Design of Shredder Machine for ELV Tyres

S. M. Auti, Jinesh Sheth, Prakriti Tulasyan, Asmita Gaikwad, and Purnima Bagwe

Abstract Waste tyres generated in India make up around 7% of the total waste tyres of the world. With the advancements in the automotive industry, the tyre industry is rapidly increasing through projected growth of 6–8%. With this development, the amount of tyre's waste increases and the risk to the environment increases. Recycling of tyres helps to reduce the negative effects. Tyre shredding is the first step towards recycling as well as reducing the space needed by waste tyres. This study has mainly focused on detailed shredder machine design and analysis. The components of the system were modelled using 3D modelling software, and ANSYS was used for its finite element analysis (FEA). In this analysis, a couple of criteria for cost-effective shredding of scrap tyres were addressed. More emphasis was on cutting blade design. Analysis revealed that design was safe taking into account safety and strength criteria.

Keywords Shredder · Gearbox · Tyre shreds · End of life (ELV)

1 Introduction

When an automobile life is prolonged through repeated repair and reconditioning, the vehicles ultimately become unusable and have to be scrapped. At this stage before scrapping, the vehicles are termed as "end-of-life vehicles" (ELVs). With such a huge number of ELVs in India, waste tyres generated from them are huge in volume [1]. Waste tyre production is present even during an automobile's lifetime and not just at the end of life. Every year about 1.5 billion tyres are manufactured globally, which eventually turns into waste tyres. A shredder is a mechanical device for cutting the tyre into small pieces. Nowadays, recycled tyre material is used in various applications,

S. M. Auti (✉)
Research Scholar, Department of Mechanical Engineering, Veermata Jijabai Technological Institute (V.J.T.I.), Mumbai, Maharashtra 400019, India
e-mail: shashikant.auti@gmail.com

J. Sheth · P. Tulasyan · A. Gaikwad · P. Bagwe
Undergraduate Student, Department of Mechanical Engineering, Dwarkadas J. Sanghvi College of Engineering, Mumbai, India

H. Vasudevan et al. (eds.), *Proceedings of International Conference on Intelligent Manufacturing and Automation*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-15-4485-9_64

from garden pavers to playground floors. It also includes by-products such as gravel substitute, crumb rubber, landfill medium, filters for wastewater treatment, garden mulch, steel wires and fuel derived from tyre. The project includes design of the tyre shredder and analysis of the same with concerns regarding portability, strength, durability and ergonomic factors.

The main aim of this research is to design and analyse a prototype of scrap tyre shredder with the goal of achieving high productivity cost-effectiveness and safe operation. The secondary goals considered for this prototype are motor selection to give the required amount of torque and gearbox design to obtain the required turning velocity and shear force.

2 Literature Survey

Rodgers et al. evolution of different types of low-speed shredders was addressed in their study. Type 1 shear shredder combines two counter-rotating shafts, which do not inter-mesh with each other. Instead, they cut against a stationary anvil bar equipped with replaceable and adjustable knives. Type 2 shear shredders can be considered as a tool for simple size reduction or shredding before further processing. Type 3 design must take into consideration all downstream process specifications (a) the shredder output must be reasonably consistent in shape. (b) The raw material is bulky and not easy in the interface between the cutters [2].

M. Sakthivel et al., in their research work titled Design and Analysis of twin shaft shredder using PRO-E and HYPERWORKS SOFTWARE, recognized the selection criteria for the choice of crushing/shredding machine. The first factor is choosing the type of material for the reduction. The second factor is the size of the material for shredding. The third factor is the productive capacity. The fourth and the final factor is the final product particle size. This research helps for deciding the required factors or parameters to be used in designing [3].

Malina Vatskicheva and Irena Grigorova, in their research work titled Study of Two-Shaft Shredder for Crushing of Concrete, Rubber, Plastic and Wood, proposed a shredder for concrete railway sleepers crushing. According to the research, two-shaft shredder is the optimal combination of structural and economical parameters. It also approached to allow detail assessment of the machine elements, under various load conditions. All the power calculations are taken through this and estimated various parameters like number of blades, their position, shaft rpm, number of cogs, cutting area of blade, material volume to be cut, etc. [4].

