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Additive Manufacturing of a Shredder

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Abstract. Shredders have become an indispensable part of modern life. Variety of shredders are available for different purposes such as Paper shredders, metal shredders, etc. They come in different sizes, ranging from small sizes for household applications to large sizes for industrial applications. These shredders are used to break down the material into smaller pieces so that they could be disposed of more easily and efficiently. Currently, these shredders are majorly used by large industries for waste disposal systems. This process of shredding the large waste produced by common households by itself will take an enormous amount of energy when accumulated overall as they mainly use fossil fuels for this purpose. This can be reduced by reducing to an extent if all the possible household waste is manually shredded at houses themselves instead of taking it to the industries. For this purpose, in this study, an economical shredder that has the capability to plastics, wood, and few low strength metals like aluminium has been designed. Beginning with a base design and have worked to improvise it in considered parameters. These parameters are the shredder being efficient, economical, and lighter. The design was repaired and optimized in Meshmixer Software and then sliced in Ultimaker Cura Software and was made 3-D printable. The developed model was found to be more helpful than the conventional shredders, as to its economical viability, ease in use and handling, and to its efficiency in shredding the plastics. As a result, a successful and efficient design of a portable shredder has been developed.

1. Introduction

Shredders are devices used for cutting various materials including paper, plastics, and metals into smaller particles. They are used to easily dispose of the materials by reducing them into uniform shapes and smaller sizes. This makes the process of separation in places of disposal easier and simpler. A manual shredder too helps destroy personal documents and items sensitive and confidential at the nth minute. Thus, the use of a shredder ensures easy and efficient disposal of waste [1]. Though we speak of the advantages shredders pose, they do have some disadvantages as well. These include weight, size, and cost. These factors tend to hinder the easy procurement and usage of a shredder machine. There are large-scale shredders available that can shred massive waste. But usage of such shredders is limited to industrial purposes, where a huge discharge of energy for the process to occur is possible. But sometimes using this large shredder in personal spaces is neither feasible nor economical [2]. Thus, the usage of small-scale shredders that could be used at households, offices are useful to people with such needs.

In Design and development of mini plastic shredder by Sudhakara Reddy [3], they have come up with a basic design for plastic shredder machine, which could be of use to micro small and medium enterprises. The shredder though isn't portable, but efficient to crush plastic into smaller pieces. Here the aim is to develop a design, which could shred not just plastic but also low strength metals and be portable for easier handling and use. Using this kind of small household shredder that uses only our mechanical energy for shredding can save a lot of energy. The large-scale shredders use a huge amount of electricity for such applications in industries. If many people start shredding basic stuff at home and then dispose of it, then it's not needed to have such industrial shredders. This proves that a small effort put in by many people can have a huge impact on the environment. Hence, the more the number of people use, more the energy is saved. This not only saves electricity but also reduces noise pollution, air pollution due to dust released from large shredders too. While these advantages of a small shredder are investigated, the most important factor is the efficiency of the cut [4]. It is a crucial factor when one chooses their shredder. Thus, a sharper blade design is essential to have a better cut [5]. Thus, we have tried to overcome these factors by designing an economical and a compact designed shredder machine. We have incorporated a blade design system to have sharper and more precise cuts. We have intended to bring down the size of the entire machine by not bringing down its efficiency. By doing so it has also been ensured that with these changes the machine remains economically affordable. We have performed FEA and Slicing- Repairing operations to understand any constraints that have been posed by the proposed design and have addressed them.

2. Methodology

The aim is to design a 3D model of a shredder with help of designing software and then to re-design the Metal Shredder model based on our deliberations to improve its efficiency and other features. On the basis of making, it stronger, durable, and cost-efficient we tend to explore the usage of alternative materials for production and cost-cutting approaches as well. The main application of our shredder is for household shredding purposes that help in shredding mainly various plastic, biodegradable waste and also other light metals such as aluminium foils, etc. The flowchart below in Figure 1 summarizes the entire process involved from evolving a design to making it 3D printable. It began by selecting a Shredder Model – CAD Model and we redesigned the model to make it more precise and economical. Subsequently, the newly built model was made ready by ensuring the dimensions were accurate [6]. Once it was ready, Finite Element Analysis FEA was performed on it using ANSYS software to the parts of the Shredder Machine that were possible. Then the CAD file was converted to .STL file format and then performed an analysis to ensure no errors existed in the .STL file format. The file was then repaired using Meshmixer and ensured no errors existed and that the model is feasible for 3D printing. Using the same Meshmixer the orientation of the model was optimized [7]. Then using Ultimaker Cura slicing (material consumption, support generation, time) was performed. In conclusion of these processes successfully the model was observed to be ready for 3D printing.

