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Topology optimization of engine bracket arm using BESO

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Abstract. An engine bracket is one of the most critical components of the engine used for mounting and supporting the engine in the vehicles. Today, the automobile industry requires lightweight components, which will reduce the car's overall weight when fitted into the vehicle. Topology optimization is a technique with the help of which the surface of a component is optimized to get the required shape for having reduced weight. The weight is reduced by optimizing the material on the surface of the details. In this paper, the work done is the application of topology optimization on the surface of the engine bracket arm. Then the optimized model is tested computationally using realistic conditions. Bi-directional evolutionary structural optimization is used as a technique for topology optimization. With the help of the BESO method, the material optimization is done, and then the weights are compared with the original component. A new algorithm is developed using MATLAB codes. The sensitivity ratio is considered using the von Mises strength as a critical parameter for the BESO method for optimization. The optimized bracket model is then assembled with the hub of the component, and then the assembly is simulated for verification using standard conditions. A comparison of weight reduction is there using topology optimization.

Keywords: Topology optimization / BESO method / finite element analysis

1 Introduction

An engine is the heart of a vehicle, with the help of which sufficient power is developed for moving the car. Under different operational conditions, the machine weights are taken up using supporting components. The engine bracket is also one of the components with the help of which the engine is supported. The engine bracket arm as shown in Figure 1 takes up the engine's load during vibrations under dynamic loading conditions and the total load under static loading conditions. The engine bracket consists of steel, aluminum, and alloys. Using these materials is to get the required strength without compromising the component's functionality. The engine brackets are designed considering the engine's shape and size. A study was conducted by Viqaruddina et al. [1] using the finite element software ANSYS and presented stress plots with optimal topologies for column and beam cross-sections. They used Aluminum 7075 T6 as a material for the base control arm in the Optistruct module of HyperWorks to obtain an optimized structure of the control arm. Analysis results of the optimized control arm showed favorable results, and a weight reduction of up to 40% was achieved. Rahman et al.

performed topology optimization to reduce the weight of the connecting rod achieving around 11.7% weight reduction [2]. Effect of self-weight on topology optimization of the different structures with the static loading condition, Saxena et al. [3]. A weight reduction of about 19% in the steering knuckle was obtained using topology optimization by Srivastava et al. [4]. A versatile prosthetic finger design was made using topology optimization by Srivastava et al. [5]. Fang et al. apply topology optimization on different curves for different engineering applications [6]. A mixed mesh beam was optimized using topology optimization for making robust hybrid-compliant mechanisms by Cao et al. [7]. Structural optimization was done in order to improve the design of the engine mount bracket by Pax et al. [8]. An automotive gear train was optimized using topology optimization, making it lightweight Igami et al. [9].

2 Analysis of conventional bracket arm

First, the analysis of the original component is done to get an idea about the von Mises stresses acting on the component. The finite element analysis is done on the bracket arm using the 9 kN force as a point load as shown in Figure 2. The von Mises stress is considered as the parameter with deformation as shown in Figures 3 and 4.

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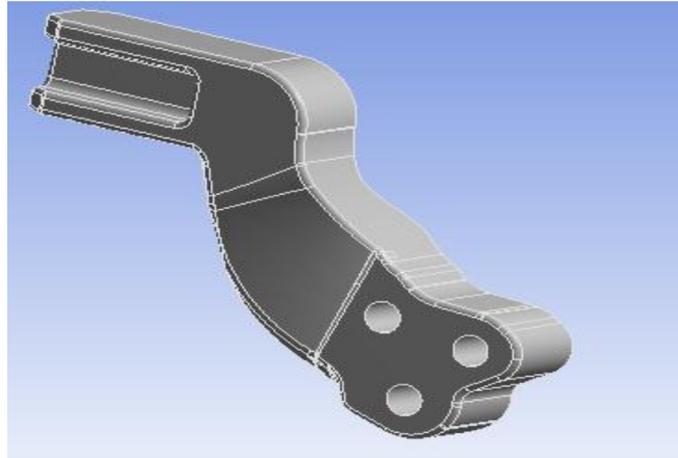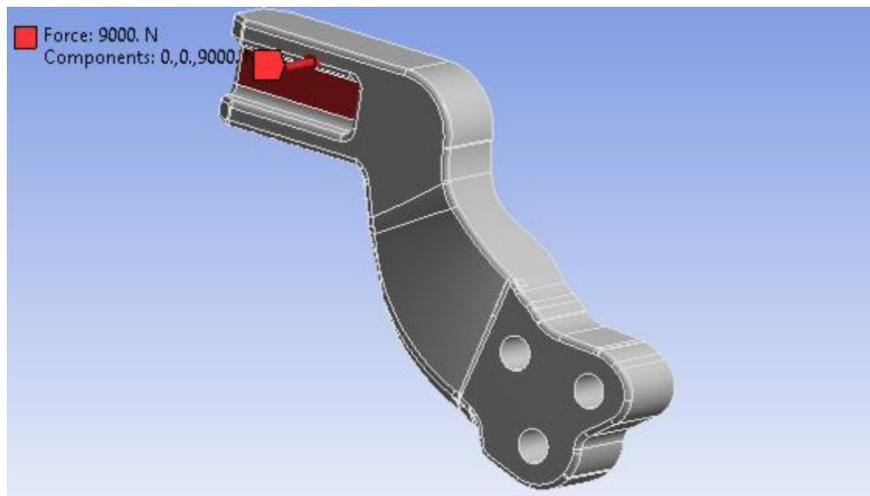**Fig. 1.** CAD model of conventional bracket arm.

