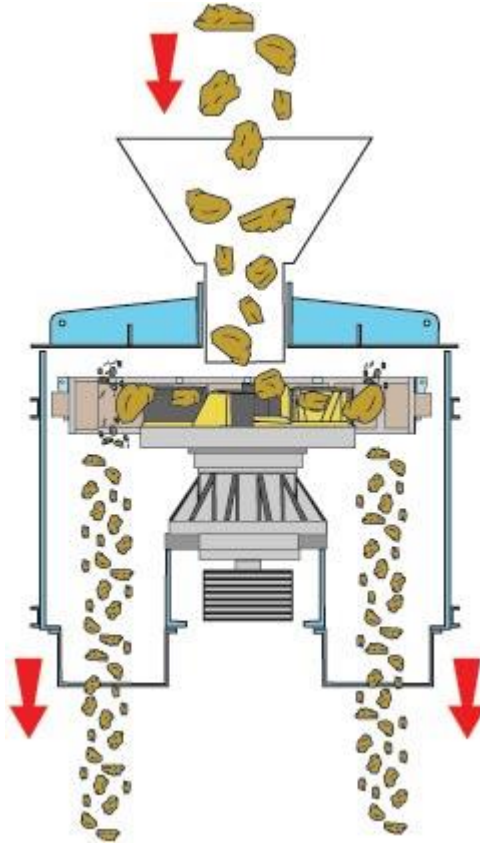


Figure 7: Vertical Shaft Impactor (How a VSI Crusher Works, 2014)

Advantages and Disadvantages

Advantages;

- Produces uniform cubical particles with a small size distribution
- Easily change product size by changing the rpm or cascade ratio
- Performs well even in high moisture applications
- First pass product yield is high (How a VSI Crusher Works, 2014).

Disadvantages;

- Size of the material fed to the machine is limited due to the design of this type of crusher
- High rpm means that any imbalance could be dangerous. For example replacing a shoe on the rotor, would mean having to replace the shoe on the opposite side of the rotor as well (Marcotte, 2015).

5 Current Equipment and Procedure

The current procedure starts begins with the labels on the bottles being removed by washing in warm water. Then again to remove any other residue such as glue. They are then divided into separate colours and then they are divided by their punt mark. These can be used to trace where the bottles were manufactured. This is done because when the crushed glass is put in the furnace, different manufacturing techniques will cause the glass to react slightly different in the furnace and the end product may be compromised. The bottles are now ready to be crushed.

Glass is currently being crushed by a small rotating breaker bar crusher. This is very similar to a hammer mill but the breaker bars cannot pivot at the shaft. The motor is electrical and runs off the mains socket. There is simply an on/off switch but the motor turn off if the lid is opened. It is loaded from the top with the whole lid lifting up. It crushes 25kg per hour which equates to about 50 standard 750ml wine bottles. The end product of this is large cullet which is an average size of 50mm. The cullet is then allowed to dry.

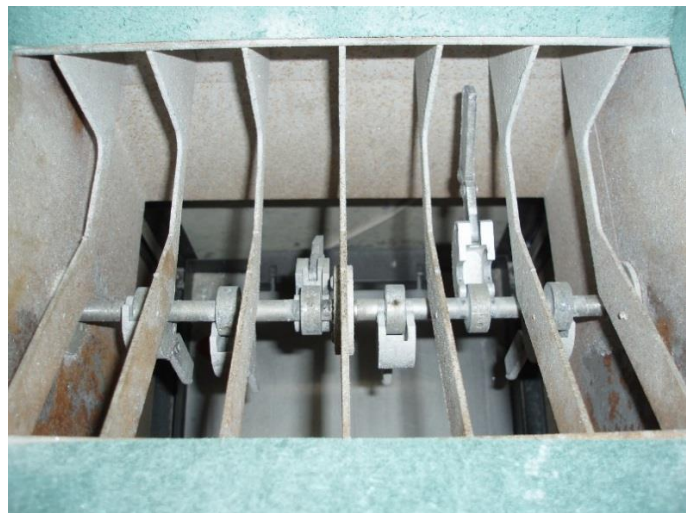


Figure 8: Current Crusher and Figure 9: Crushing Hammer Configuration (Oseng, 2009)

The dry cullet now needs to be crushed to specific fragment sizes. To achieve this another type of crusher is used. This is a laboratory scale, roller crusher which again runs off the mains and consuming 0.25 kW. 15 kg of the large cullet is crushed in an hour. Varying sizes are produced which need to be sieved. Three sieves are used to create four ranges. These being 0-2 mm, 2-6 mm, 6-12 mm and above 12 mm.