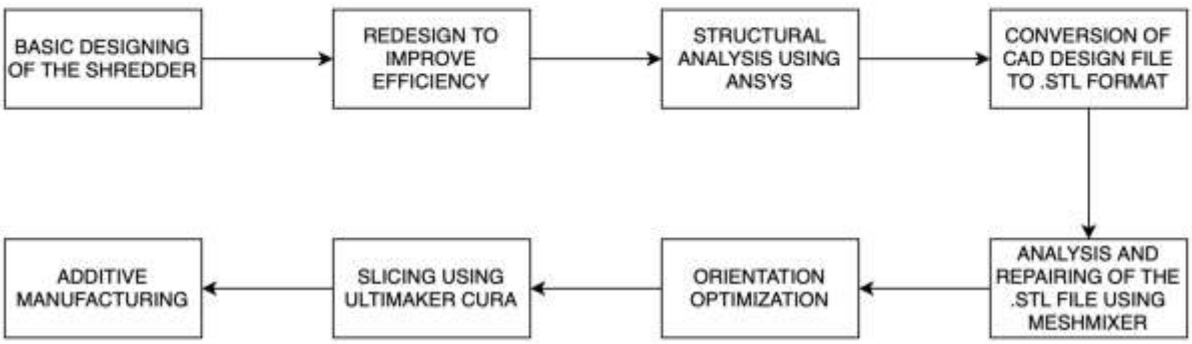

Figure 1. Flowchart of the Additive Manufacturing Process

2.1 Design and modelling

At first, a basic model of a shredder as shown in Figures 2 & 3 was considered, and using its assumptions of size, material, and weight a tentative CAD model was designed and then, later, performed the changes in the model to make the cut sharper and more precise; to decrease the overall weight and size of the Shredder Machine and thus economical. Considering these factors, we made changes in our CAD model using SolidWorks Software. The various parts that are included in a Metal

Shredder are Gears, Shredder Shaft or blade axis, box, handle, lever, blade, hopper, and nuts, bolts, bearings.

(a)

Figure 2. Images of Shredder before Redesigning Back View

(b)

Figure 3. Images of Shredder before Redesigning Front View

2.2. Redesigning

Redesigning is the process of modifying an existing design of a model. Redesigning is generally done to improve the shortcomings of the existent model by inculcating newer elements or eliminating the existing ones [8]. Here, to overcome the listed disadvantages of a manual shredder, we have redesigned the model. In this process of redesigning, we have added a hopper, sieve plate and airflow pores have been added. Each of the modifications has its own set of benefits, which are detailed below: Figures 4, 5 & 6 depict the side top -left and top -right views of the redesigned model.

1. Scattering of the shredded parts are reduced largely by increasing the length of the hopper
2. Our blade design helps in a more effective and faster cutting
3. Small air vents are made at the backside of the shredder to reduce the heat generated in the blades and as a lubrication, pouring platform to improve the life of blades by reducing the wear caused by friction.
4. An inclined sieve plate is added to as the shredded pieces fall it gets segregated according to the size itself and the large size ones can be sent for shredding again.

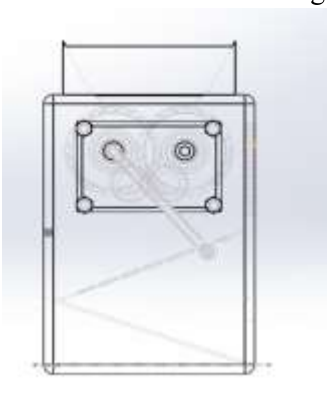

Figure 4. Shredder Side View

Figure 5. Shredder Top Left View

Figure 6. Shredder Top Right View

2.3. Blade Analysis

In this research, a shredder blade with three cutting edges is used. The geometry and shape of a single blade have been generated using SolidWorks as shown in Figures 7 & 8. The blade has a hexagonal hole for fixing it to the drive shaft.