Fig. 2. Application of 9 kN load on face of bracket.

The boundary conditions considered for the analysis fixing the three points and application of points loads on the face of the bracket arm.

The total deformation is according to the von Mises stress that occurs on the surface of the bracket. The load of 9 kN is applied on the bracket arm's rare end to take the cantilever beam's corollary, having one end fixed and the other free. The exact role is for the engine bracket, as deformation occurs near the free ends when the load is applied on the free end. The analysis aims to check the effect of the load on the conventional bracket arms.

3 Topology optimization

Topology optimization is a mathematical optimization technique used for material optimization on the component's surface. The optimization takes place under the given conditions with the given constraints. *Topology optimization* is a technique used for different design optimization purposes.

Objective function Min $F(x)$ subject to $g <= 0$

$$h(x) = 0$$

where (x) is a design variable. Here the objective function includes the function of mass whereas constraints include data of stress and volume. For carrying out the topology optimization of the bracket arm, some primitives are taken like rectangle, triangle, and square; in addition, based on the feasibility of the problem of designing the bracket, a triangle shape is chosen for topology optimization so that after optimization a new design is created which has a lightweight and can be used in vehicles. The dimensions for the geometry are two lengths of triangles 100 and 110, and the height is 30 mm along with the initial thickness of 15 mm. The CAD model of the geometry is made using CREO software. Three circles of 3 mm diameter are made on the three ends of the triangular geometry. An initial load of 141 N is applied on the circle of the pointed end of the triangle as shown in Figure 5, while the two circles on the other end of the bracket are fixed. The FEA analysis is done
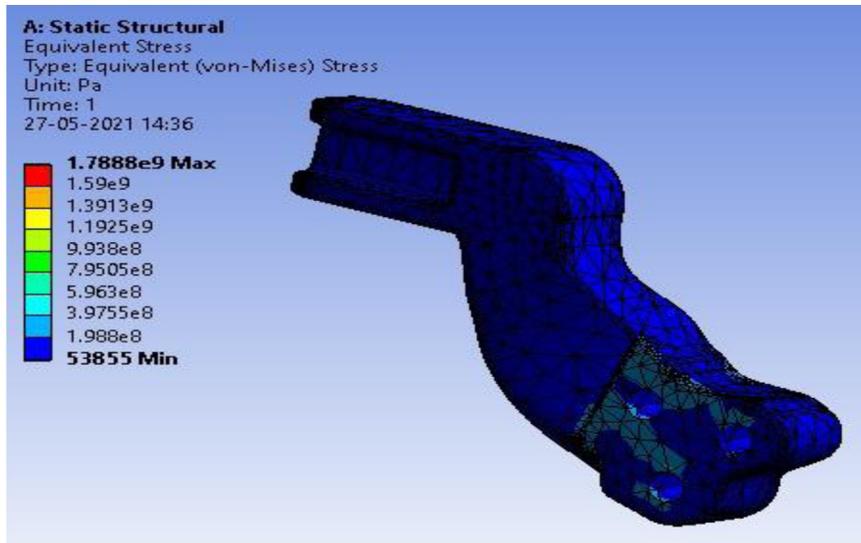
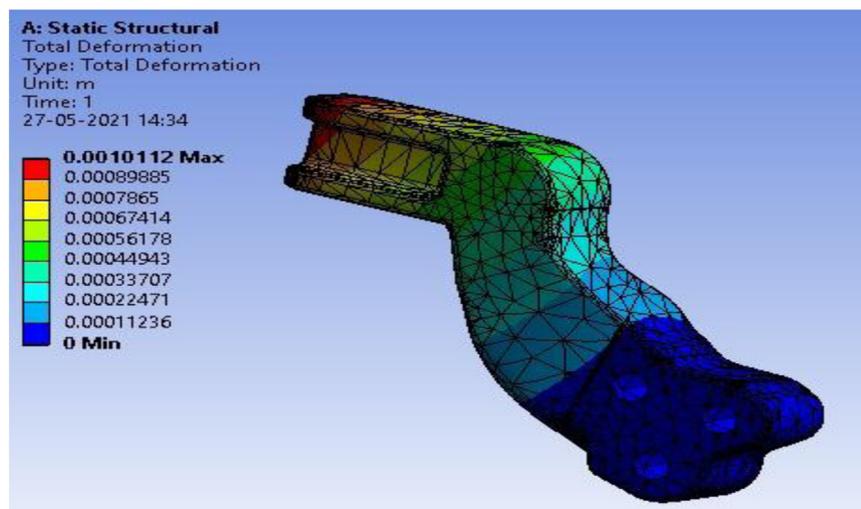**Fig. 3.** von Misses stress on the surface of the bracket.