The cullet is then put into a mould and configured into the desired pattern and put in the furnace at a temperature and amount of time that is required to produce the finished product. (Kleprlikova, 2016)

5.1 Problems with Current Equipment and Procedure.

5.1.1 Contamination

Although not visible with simple inspection, steel particles were present in the final cullet. This was discovered subsequent to it being placed in the furnace when the steel particles become very clear as shown in figure 9. The solution to this was to use ultra high strength magnets. Attaching these magnets to one side of a sheet of steel and running the cullet over the other side of the steel sheet, removed the steel contaminant and left it attached to the steel sheet. The process is shown below.



Figure 10: Contaminated Recycled Glass Tile (Oseng, 2009)



Figure 11: Magnets on Steel Sheet and Figure 12: Contaminant Removed by Magnets (Oseng, 2009)

5.1.2 Production Rate

From initial cleaning of the bottles, to the final cullet ready to be placed in a mould takes days. A large part of that is down to the drying which itself can take 24 hours. But the crushing itself is a drawn out process. Two crushers are needed to produce the required cullet size where ideally it would be just one but even if two were required, the time taken is still unwanted. It takes 96 minutes to crush 15 kg of cullet of the required size. Due to the time taken, the amount of cullet produced is naturally limited.

5.1.3 Feeding the Breaker Bar Crusher

To feed the first crusher, the lid must be lifted and the bottle put in. However when the lid is lifted, the shaft stops turning for safety reasons. Doing this over and over causes unnecessary strain on the engine and other components which could be avoided. It also means the glass is breaking as soon as the impact is sufficient but not at the top speed of the crusher. These things also mean crushing time is increased unnecessarily.

6 New Design

The main goal is to design a single crusher to replace the two which are currently used to produce the required cullet size and quality. Of the two crushers currently being used, one is an impact crusher and one is an abrasion crusher. As discussed previous, impact crushers are better suited to crusher glass due to the highly abrasive nature of glass which causes a great deal of wear on abrasion crushers. For this reason an impact crusher will be designed. Various grain sizes are required so the crusher must be adjustable to allow for this. The time taken and likewise the amount of cullet both need to be improved. Using one crusher instead of two will automatically help this. Contamination of the cullet must be eradicated as this has a significant effect on the final product. The grain size that will be used the most for the reception desk is 0-2mm. Larger sizes will also be used but in less quantity.

The hammer mill impact crusher is best suited to the needs of this project. The feed opening will be large enough to allow bottles of wine to be fed directly in to the machine. As opposed to the vertical shaft impactor which needs material fed in to be far smaller, meaning the glass would need to be pre crushed by another machine. Impact crushers can produce a wide range of particle sizes which is a key requirement. The particles produced are very even and spherical. The maintenance of hammer mills is also reasonably straight forward.

The hammer mill crusher encasing will be a very simple design with a few key features. The bottles will be fed into an angled feeder at the front of the crusher. This is an important difference from the current machine. Having this feeder will mean the motor can keep running as bottle after bottle is fed in. As a result the hammers will crush the glass at the desired speed instead of breaking before the motor reaches its desired speed after starting back up form when the lid is closed. The lid of the new design will therefore be closed during crushing but as with the current design, if opened, the motor will stop turning as a safety requirement. The engine will also have a longer working life than the current crusher because it's a lot of unnecessary strain on the engine turning on and off again constantly. The angled feeder will have a simple hinged opening so the bottles can be pushed through but will swing back closed as soon as the bottle passes to stop any glass or anything else being thrown out during crushing. The crusher will be of similar size to the current crusher with dimensions of 604x680x404mm.