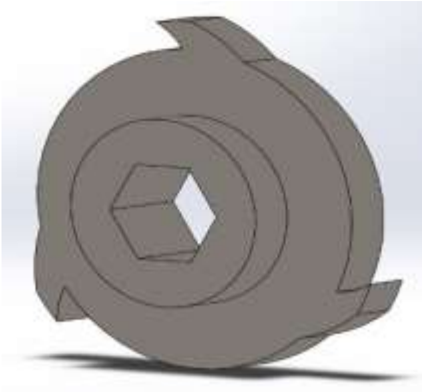

Figure 7. Shredder Blade Front View

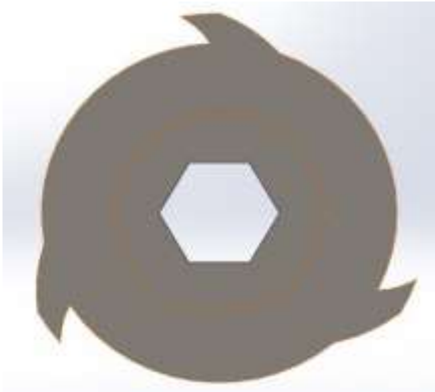

Figure 8. Shredder Blade Back View

The procedure for determining the distributed applied cutting (shredding) force at the edge of the blade is illustrated in Figure 9. Initially, the material for the blade and the material which is going to be cut the most is decided, and analysis is done using the calculated values of force by considering the above decision.

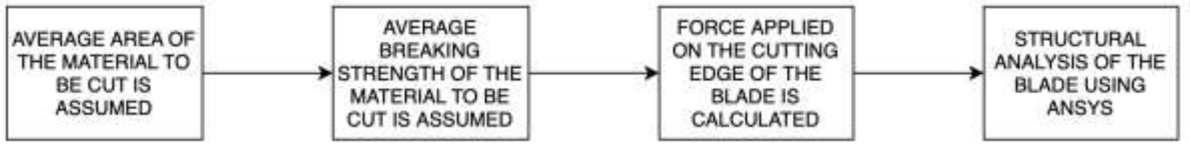

Figure 9. Schematic of the Steps involved in Blade Analysis

In this paper, the blades are made of 316 stainless steels with an ultimate tensile strength of 580 MPa, Yield strength of 330MPa. The shredder blades can be manufactured by 3d printing techniques. The 316 Stainless Steel 3D printing is produced by fusion or laser sintering [9]. Two possible technologies exist for this material: SLM (selective laser melting) and DMLS (Direct Metal Laser Sintering) technology. The laser beam brings the metal powder close to its fusion point layer after layer to print the objects. The calculations for the analysis of the blade are shown below:

1. Material to be cut: PET and other weaker materials
2. Material of the blade: 376 stainless steel (3D Printable)
3. Ultimate strength = 80 Mpa ; Factor of safety = 1.5
4. Breaking strength T_{br} = ultimate strength * factor of safety = 80*1.5= 120 Mpa
5. Cross sectional area of material to be cut (A) = w * t
   i. w – width of the cutting blade edge = 0.01 m = 10^{-2} m
   ii. t – average thickness of the plastic material to be cut = 0.07cm = 7 * 10^{-4} m
6. A = w * t = (10^{-2}) * (5* 10^{-4}) = 4 * 10^{-6} m
7. Cutting force = T_{br} * A = 600 N.

Therefore, on average a force of 600 N will be applied to the blades of the shredder. Finite Element Analysis was done to verify the structural and deformation properties that the shredder blade can withstand using ANSYS software. 3D modelling of the blade was imported from SolidWorks to the ANSYS. The static structural analysis was done considering only static stresses and strains; no vibration or dynamic analysis was considered [10]. The boundary conditions were applied in the model; the hexagonal hole in the blade centre has been fixed in all coordinate directions. The calculated cutting force (480 N) was applied to the blade top edge.