Albert J. Shih and Ryan C. McCall presented the kinematics of the relative motion of the adjacent disk cutters in their research work. It was discussed that the wear of tool blades made of AISI D2 and CW tool steels is comparatively less [5].

Sekar L. R. and Vinoth Kumar, in their research work, discussed the methodology behind deciding number of cutting edges. Design of shredder blade is being upgraded. In the upgraded blade, it is studied about how reversing action of the blade may also damage the cutting edges. This research focused on criteria for material selection and different hardness increasing processes for cutting blade [6].

3 Shredder Design

A counter-rotating twin-shaft model was designed for the shredder machine. The machine has a good strength and is compact with an overall dimension of 620 mm × 290 mm × 220 mm. The components of the machine include cutting blades, hex and circular shafts, spacers, side support knives, frame, custom gearbox, bearings, coupler and a motor. It is a secondary shredder (Type 3) machine which requires pre-cutting of the vehicle tyre in a primary shredder.

The material selection is done on the basis of strength required and cost-effectiveness [4]. EN24 steel is selected for the majorly loaded components of the machine. It is a standard component of steel with high tensile and shear strength, good wear resistant properties, high Brinell hardness number for safety in pitting failure in gears and easily available in the market with standard costs.

The power requirement of the shredder is based on the productive capacity of the shredder [4]. A quarter of standard car tyre primary shreds were assumed to be reduced to fine and uniform-sized particles per minute, giving the productive capacity of 180 kg/h. The required speed, torque and power from the calculations were 73 rpm, 267 Nm and 3.067 kW, respectively. A very low-speed, high-torque motor would be required for driving this shredder which was practically not cost effective. Hence, a reduction mechanism was beneficial for a certain motor to drive a very low-speed, high-torque shredder.

According to the available motors, the most convenient motor was 3.7 kW, 960 rpm which results in the requirement of the reduction ratio of 13.15. Hence, a two-stage gearbox was used with input speed (N1) of 960 rpm and output speed (N4) of 73 rpm. The reduction ratio was kept into ascending order in order to minimize the load and smooth functioning. The value becomes 3.60 and 3.65 for Stage 1 and Stage 2, respectively. Spur gear pair is used in both the stages for high transmission efficiency (98%) and economical design. Design criteria were based on bending and wear, since sliding velocity is very less. The dimensions of the gearbox are shown in Table 1. The two hex shafts run at different speeds. This differential rpm gives different relative tip velocities between the blades on adjacent rotors. This feature provides better shearing action [3]. CAD model of the gearbox is shown in Fig. 3.

A hex shaft is used for placing the cutting blades in a particular phase difference between the consecutive blades for continuous shredding action and to eliminate the inter-rotation between the cutting blade and shaft. Shafts are designed and analysed under point load, bending moment and torsion. Figures 1 and 2 show the vertical and horizontal bending moment diagram, respectively.

Thus, the equivalent bending moment 616.574 Nm along with the torsional moment 267.525 Nm resulted in a minimum shaft diameter of 30 mm. CAD model of the hex shaft is shown in Fig. 4.

Table 1 Gear dimensions

	1st stage		2nd stage		
	G1	G2	G3	G4	G5
PCD (mm)	36	130	54	198	168
Addendum (mm)	2	2	3	3	3
Dedendum (mm)	2.5	2.5	3.75	3.75	3.75
Addendum diameter (mm)	40	134	60	204	174
Dedendum diameter (mm)	29.75	123.75	44.625	188.63	158.63
Speed (rpm)	960	265.85	265.85	73	89