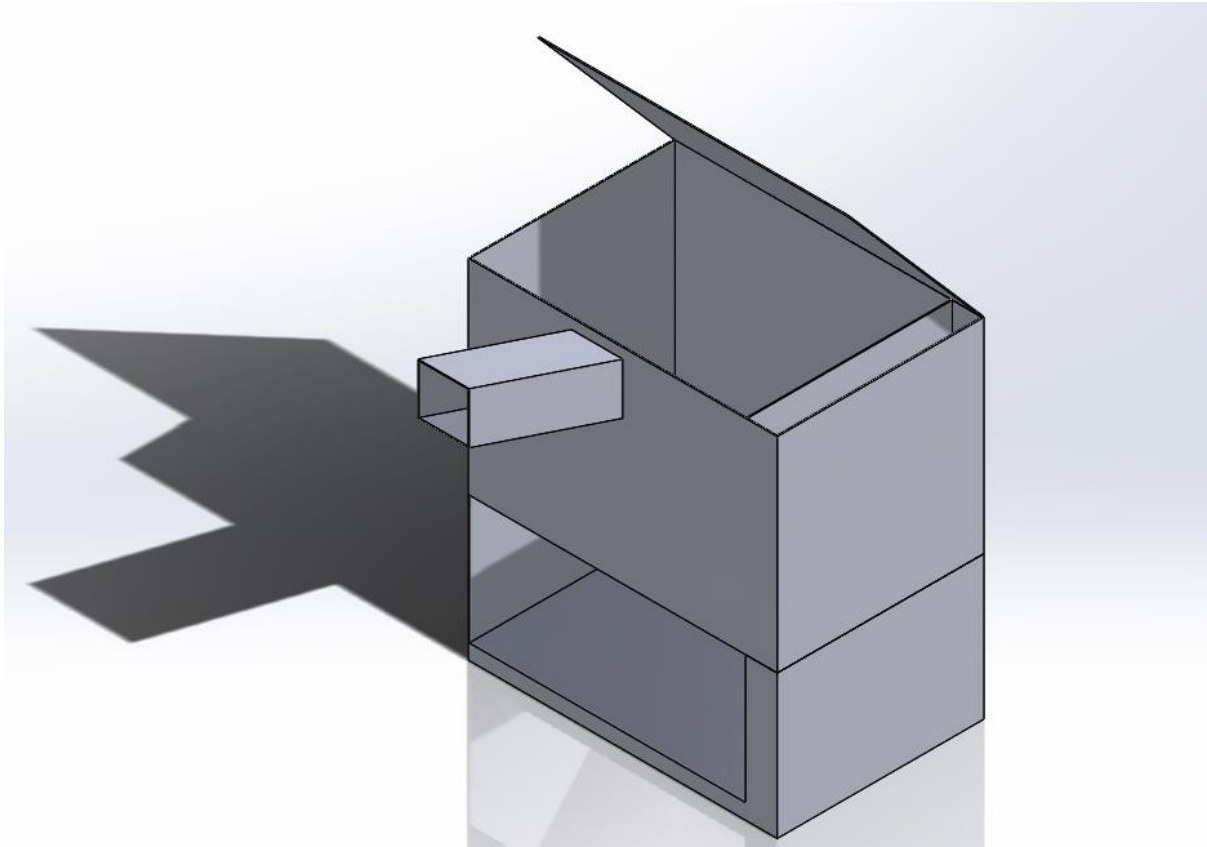


Figure 13: Crusher Body

The hammer setup will determine how the glass is crushed and the cullet produced. As previously discussed, varying sizes of cullet are needed depending on the use. This can be done changing the speed of rotation. The higher the rpms, the smaller the cullet size. Motor speed can easily be adjusted using electronic speed controller. These work by manipulating the voltage that is applied to the motor. It achieves this by switching the battery connection on and off around 20,000 times a second. This rate of switching is too fast for the motor to detect so the motor averages this out. This means the battery is only connected for half the time, and therefore the motor sees a 240V battery as a 120V battery causing the motor to turn at half the speed. These ratios can be adjusted so the motor can vary smoothly from top speed to a low speed. These can also be used to reverse the direction of the motor. An example of an electronic speed controller can be seen below (What Does a Motor Speed Controller Do?, 2017).