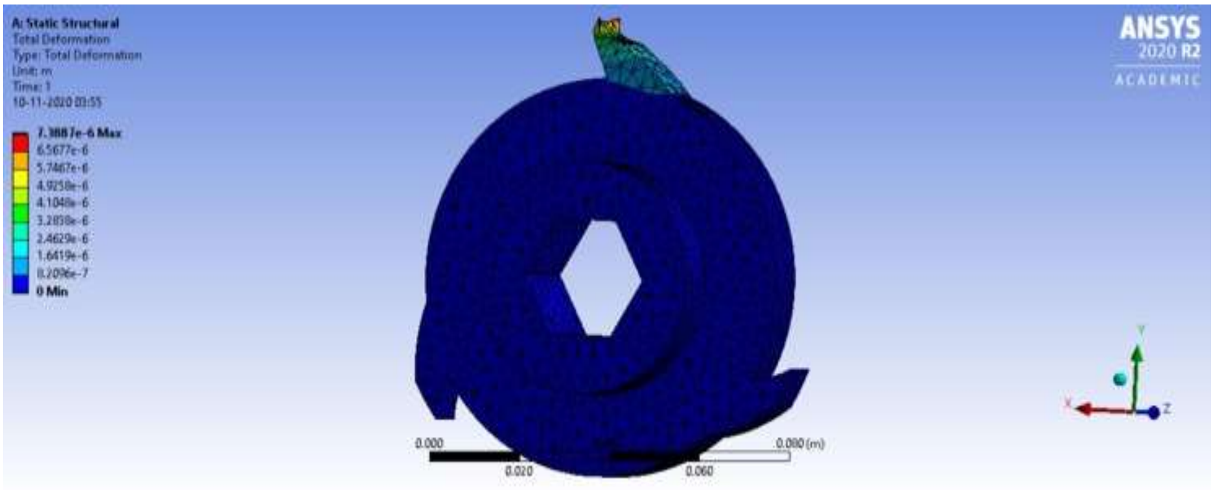

Figure 10. Total Deformation on the blade

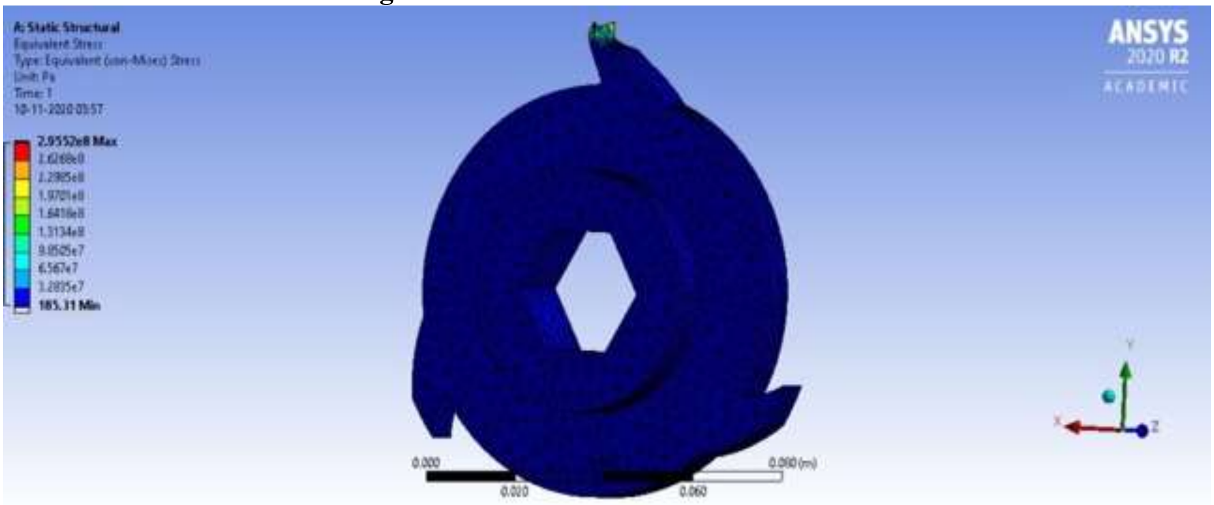

Figure 11. Equivalent Stress on the blade

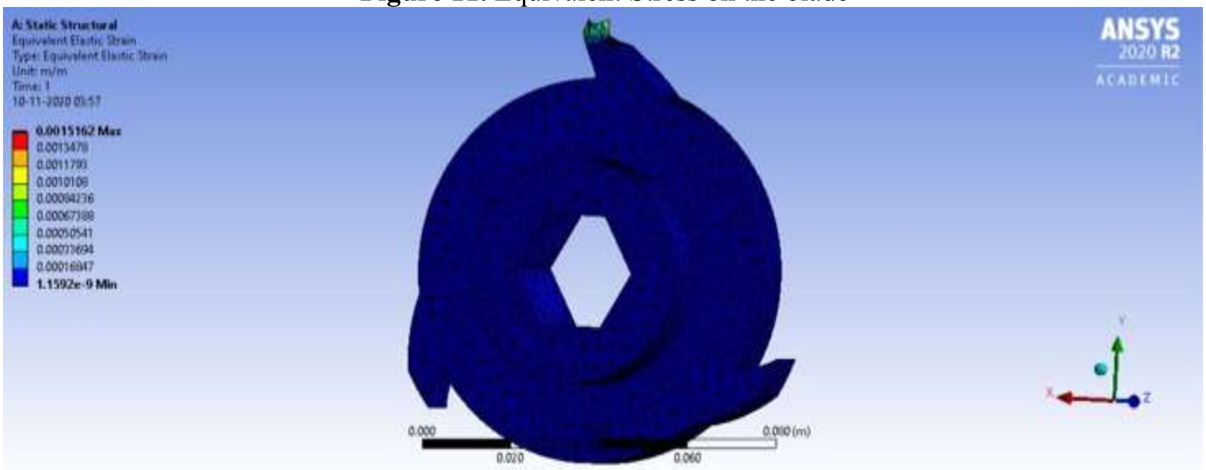

Figure 12. Equivalent Strain on the blade.

The results obtained from the ANSYS as seen in Figures 10, 11 & 12 indicate that the maximum Von Misses stress is 295 MPa, which is safe in values compared to the yield stress of the blade material. The maximum total mechanical strain is $1.516*10^{-3}$N/mm^{2}, and the maximum deformation is $0.73*10^{-5}$ m.

3. Pre – Processing Steps for 3 – D Printing

3.1. File conversion

The designed shredder model is converted from Solidworks file into STL file directly by exporting it and saving the file with ". STL" file extension. It was saved as STL binary format in specific as its comparatively more compact file format for. STL without losing its quality.

3.2. STL file repair

The repairing of the STL files is done using the Autodesk Meshmixer software. The file conversion process doesn't convert the model to STL file exactly the way it's expected to be and gives rise to a lot of geometrical errors. The geometrical errors include holes in the mesh, non-closed surfaces, bad edges, no shared edges between surfaces, unwanted surfaces, and file size being too large for 3D printing [11]. These errors, if they are left unchecked, will affect the 3D printing of that component. Different types of errors encountered in the Meshmixer software are denoted by different colours given below: Blue - denotes the holes present in the mesh (errors can be fixed); Magenta - denotes the disconnected components in the mesh (errors can be fixed); Red - denotes the mesh is not watertight (errors can be fixed); Black - error cannot be fixed.