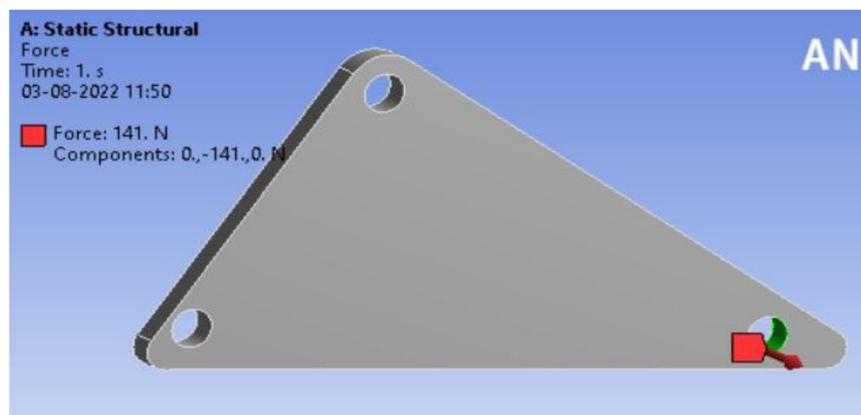**Fig. 4.** Total deformation on the face of bracket arm.
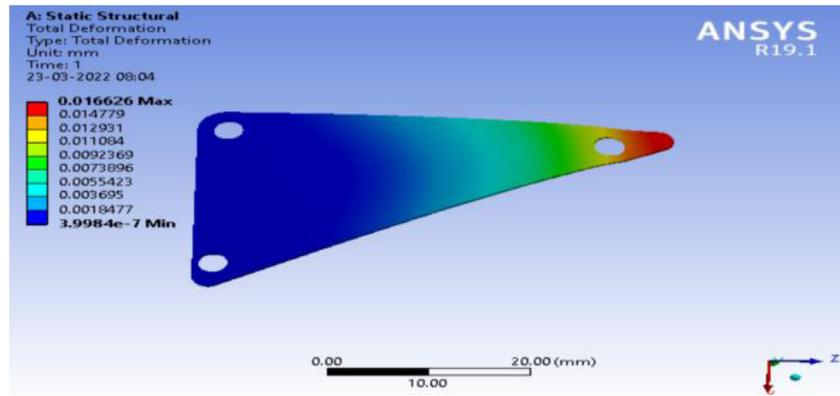

Fig. 5. Loading conditions.
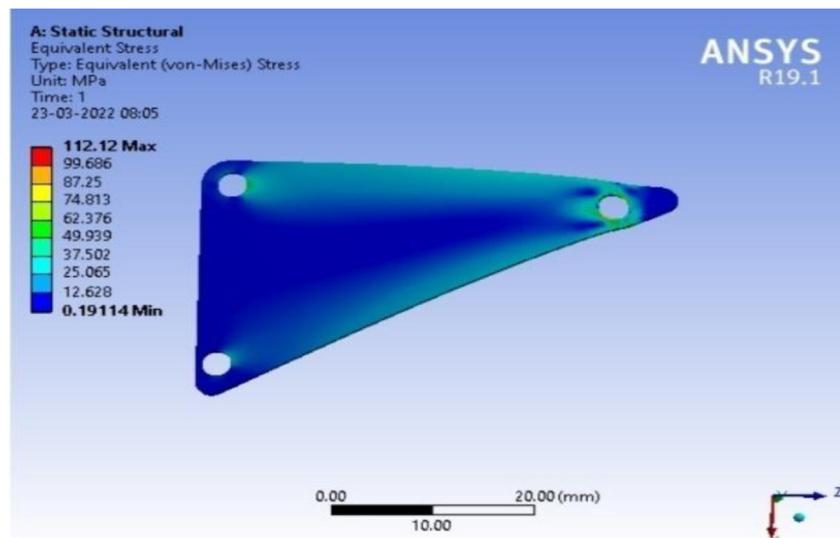
Fig. 6. Total deformation.