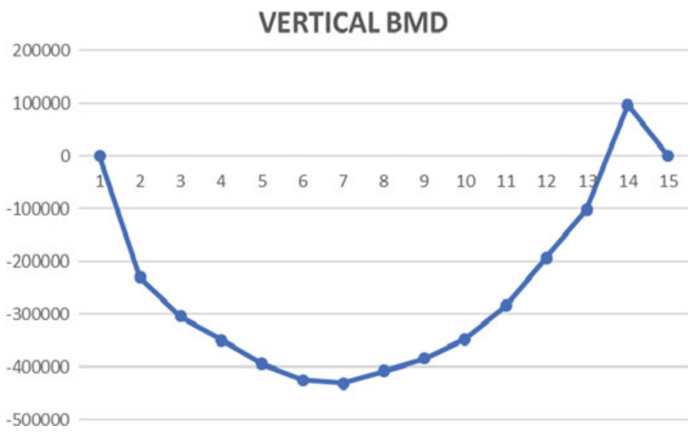

Fig. 1 Vertical BMD

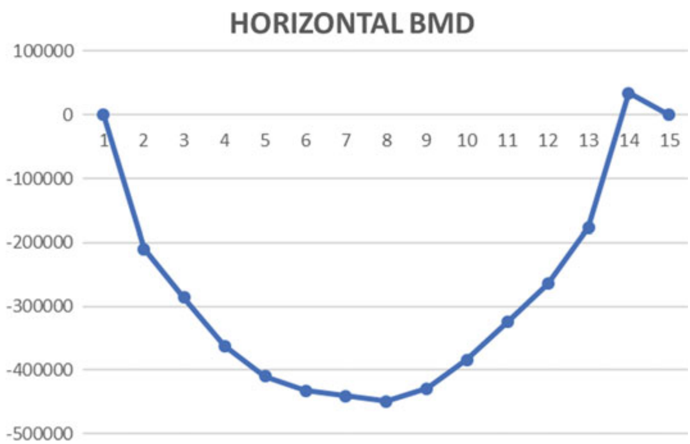

Fig. 2 Horizontal BMD

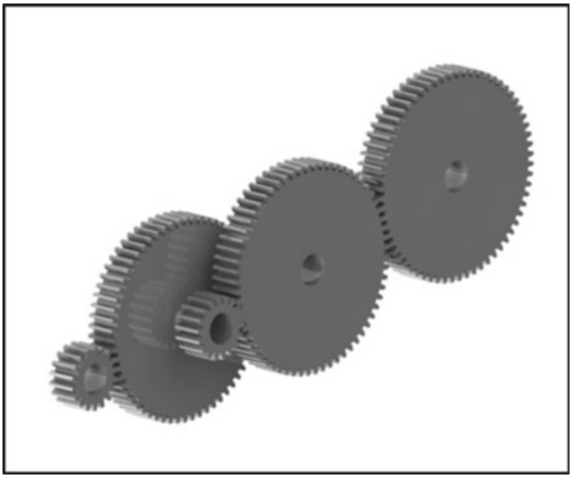

Fig. 3 CAD model of the gearbox

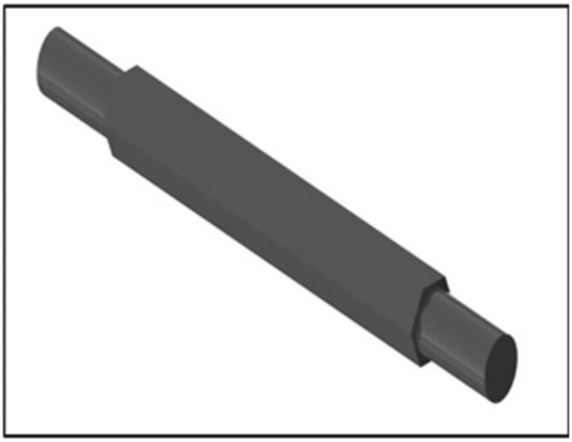

Fig. 4 CAD model of the shaft

The conventional design of cutting blade is modified for obtaining optimum cutting action with available torque. The rake angle of 6° and top/back clearance angle of 12° are used in the design of cutting blade. The wear and tear of cutting edges is reduced with this developed design [6]. The blades are in phase of 30° with each other with three cutting edges on each blade. CAD model of the cutting blade is shown in Fig. 5, and the representation of the above parameters in terms of 2D sketch is shown in Fig. 6.

Motor shaft is connected to the gear shaft using a muff coupler. Keys and keyways are used to lock the rotation between the gear and shaft. To take the radial load of shaft under highly fluctuating conditions, bearings are selected.