After opening the STL file in Meshmixer software, we noticed that the component looked a bit shapeless and lacked sharpness across the surface. That implied that the file required file analysis and file repair, and other analysis after repairing to make sure the file goes perfectly fine to the 3D printing process. From the left panel, the 'edit' option was selected. Under the 'make solid' option, solid accuracy and mesh density was increased to appropriate levels to obtain the desired sharpness and shape. As the values were adjusted, we obtained the model view after each value adjustment allowing us to control the sharpness and accuracy of the STL file. Once the desired shape and sharpness is obtained, the analysis option is selected, and the various errors in the file appear, which is reviewed and analysed. The model was repaired for all errors by fixing the hole fill mode we require for each component respectively. The auto-repair option fixes all the holes as well as intersecting and floating triangles [12]. Now the file is repaired completely. Then after repairing the file of its error now the thickness analysis was done. In some rare cases, 3D printing failure is caused due to insufficient wall thickness of the component. This insufficient wall thickness might lead to loss of details and 3D print failure at times, so thickness analysis was also done alongside file repair to make sure that the file is completely all right for 3D printing. Cone angle, Cone Samples and Grazing Angle are the other technical parameters that deal with the angle between different numbers of rays from one side to the other [13]. Generally lowering the cone samples and setting a higher graze angle is preferred to improve processing time.