Fig. 7. Von Mises stresses.

with fixed boundary conditions on the other end of the plate. Equivalent stress of 112.12 MPa as shown in Figure 6 and total deformation of 0.016626 mm as shown in Figure 7 occurs.

4 Topology optimization of the triangular plate using BESO

BESO algorithm is a Bi-directional Evolutionary Structural Optimization algorithm. BESO algorithm deals with adding and removing material wherever needed for optimized design. Which is used to obtain a compliant structure from the primitive design domain; by applying the BESO algorithm, a compliant structure of the motion amplifier is obtained. Here the material removed and added is considered by considering the binary numbers 0 and 1, as 0 means the removal of material, and one means the addition of material on the component's surface. In order to apply the BESO method, the FEA analysis is done first on the triangular geometry. Static analysis is to be done

considering the boundary conditions. Load Application is according to the need. Consideration of Von-mises stress as a parameter for Topology Optimization is necessary. Deformation is also considered concerning the applied load.

$$F = K \times u,$$

$F =$ Force, $K =$ Stiffness, $u =$ Component vector.

5 MATLAB code for topology optimization

Sensitivity factor is used to find the optimum value of the material that can be removed concerning the von Mises stress acting on the design space on the application of load as shown in Figure 8. Sensitivity factor = von Mises stress/ yield strength of the component filter application = mean value of the sensitivity factor is taken as a parameter for deciding the binary values 0 and 1. 0 = Material Subtracted from Design Domain (Material should be removed where value of sensitivity is lower). 1 = Material Added in the
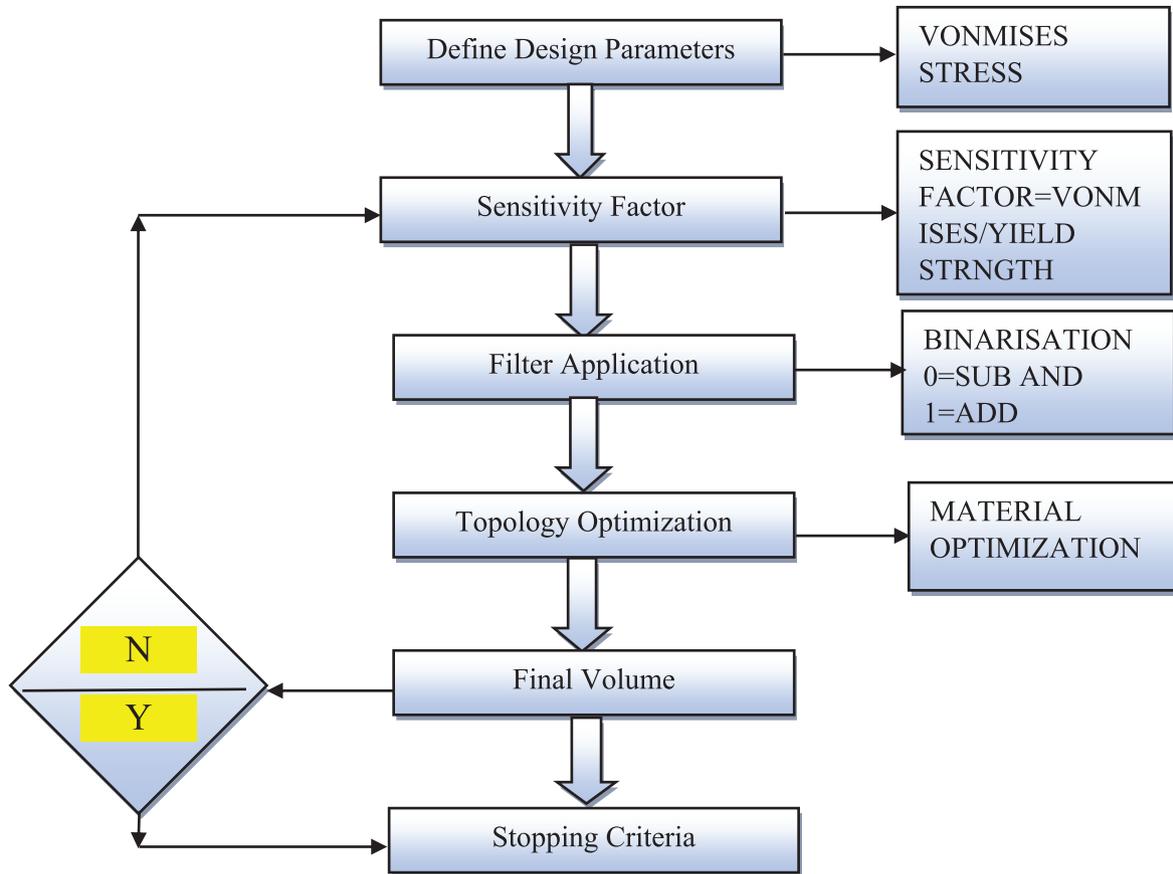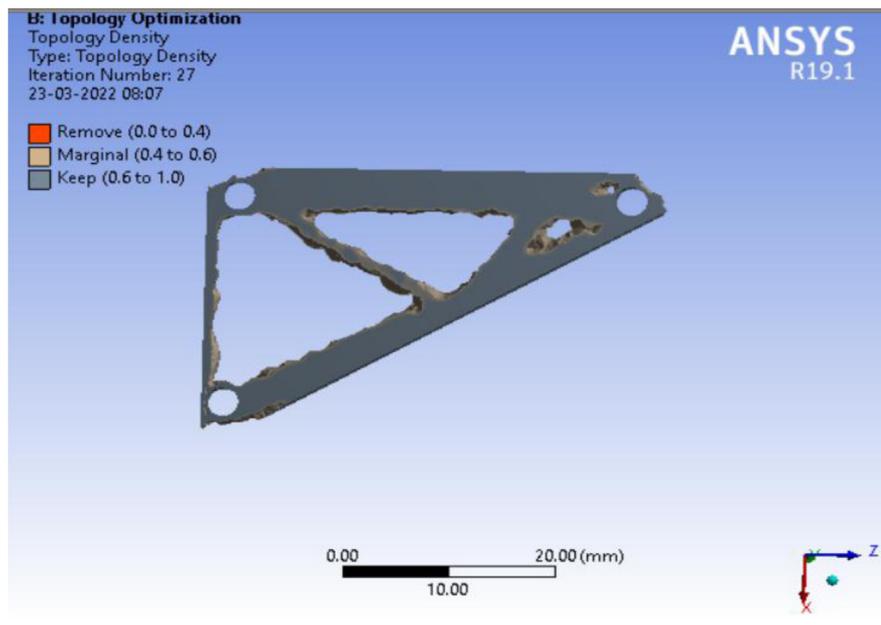
Fig. 8. Flow chart for BESO algorithm.