Three-phase induction motor has a high starting torque, good speed regulation and reasonable overload capacity. An induction motor is a highly efficient machine

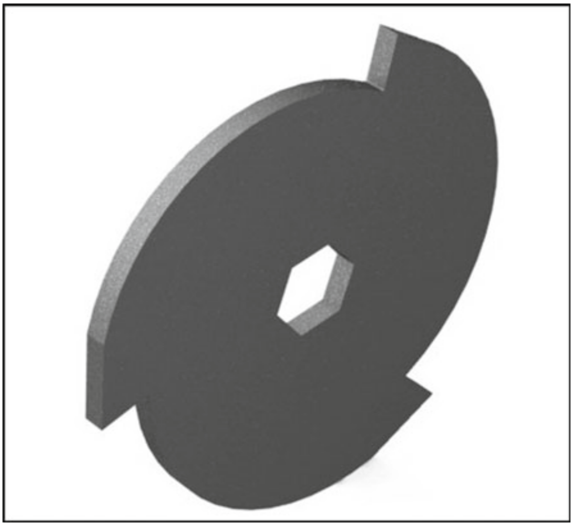

Fig. 5 CAD model of the cutting blade

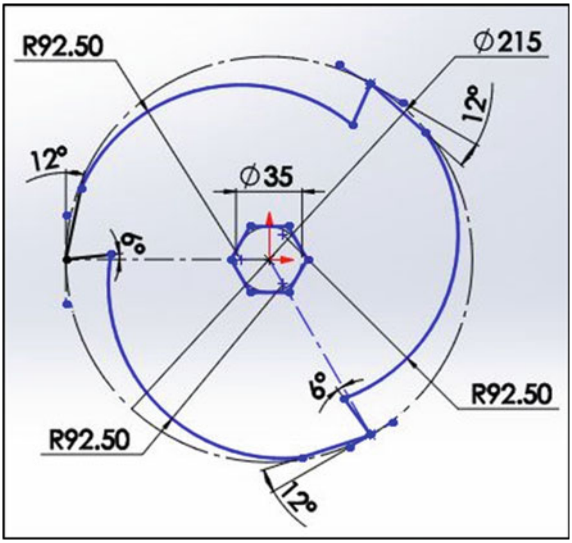

Fig. 6 2D sketch of the cutting blade geometry

with full load efficiency varying from 85 to 97%. It is good at maintaining their speed even under load. It does that by drawing more current in order to maintain the speed. Hence, considering the allowable power requirements and less cost requirement of motor, three-phase induction motor was selected for the shredder.

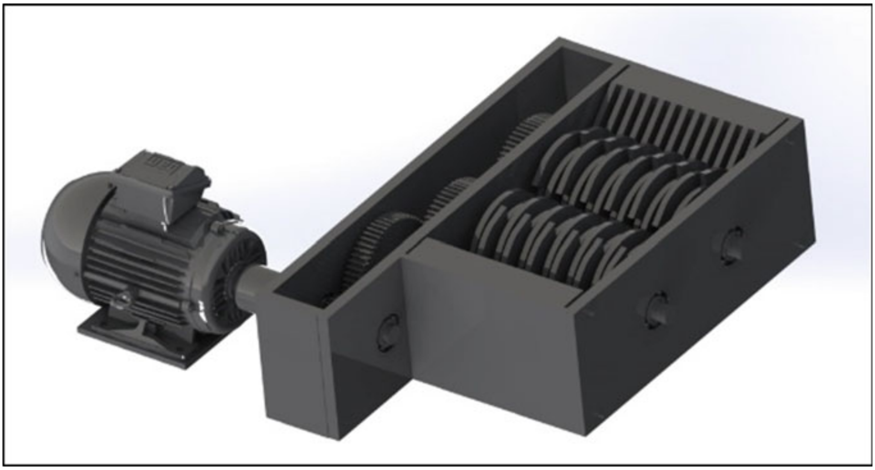

Fig. 7 CAD model of the tyre shredder machine

4 CAD Model of the Assembly

The final assembly of the shredder machine for ELV tyres is shown in Fig. 7 [3].

5 Results and Discussion

The shredder machine is structurally analysed by doing FEA on various parts of the machine. The equivalent von Mises stress for shaft is 136.64 N/mm^2, factor of safety for shaft is 1.8296 and maximum total deformation for shaft is 0.016757 mm. This analysis is shown in Figs. 8 and 9.

The equivalent von Mises stress for blade is 88.375 N/mm^2, factor of safety for blade is 2.8289 and maximum total deformation for blade is 0.01542 mm. This analysis is shown in Figs. 10 and 11.

The equivalent von Mises stress for blade and shaft assembly is 436.82 N/mm^2, factor of safety is 1.9733 and maximum total deformation is 0.14967 mm. This analysis is shown in Figs. 12 and 13.