Figure 14: Electronic Speed Controller (T.W.T Speed Controller, 2017)

Another way to produce varying size cullet is to have a different hammer configuration. The more hammers the smaller the grain size produced. The space between the hammers themselves and the space between the hammers and the crushing chamber all contribute to the grain size. The smaller the gaps, the smaller the grain size. Having less hammers also equates to smaller grain size.

6.1 Hammers

6.1.1 Hammer Design

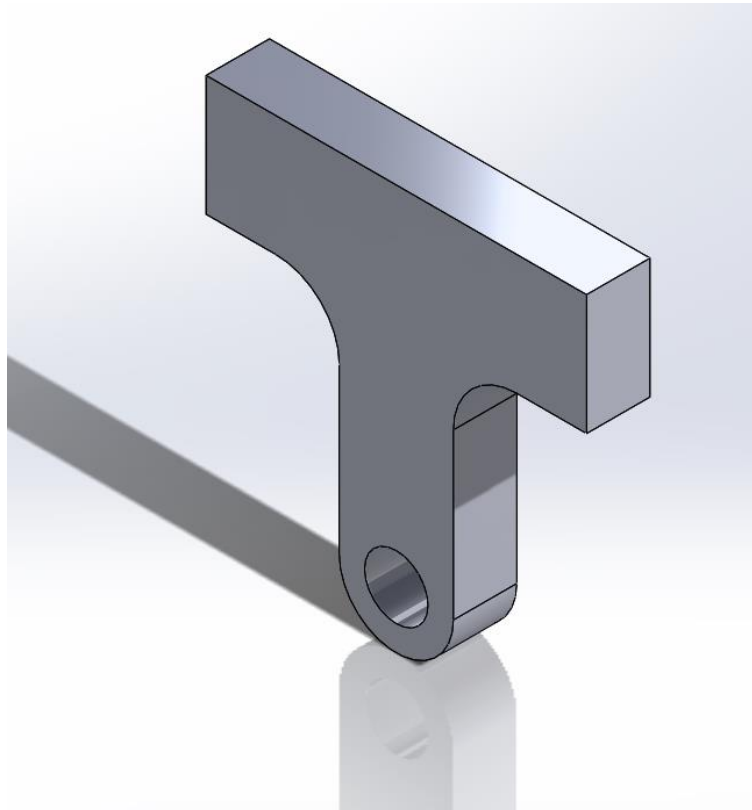


Figure 15: Hammer

The hammer itself is a 'typical' hammer design. It has 10mm fillets where the head of the hammer starts to prevent sharp 90° corners which would be susceptible to high stress. These are known as stress raisers. The difference a fillet has on stress is shown below.

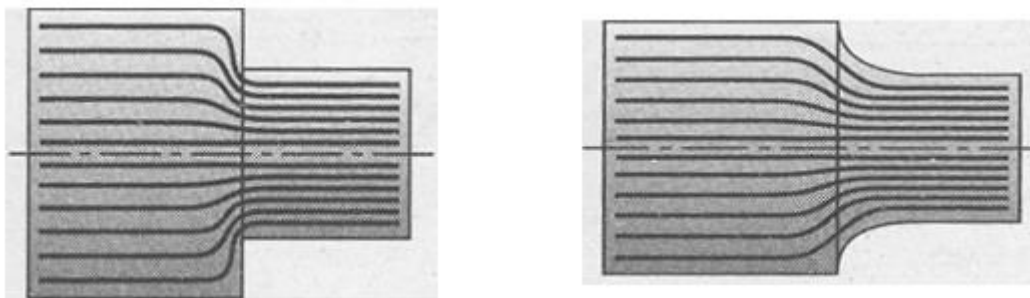


Figure 16: Stress Concentration (*Fundamentals, stresses types and other considerations, 2017*)

The diagram on the left shows stress flow lines gathering together at the corners causing high stress concentration. Fillets are introduced on the right and clearly shows the flow lines being less interrupted and transitioning more smoothly, reducing the stress on the object.