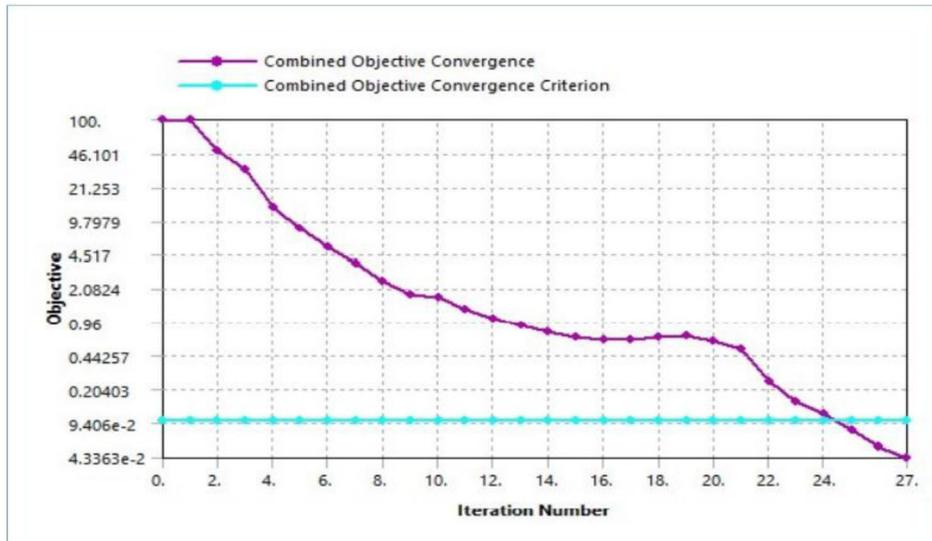**Fig. 9.** Topology optimized triangular shape for bracket.
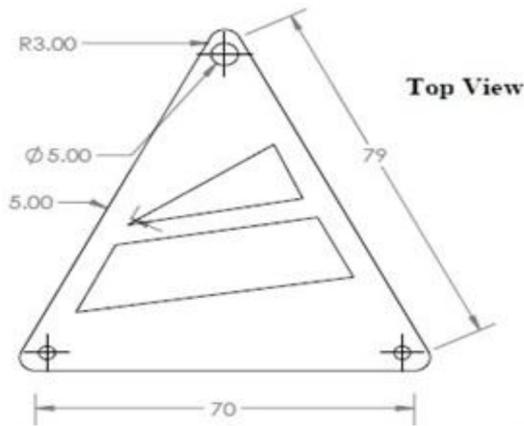
Fig. 10. Iteration chart for topology optimization.
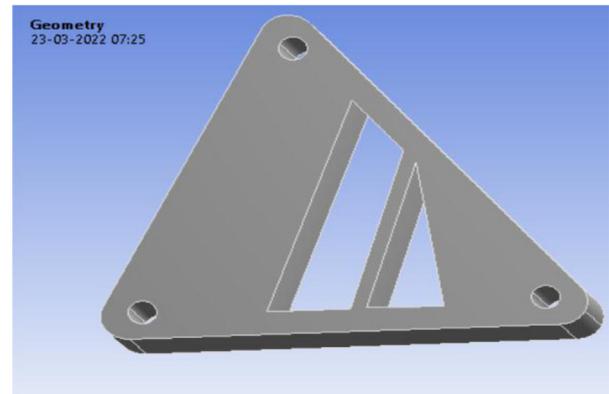