Blades, Blade Axis, Lever, Handle, Box, Spur Gear, Hex Bolt were the parts that were to be repaired. Results with Comparison to before and after repairing shown in Table 1. Since the parts looked distorted and blunt, the goal was to achieve the sharpness of the part files and to fix design errors. For that, the solid accuracy and mesh density values were changed to get an accurate and sharp model of the part file. On a scale of 0 to 512, 300 was selected for both the solid accuracy and mesh density with a cell size of 0.308 mm and 0.237 mm respectively [15]. Once we get a proper desired part, it is checked for errors in the form of coloured pop-ups (namely blue, magenta, red and black) in the areas where errors were present. Using the auto-repair option the error found was removed by setting up the hole fill as minimal. Even if there weren't visible errors during the file repairing, using the auto-repair option removes every minute of errors in the part files. This helps us ensure that it does not significantly affect the 3D printing process. Once the file was repaired, the thickness analysis was done with minimum thickness set as 0.1 mm and minimum defect size set as 0.1 mm. Also, the cone angle, cone samples, and the grazing angle were set with the default values of 10, 20, and 30 respectively. The errors generated while performing thickness analysis were removed by using the auto-repair option. Once the thickness analysis was done, the orientation optimization was done with the overhang angle set to 45 degrees to minimize the support structures' requirement. Then the mesh percentage was reduced by different percentages accordingly to maintain the file size below the 50MB file size limit.

Table 1. Comparison of the STL files before and after repairing

Components Names	Before Repair		After Repair	
	Vertices	Triangles	Vertices	Triangles
Blade	186	372	310392	620784
Blade Axis	323	642	176227	352450
Lever	275	546	62694	125384
Handle	1059	2114	249553	499102
Box	9444	20272	470978	943344
Spur Gear	444	888	395513	791026
Hex Bolt	205	406	255071	510138
Final Assembly	17740	36832	527620	1056660

3.3. Methodology for orientation optimization
The orientation optimization is also done using the Meshmixer software itself. Once the file was repaired, the orientation optimization option under the analysis option from the left panel was selected. Now once the orientation optimization is done, we get the required orientation of the file for 3D printing. The orientation angle was set to 45 degrees as most of the plastic layer created is supported by the previous layer below it [14]. These 45 degrees overhang angle is also necessary to be followed to reduce the number of support structures required while 3D printing. Before Exporting the new .STL file, there was one more thing that also impacts the 3D printing process that is the file size. Since the file size is limited to 50MB for 3D printing, considering that the accuracy level and mesh density were changed. For the files which exceeded the 50 MB file size limit, its file size was reduced by adjusting its mesh percentage, and to maintain its shape, the 'shape preserving' option was selected. After the file repair, orientation optimization, and file size limit were optimized, the file was exported and saved as a new .STL file. It was saved as STL binary format in specific as its comparatively more compact file format for. STL without losing its quality.

3.4. Slicing the parts and the assembly file
We first chose the desired printer from the options available. We then imported each repaired file and assigned the material for our parts to be Polycarbonate. For placing all our components into the window, we used the standard coordinates (0,0,0). For a few files, which did not fit into the Ultimaker window, we scaled them down to the appropriate ratio for better slicing. Few components needed additional support and build plate adhesions, for them to be stable while printing. We have initialized layer height, infill %, infill pattern, speed, printing temperatures, cooling, support generation and build plate adhesions which are all available under the custom basic settings in the Ultimaker CURA window. The inputs are as shown in Table – 2. The outcome of the slicing of each part is as depicted in Figure 13. Different infill patterns available:

1. Triangular - It is one of the strongest patterns since triangles provide the strongest shape. It also ensures uniform strength in every direction, and they are least likely to deform and, they provide the best support structure.
2. Octet - It uses multiple infill lines to create this pattern and is considered a combination of tetrahedral and cubic shapes. The load on the structure gets distributed to the overall area and hence is used when moderate strength is required. This pattern also ensures to prevent pillowing.
3. Cross - Although this pattern takes more time for printing, it is useful to be used when a soft and flexible body is required. It can be used for parts that do not require more material density and strength.
4. Tri-Hexagon - It gives maximum strength in the horizontal direction and has high shear resistance. This pattern is also useful for materials that don't require more material density or strength.
5. Zig-Zag - It gives more strength, especially with higher infill density. It is also suitable for the nozzle as it prevents any interruption during any layer and provides an extremely smooth surface finish.

6. Quarter cubic - It is like the cubic pattern but has an effective and much easier distribution of load, which thus gives high strength.
7. Grid-It gives very good strength and gives an excellent and smooth surface finish. It is useful for materials that need more material density and must bear more load.
8. Concentric - This 2D pattern produces waves through the interior of the print - by forming parallel rings within the structure. This pattern is useful when infill % is more.