6.1.2 Crushing Mechanism

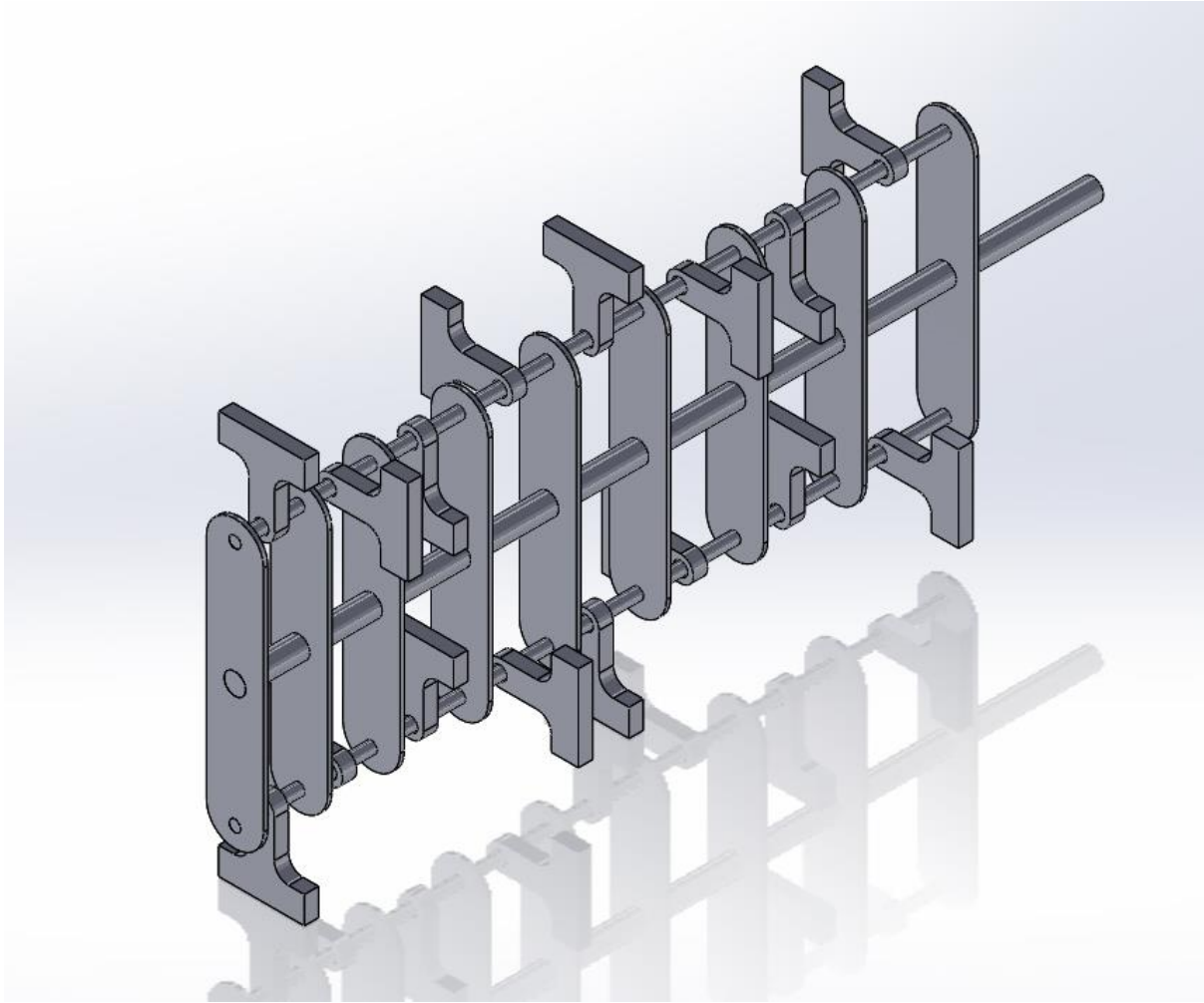


Figure 17: Hammer Configuration 1

The configuration above would be used to produce larger cullet sizes. The central shaft is connected to the motor. Hammer spacers are then used to connect the central shaft to two other shafts that are opposite to each other. All of these are fixed. The hammers are between each spacer. The spacers also stop the hammers from gathering at one end and make sure they stay in their region. There are 16 hammers in total. These hammers are free to rotate about their shaft. The free rotation helps the hammers transfer energy to the glass. It also means there is less stress on the central shaft and therefore the motor so the engine maintains its speed. The engine does not have to work as hard which means a longer life for the engine. Free rotation also reduces the stress on the two other shaft and the hammers themselves. All of this increases the working life of the crusher. The hammers are not long enough to collide with the central shaft. This could cause issues such as unbalancing the rotation. It could cause damage to the hammers or the shaft and might lead to chipping which will then lead to contamination of the cullet.