Fig. 11. Improved design of a bracket.

Fig. 12. CAD model of improved bracket design.

6 Improved design after topology optimization

After topology optimization, since the edges of the components are regular, it was modified with new dimensions to give it a perfect shape for the analysis. The dimensions given here are thickness increased to 24 mm and three circles are of 3 mm dia each with length of 110 mm and 79 mm and width of 70 mm for concept development of new bracket as shown in Figure 11 along with the improved CAD model as shown in Figure 12. Then FEA analysis of new designed bracket is done for Von Mises stress as shown in Figures 13–15 with respect to three condition as shown in Table 1 & 3.

7 Analysis of new bracket arm with assembly

The new bracket arm, which was designed as a result of topology optimization, is now analyzed with the help of FEA using the same loading conditions as in Table 2.

Design domain (Material should be added in the place where the value of sensitivity is higher). Final volume is decided through topology optimization.

The output obtained concerns the sensitivity factor, as binarization is done using 0 and 1. Limiting value in the algorithm is taken 0.5, and according to that, a set of values is assigned initially as the expected result obtained from FEA analysis. Values that are taken below 0.5 is taken as 0, and above that, it is 1. Accordingly, material addition and subtraction are done until it gets topology optimized and reaches the desired value. Then with the help of this algorithm, the optimization is done using ANSYS as shown in Figure 9 with the topology density element from the removal of material up to 40% and material retained up to 60%. Twenty-seven iterations are done such that the final convergence as shown in Figure 10 comes on the component's 27 iterations of the topology optimization.
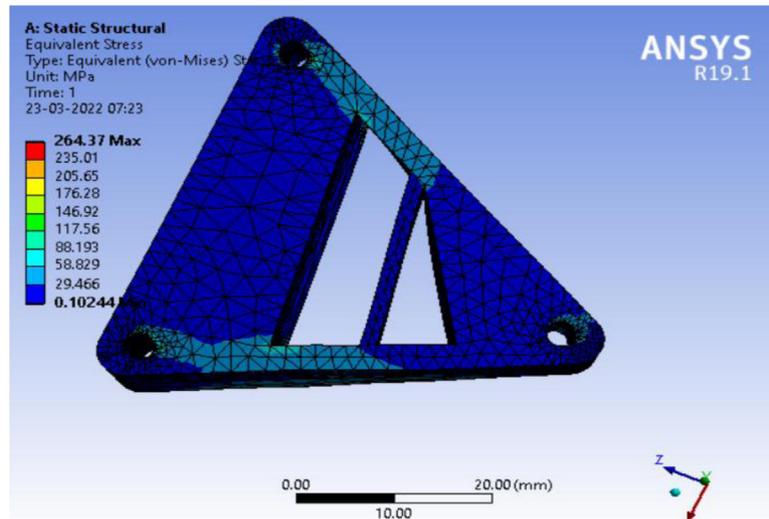
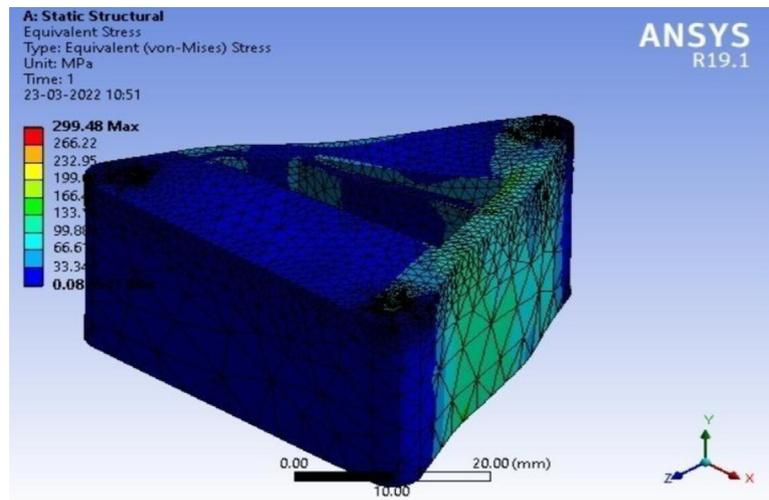**Fig. 13.** Equivalent von Mises stress for pot hole launch.