Table 2. Details given into the Software for Slicing the Design

Part	Layer Height (mm)	Infill %	Infill Pattern	Speed mm/s	Build Volume Temp	Print Temp	Build Plate Temp	Print Time (min)	Weight (g)
Blade	0.18	15	Triangle	50	41	270	110	497	44
Bolt	0.12	14	Grid	52	40	275	115	43	4
Blade Axis	0.16	13	Octet	57	35	275	120	313	27
Box	0.14	14	Zigzag	59	35	280	120	626	867
Lever	0.1	11	Cross	60	37	275	114	445	28
Handle	0.14	10	Tri-Hexagon	50	36	265	115	125	16
Gear	0.15	13	Concentric	60	40	265	110	75	9

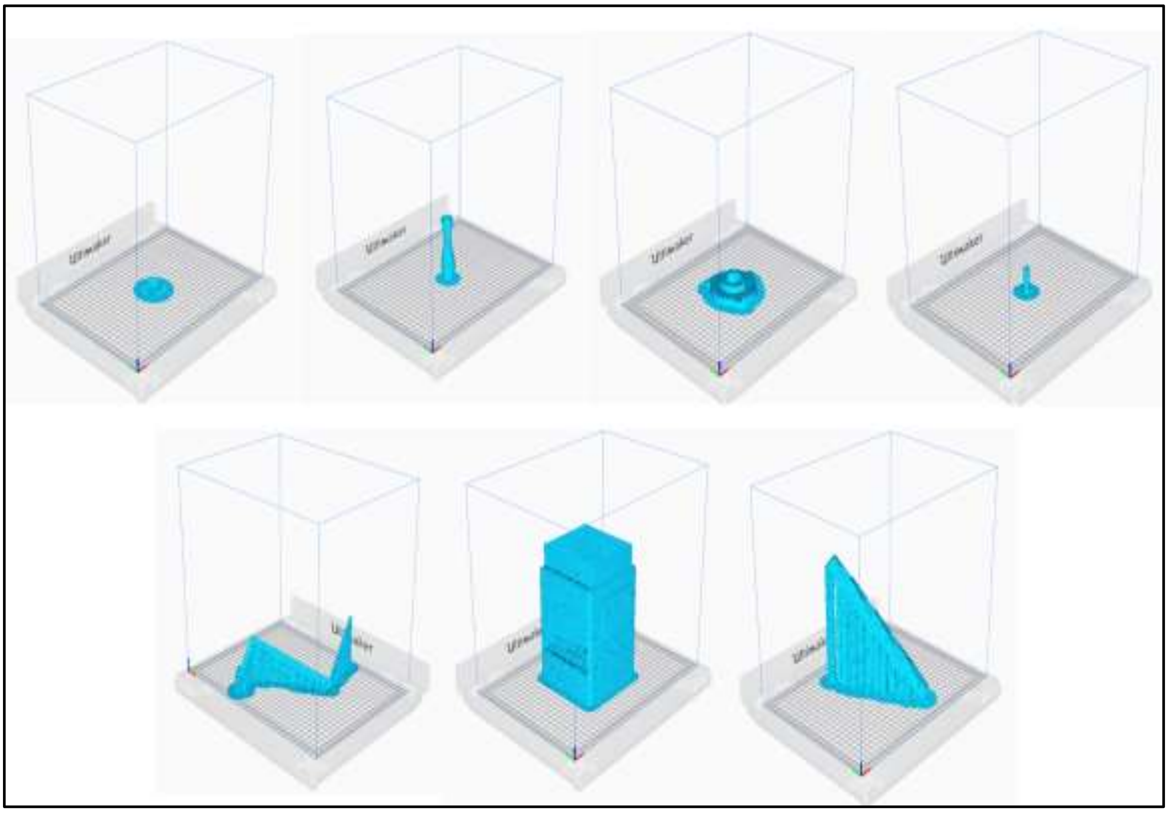

Figure 13. Depicts images of all parts of the design after the Slicing process in Ultimaker Software.

4. 3-D Printing

A design that had been altered to meet the new modifications as proposed was considered. Then finite element analysis was performed on the same design. Then the file was converted into STL format. Subsequently Slicing and Repairing were done with the design and problems were addressed. Then part by part printing of the entire assembly was analysed and the results are shown in Table 3.

Table 3. Material and Mass of Shredder Components.