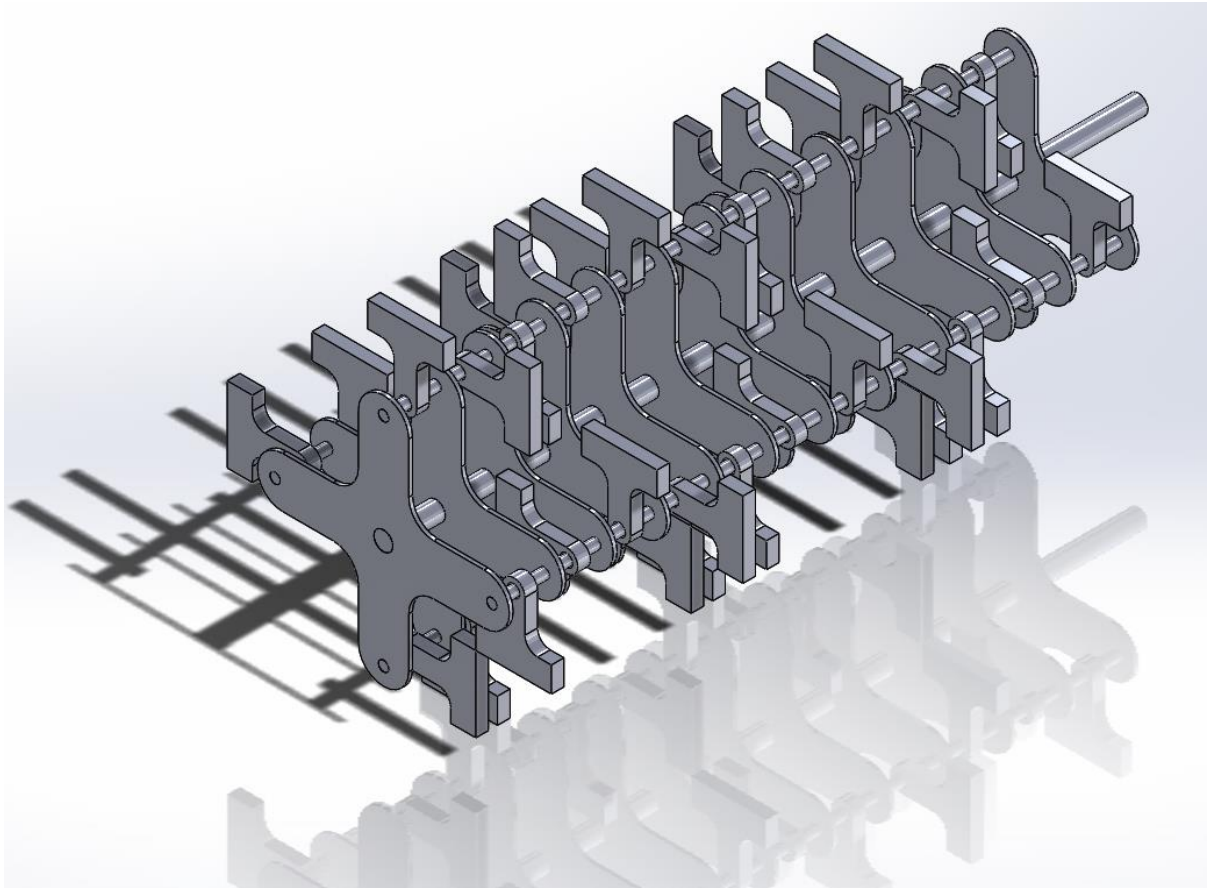


Figure 18: Hammer Configuration 2

When a smaller grain size is required the above hammer configuration will be used. Once again the central shaft is connected to the motor. The hammer spacers now connect the central shaft to four other shaft at 90° increments. The spacers are also closer together and there are more of them than the other configuration. This achieves the environment to ensure smaller grain size. There are now four hammers between each spacer instead of two, making 44 hammers in total. The hammers are now closer together