Fig. 14. Equivalent von Mises stress for sudden launch side declutching first gear.

For the three conditions, the consideration of forces on the component is taken such that all the ends are fixed, and load is applied to the center of the component as shown in Figure 16. The purpose of analysis with assembly is to determine how much force the component can withstand under different loading conditions when applied with the hub assembly for the engine.

The material for this analysis is also considered as structural steel having the same properties as for the design and analysis of new bracket. The yield strength is considered as 350 MPa.

8 Results and discussion

The analysis of assembly of topology optimized bracket with assembly is analyzed using the conditions of Table 2 and the Von Mises stress value for the three cases as shown

in Figures 17–19 and tabulated in Table 4. The results show that the new topology optimized model of the engine bracket arm is safe under the given loading conditions for the structural steel material. Yield strength is considered as the criteria for the analysis of the topology optimized bracket. After doing the topology optimization for redesigning the engine bracket arm, there is weight reduction as the optimization is for the material of the component, which got optimized by applying the BESO algorithm as shown in Table 5. The result shows that the weight of the original component is reduced by 50% with assembly as compared to the weight of the original bracket without compromising its functionality. Its strength is checked with the use of FEA analysis that verify it's as all values of Von Mises stress for all three conditions of loading is less than the yield strength of material (structural steel) and thus can replace the original component.
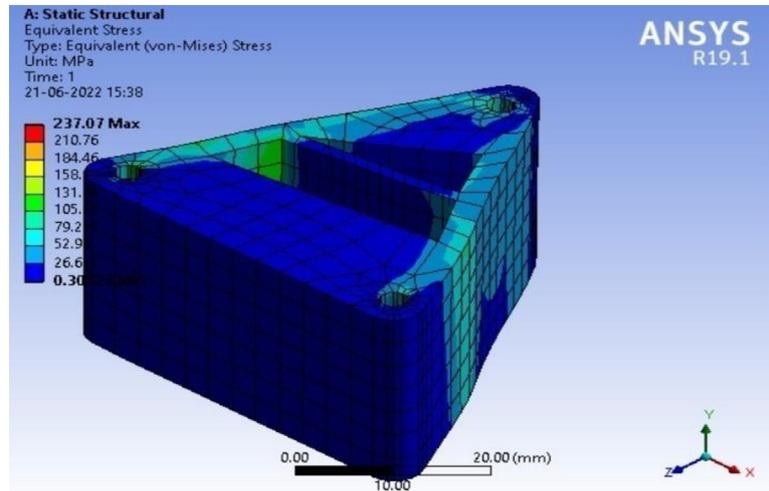
Fig. 15. Equivalent vonmises stress for sudden launch side declutching reverse.

Table 1. Von Mises stress and deformation.

Load	Vonmises stress	Deformation
9 kN	1.7888×10^3 MPa	1.0112 mm

Table 2. Loading condition for FEA analysis for modified design.

Loading condition	Loads			Acceptable limit
Pot hole pass (10 km/h)	200	(−1500)	2600	
Sudden launch side (declutching first gear)	4200	(−250)	7600	Max vonmises stress < yield strength of material
Sudden launch side (Declutching reverse)	(−4900)	(−300)	3000	

Table 3. Von Mises stresses and deformation.

Loading condition	Von Mises stress	Deformation
Pot hole pass (10 km/h)	264.35 MPa	0.029084 mm
Sudden launch side (declutching first gear)	299.01 MPa	0.024536 mm
Sudden launch side (declutching reverse)	237.07 MPa	0.024849 mm

Table 4. Results of analysis of von Mises stress for safe design criteria for assembly.

Loading condition	Von Mises stress	Safe design criteria
Pot hole pass (10 km/h)	288.82 MPa	
Sudden launch side (declutching first gear)	325.97 MPa	Von Mises stress < yield strength of material (350 MPa)
Sudden launch side (declutching reverse)	136.68 MPa	

Table 5. Result of weight reduction after topology optimization.