The maximum total deformation and factor of safety for gear assembly are 0.017733 mm, 2.0026, respectively and are shown in Figs. 14 and 15, respectively.

Design of this shredder was focused on the particle size. Particle sizes produced by the existing shredders were large and non-uniform of sizes 50–150 mm. This shredder produces fine and uniform particle size of 5 mm. Hence, 90–97% reduction in particle size is achieved. The low speed, high torque generating gearbox reduces the requirement of higher power motor to 5hp, aiming at a small-scale productivity of 180 kg/h with high-quality shreds. The size of cutting chamber is 537 × 175 mm

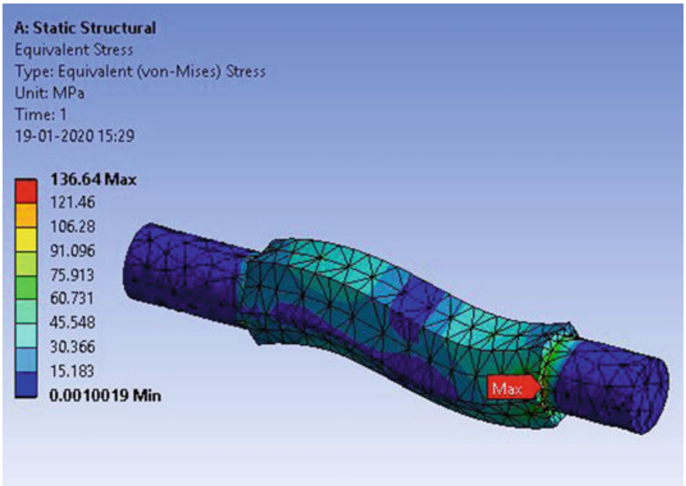

Fig. 8 Equivalent von Mises stress for shaft

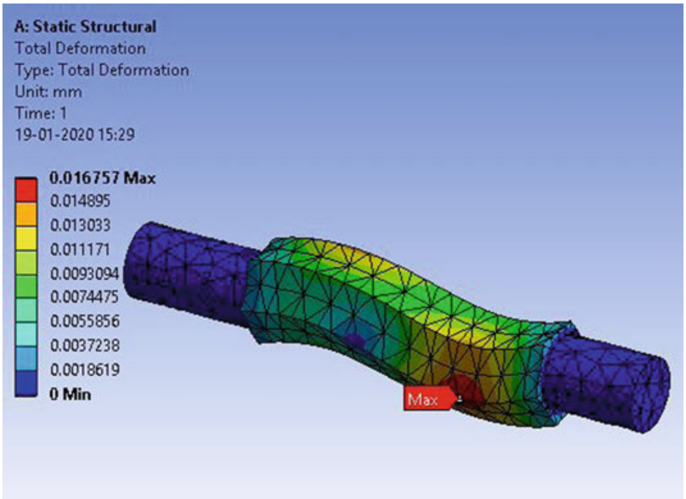

Fig. 9 Total deformation for shaft

which is very compact as compared to the conventional shredders having the cutting chamber sized 1200 × 800 mm.