in all directions. This has to be carefully designed to ensure the hammers won't collide into one another during crushing. The space between the hammers can be seen bellow.

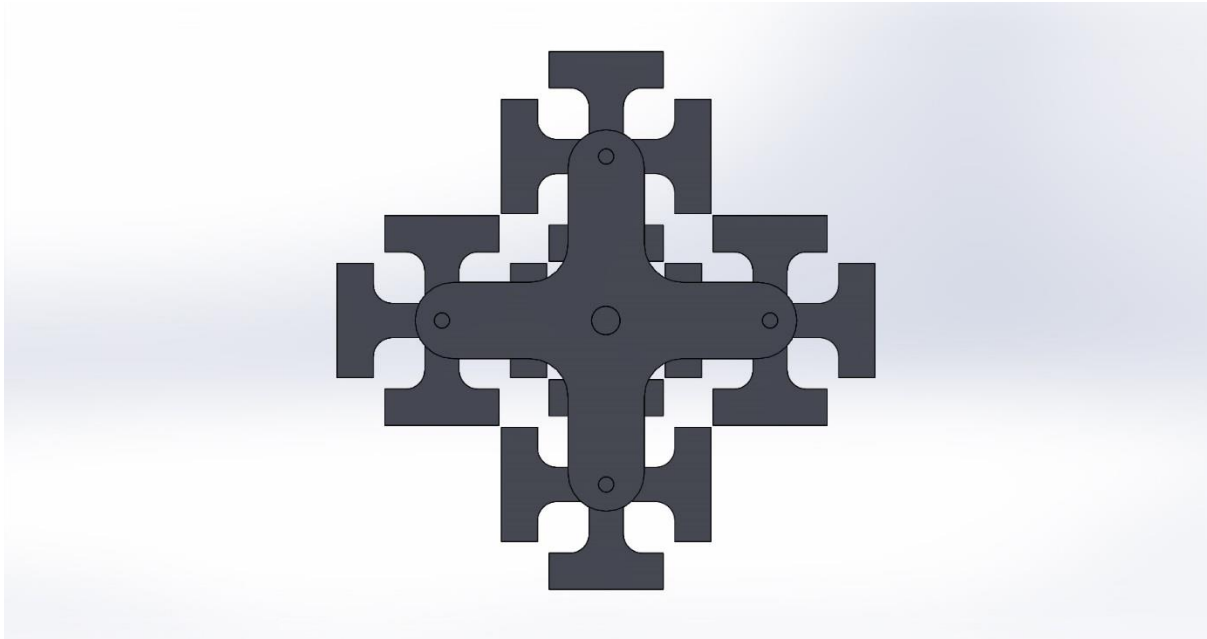


Figure 19: Space Between Hammers

The hammers colliding with each other could cause damage to the hammers and as discussed with the other configuration, this could cause chipping. It also hinders the production of small grain sizes as the gap between hammers is a big factor in grain size and if there is no gap to go through this glass can't be reduced in size.