S. No	Components of the Shredder Model	Material	Mass of component (g/per unit)	Quantity	The total mass of each component(g)
1.	Blades	316 Steel	192.52	20	3850.40
2.	Blade axis	Polycarbonate	354.50	2	709.00
3.	Box	Polycarbonate	4298.69	1	4298.69
4.	Lever	Polycarbonate	72.51	1	72.51
5.	Handle	Polycarbonate	33.56	1	33.56
6.	Hexagonal Bolts	Polycarbonate	4.57	4	18.28
7.	Spur Gears	Polycarbonate	8.78	4	35.12

The shredder blades can be manufactured by 3D printing techniques. The 316 Stainless Steel 3D printing is produced by fusion or laser sintering. Two possible technologies exist for this material: SLM (selective laser melting) and DMLS (Direct Metal Laser Sintering) technology. SLM process involves fully melting the powdered material. The laser beam brings the metal powder close to its fusion point layer after layer to print the objects. Post-processing for SLS includes Sandblasting, Vibratory finishing, Abrasive flow machining, Plasma polishing, and micromachining.

For the other parts of the shredder, PC (Polycarbonate) material is used for printing. PC is highly valued by the additive manufacturing industry for its strength and transparency. It has a much lower density than glass and the polycarbonate filament can withstand temperatures ranging from -150°C to 140°C, thus expanding the number of possible applications. Polycarbonate printing is done by FDM (Fused Deposition Modelling) process. FDM is the cheapest form of 3D printing technology accessible to everyone. It uses polymer materials in a filament form which are melted by a heater and then extruded onto the build platform in subsequent layers to form the final part. FDM gives a layer thickness of 0.1 to 0.05 mm. Post-processing for FDM includes: Sanding, Polishing, Painting, and Smoothing with acetone.

5. Results and Discussion

A simple manually operatable and 3D printable shredder that is both user-friendly and secure for operating was built. Various features were achieved in this design compared to the models available. The noise level was minimized to the extent that it doesn't require a motor. Its performance is increased in different ways, such as the air pores created on the shredder's back wall, which help to cool down the blades. Also, due to the simplicity of the design, 3D printing of such a product becomes way easier. In doing so we have achieved a design that could be commercially viable. This could further extend the design to be encouraged to manufacture and if used in large quantities to dispose of the waste properly and effectively.

A comparative analysis between our proposed model and the existent shredding models is as follows:

The Shredder Machine proposed is to function manually, without any energy required (except Mechanical Energy). Most large-scale industrial shredders are run by electricity. The scattering of particles has been reduced in the proposed model. In comparison, industrial shredders tend to lack this capability, quite often particles scatter in high levels – causing pollution and a potent threat to the surrounding environment. The blade is designed for personal use – is effective enough to cut lightweight steel and other metals and to cut them rapidly and effectively. The shredder being operated manually in no way lacks behind the industrial shredders in the cut generated due to effective cut by the blade. The air pores provided ensure proper air movement to keep the blades cool, from the heat generated during the process. Additionally, a lubricant pouring platform ensures the blades are lubricated when needed, thus, ensuring the longevity of the blade from the wearing caused due to friction. This factor isn't possible in the case of industrial shredders where blades wear and tear often due to their extent of use and largely lacking air vents for cooling.

The provision of sieves ensures uniform shredded particles are collected before disposal. The further provisions include the design being all filleted at the ends and occupying lesser space, thus, ensuring easier and safer use for individuals in houses or offices. Also, unlike in the case of Industrial Shredders, these shredder machines don't need experienced operators but could be operated by any and everyone. In comparison to traditional and industrial shredders, the possible shortcoming of the proposed model is the fact of the horizon of materials it could shred. While there are no restrictions of the nature of materials that a traditional shredder would shred, our model is restricted to paper, plastics, and lightweight metals only, which for domestic use shall be feasible.

6. Conclusion

Shredder machines have gained importance today due to more stress in proper disposal of waste. As the world looks for effective disposal of waste in an environmentally – friendly manner, shredder has emerged as a reliable option. Shredders are expected to play a critical role in the disposal of various materials in an effective and easy manner. But portable shredders shall help play an even more crucial role – to begin perfect disposal of shred waste beginning from home. Existing shredders pose various range of issues – size, weight and shredding of selected materials. Here a portable shredder design has been developed which has overcome these shortcomings. The blade analysis has shown the blades could operate under safe limits (stress is 295 Mpa) and yet shred a variety of materials. The model being 3-D printable provides further scope for any altercations and act as a base for larger manufacturing opportunities in the future. Thus, the design is developed in large scale the function ability and economics of the shredder being prudent shall make the design successful. Thus, the large-scale usage of the same could ensure safer disposal of waste in an environmentally friendly manner.

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