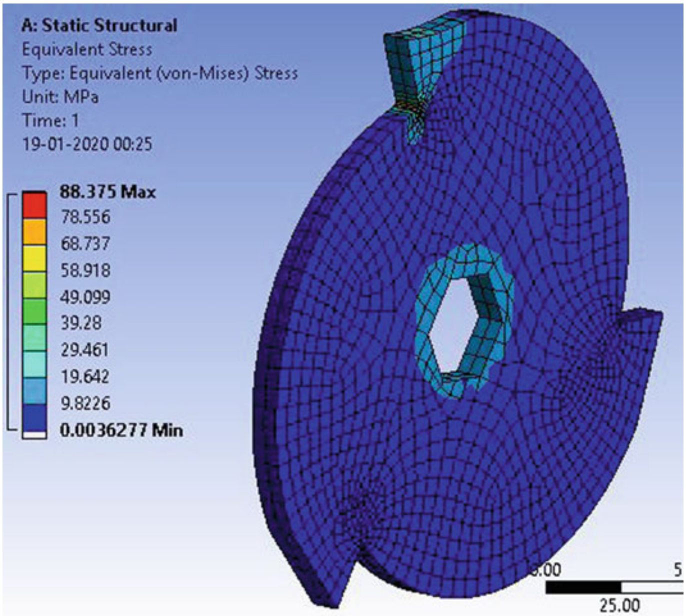

Fig. 10 Equivalent von Mises stress for blade

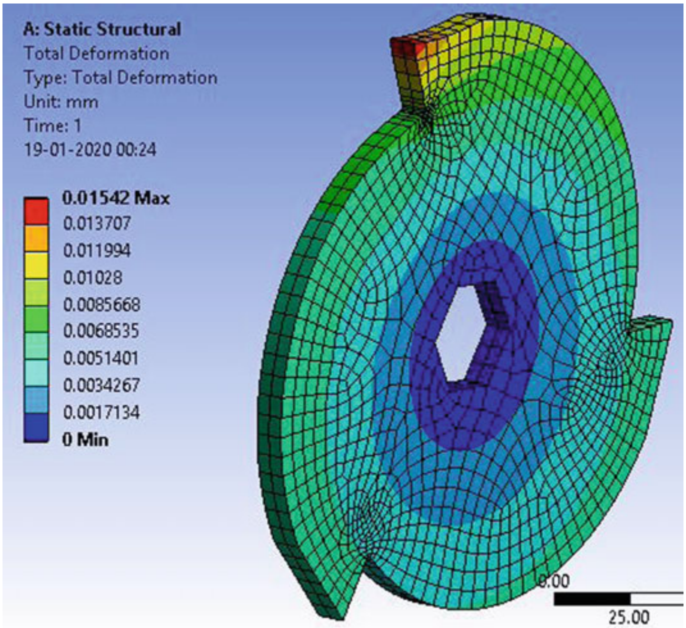

Fig. 11 Total deformation for blade

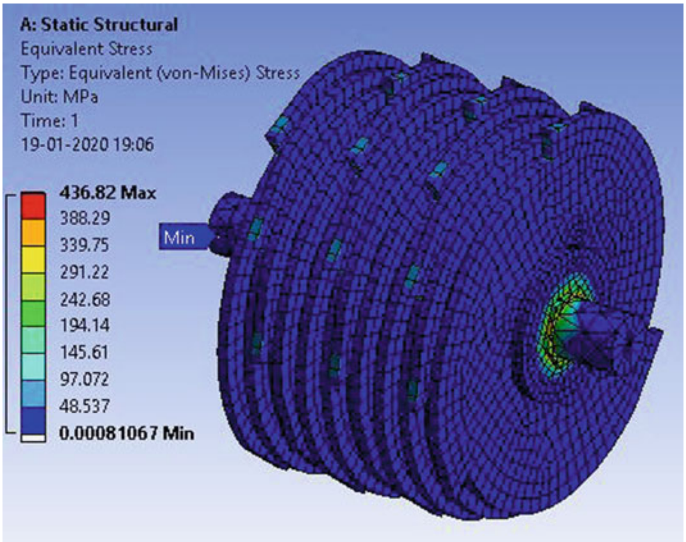

Fig. 12 Equivalent von Mises stress for shaft and blade assembly

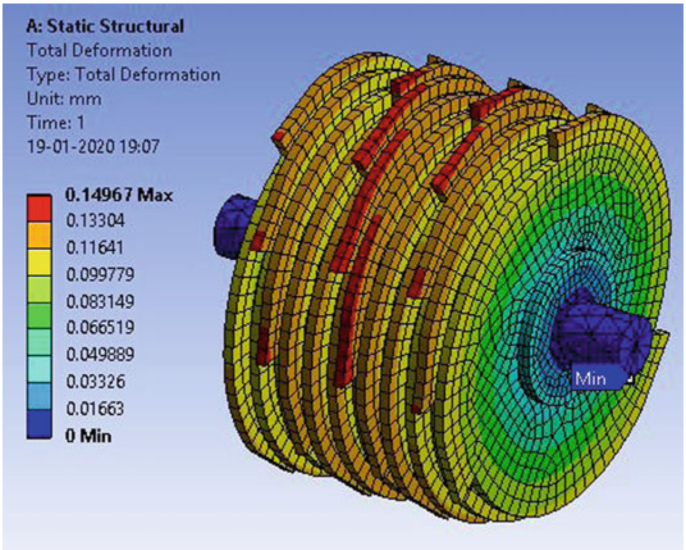

Fig. 13 Total deformation for shaft and blade assembly

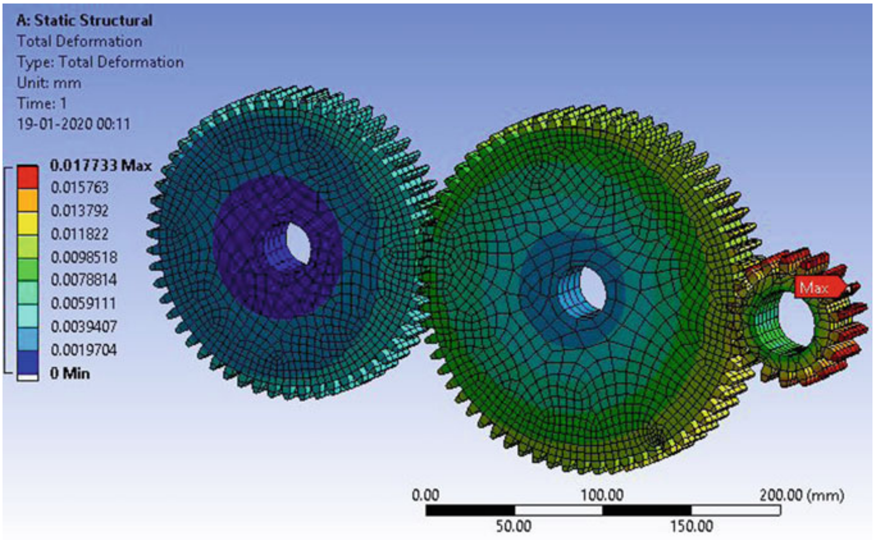

Fig. 14 Total deformation for gear assembly

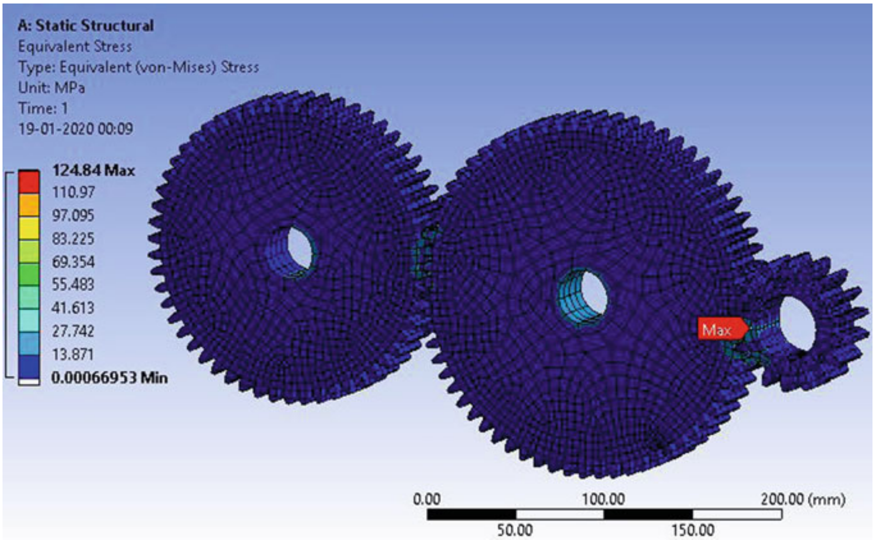

Fig. 15 Equivalent von Mises stress for gear assembly

6 Conclusion

In general, conventional tyre shredders are a primary shredder that shreds the whole tyre into large pieces. This tyre shredder is a secondary shredder that reduces primary shredding in fine-sized particles. In the case of blade sharpening or replacement of any damaged parts, the cutting chamber is designed taking into account the ease of disassemble. Hence, maintenance is easy.

Finite element analysis of shaft, blade and gearbox, performed using ANSYS, shows that the design was safe considering safety and strength criteria. The design of the tyre shredder method is perfect for achieving fine shredding of particles. Such fine particles were used for the process of pyrolysis where process yields are affected by particle size.

A similar configuration can be used to shred other pieces of ELV made of plastics such as PVC and ABS by making minor design changes in blade geometry.

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