These two hammer configurations will be interchangeable to give very good flexibility for the user. The main reason being what size cullet is required. It also increases the life of the crusher because each configuration is only doing the work it needs to. If there was a single configuration and changing the speed was the only way of producing different size cullet, the hammers would wear faster. The engine would also have to work harder more often decreasing its working life. Having two configurations also means there is a greater range of cullet that can be produced than having one configuration which would be a compromise of the two designs. Being interchangeable would also mean that over time as the hammers start to wear, increasing the chance of contamination, a new set could be manufactured increasing the life of the crusher even more. The interchangeability would be achieved with a simple two piece shaft collar which will act as an adapter for the different hammer configurations. An example of one is shown below.



Figure 20: Shaft Collar (Ruland, 2017)

6.2 Materials

As mentioned when discussing the current crushers, contamination was a big issue. This was solved by using ultra high strength magnets to remove the contaminant but this would ideally not need to be done. The material choice is therefore important. The main source of contamination was the roller crusher and as stated previously, abrasion crushing is not a good crushing method for glass because glass is very abrasive which causes material to be removed from the rollers. The current crushers used mild steel as the crushing tools.

To avoid wear and therefore contamination, a wear resistant material will be ideal. Stainless steel is a very common and versatile material which will be very well suited for the hammers and crushing chamber. Stainless steel gets its unique properties from the high concentration of chromium (minimum of 10 percent) as compared to low carbon steel (Mid City Steel, 2017). Its stand out property is its resistance to stains and corrosion. It does not corrode in normal atmospheric environments which will be the case for the crusher. Other benefits of stainless steel include;

- Good impact resistance due to its high toughness

- Strength to weight ratio is better than average steels and allows material thickness to be reduced
- Easy to fabricate with modern steel making techniques and can be shaped and cut as easily as normal steels
- Value for money is often better than other steels in the long term when the total lifecycle is taking into account due to the benefits discussed (ssina, 2017).

Finally stainless steel is a very sustainable product. In the United States for example, new stainless steel is made up of up to 50 percent remelted scrap metal. Stainless steel itself is 100 percent recyclable (Mid City Steel, 2017). With sustainability being a large and important part of this project, and being important in the world today, these are vital benefits. This along with the many other advantages make stainless steel an excellent choice.

6.3 Manufacture

The hammers and hammer spacers will be cut to shape using an abrasive waterjet cutter. There is an in house waterjet cutter which can be used located in the Dynevor Centre for Art, Design and Media building. This waterjet can cut very hard materials which includes stainless steel. Abrasive waterjets are a very good cutting machine which use a high pressure stream of water, with abrasive added, to cut various material. The engineering drawings created in CAD are programmed into the machine and these shapes are cut. The parts can be 'nested' together very closely to ensure there is as little waste material as possible. Abrasive waterjet cutters do not produce any heat affected zones (HAZ). This prevents any distortion of the material but crucially for stainless steel, no HAZ means that the material properties which are imperative to the crusher functioning properly, are not affected in any way (Eteer, 2016). All of these reasons make the abrasive waterjet the ideal cutting tool for this scenario.

7 Conclusion

The newly designed crusher has several main improvements over what is currently available. The need for two crushers has been eliminated and both roles are now done by one crusher. The new design will be crush cullet more precisely within a smaller range. The adjustability is also a big improvement. With varying size cullet required, this is a key component which wasn't sufficiently done by the current crushers. With the use of Stainless Steel, contaminated cullet will not be a problem. The working life of the new crusher should be considerably improved. This is achieved by the hammers being free to rotate, reducing stress and strain on many components, the engine running constantly instead of being cut off and the hammers and shaft being interchangeable. All of these changes make for a more efficient crusher which will hopefully last for many years.

8 Further Work

The next step would be making a prototype out of mild or low carbon steel which is less expensive than stainless steel to ensure the crusher functions as expected. Changes can be made if necessary. The genuine crusher can then be made from stainless steel. The speed controller would be dialled to know what speed produces what size cullet.

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