Weight of old bracket arm with assembly	2.28 kg	Percentage reduction
Weight of new bracket arm with assembly	1.14 kg	Percentage reduction is 50%

Fig. 16. Boundary conditions and load condition on assembly.

Fig. 17. Equivalent von Mises stress for pot hole launch for assembly.

Fig. 18. Equivalent von Mises stress for sudden launch side declutching first gear for Assembly.
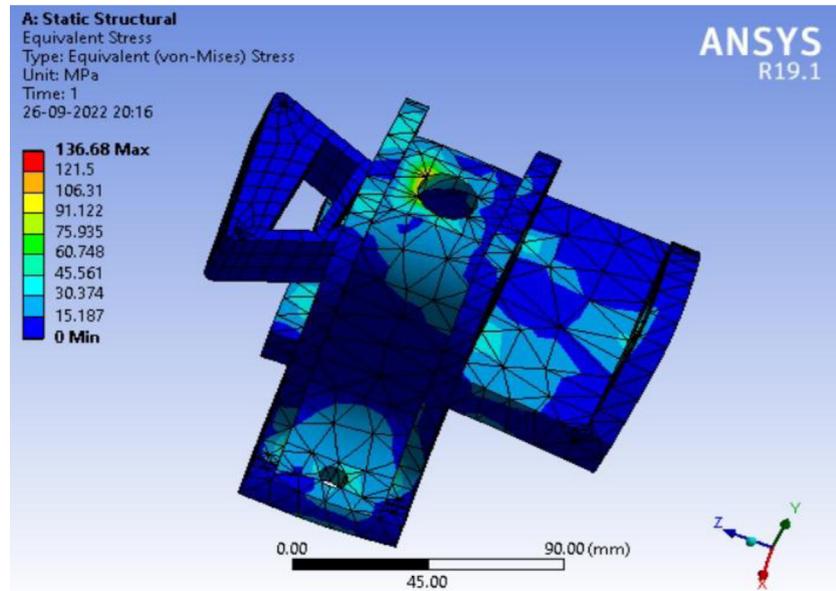
Fig. 19. Equivalent von Mises stress for sudden launch side declutching reverse for assembly.

9 Conclusion

Topology optimization is done on the surface of the engine bracket arm in order to reduce the weight of the overall assembly of the bracket. The new BESO algorithm is used for the component's topology optimization to reduce the bracket assembly's overall weight. The automobile industry requires lightweight vehicles, which will save materials that can be used for other purposes. The reduced-weight vehicles, in turn, have good fuel economy. The new BESO algorithm made using the Matlab code using the sensitivity factor calculation gives the tool to solve the problems for making the component light in weight. The binary numbers 0 and 1 are considered for material removal and addition, and the parameter considered is von Mises stress. The von Mises stress criteria give the exact locations on which the optimization is done on the surface. Then the strength of the components is validated by the FEM analysis of the component individually and with assembly. Thus topology optimization is a method for making a lightweight component for vehicles.

References

1. M. Viqaruddin, D. Ramana Reddy, Structural optimization of control arm for weight reduction and improved performance, Mater. Today: Proc. **4**, 9230–9236 (2017)

2. M. Rahman, M. Shaari, Topology optimization to design of connecting rod, in International Conference on Mechanical and Electrical Technology, 3rd, (ICMET-London 2011) (n.d.), Vols. 1–3, pp. 1615–1622

3. N. Jain, R. Saxena, Effect of self-weight on topological optimization of static loading structures, Alexandr. Eng. J. (2017)

4. S. Srivastava, S. Salunkhe, S. Pande, Application of structural topology optimization in steering knuckle design, Int. J. Simul. Multidiscipl. Des. Optim. **4** (2020)

5. S. Srivastava, S. Salunkhe, S. Pande, Design of prosthetic finger using topology optimization, in *IEEE Xplorer* (2021)

6. N.F. Wang, X.M. Zhang, Topology optimization of compliant mechanisms using pairs of curves, Eng. Optim. **47**, 37–41 (2014)

7. L. Cao, A.T. Dolovich, A. Chen, W. (Chris) Zhang, Topology optimization of efficient and strong hybrid compliant mechanisms using a mixed mesh of beams and flexure hinges with strength control, Mech. Mach. Theory **121**, 213–227 (2018)

8. X. Pan, Structural Optimization for Engine Mount Bracket, SAE Technical Paper Series 2007-01-2419

9. H. Igami, M. Thompson, K. Osodo, Automotive Powertrain Mounting System Design Optimization, SAE Technical Paper Series 2003-01-1667