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(RESEARCH ARTICLE)

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Optimization of the CAT 318B L excavator teeth bucket structure topology design using the finite element method

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Abstract

Infrastructure development in this era has developed rapidly. Excavators are generally used to dredge rivers, dismantle roads, or demolish buildings. One of the most important components in an excavator is the bucket teeth. Bucket teeth generally have two important characteristics, namely maximum performance and wear life. Therefore, the author is interested in discussing one of the problems that exist in the bucket teeth excavator and optimizing the design of the bucket teeth that are already on the market in order to produce a lighter design. In this study, optimization of the bucket teeth excavator CAT 318 BL was carried out. In this simulation used linear static method for topology optimization process. The results obtained after topological optimization were found that the mass reduction in the first variable design was 0.22 kg and in the second variable design was 0.32 kg. In addition, the maximum von misses stress in variation 1 is 141,743 MPa, while in variation 2 is 145,879 MPa. The safety factor value of the first design variable is 2.92 and the second design variable is 2.84 where it can be said that the value of the stress that occurs in both designs, although tends to increase, is still declared safe.

Keywords: Bucket teeth; Finite element method; Topology optimization; Design structure

1. Introduction

Excavators is one type of heavy equipment used as a digging machine. Excavators are generally used to dredge rivers, dismantle roads, or demolish buildings. One of the most important components in an excavator is the bucket. A bucket is a basket on an excavator that has the main function of dredging. The shape of this bucket is like a basket that has several fingers at the end of the basket called bucket teeth. The main function of the bucket teeth is like a fork which is in charge of making the dredging process easier. These bucket teeth are very influential on the productivity of the excavator.

During the excavation process, bucket teeth have the most important role, namely during penetration or excavation. This section is often in direct contact with different fields. The shape of the bucket teeth and the composition of the bucket teeth material that is not suitable will cause a poor excavation process, besides that it also causes high wear on the bucket teeth, losses in time and cost as well as reduced productivity [10].

Bucket teeth modeling can be simulated using the static analysis feature on the Altair software which is equipped with the finite element method and then it can be seen the phenomena that occur in the strength structure of the bucket teeth when the fatigue point occurs, namely with the output stress (von mises stress), deformation (displacement). , and the safety factor [12]. Therefore, the author is interested in discussing one of the problems that exist in the bucket teeth

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excavator and optimizing the design of the bucket teeth that are already on the market in order to produce a lighter design. In this simulation used linear static method for topology optimization process.

2. Material and methods

2.1. Material Identification

It is known that the material is medium carbon steel with a carbon content of 0.38%, with the results of the composition and literature (microstructure atlas), the material used in the bucket teeth is close to the material with the AISI standard, namely AISI 4140, shown in Table 1.

Table 1 AISI 4140 material data

No.	Mechanical Properties	Mark
1.	Modulus of Elasticity (E)	205 GPa
2.	Position Ratio	0.29
3.	Density	7850 Kg/m^3
4.	Yield Strength	415 MPa

2.2. Research Flowchart

In this study, the material testing steps refer to the flow chart which can be seen in Fig 1.

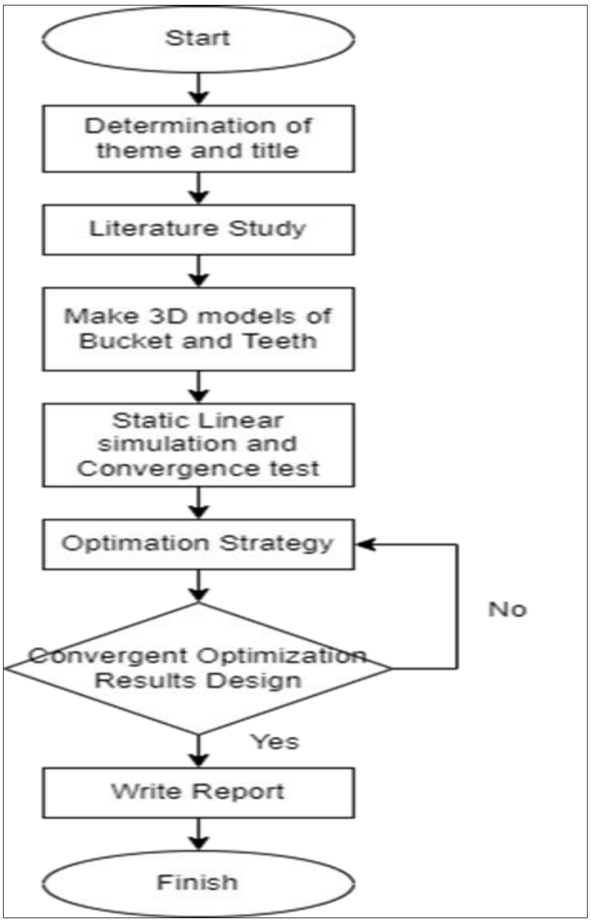

Figure 1 Research Flowchart

2.3. Bucket Teeth Excavator 3D Modeling Process

Making the bucket teeth design using CAD software using the approach of the original model. The CAD software used for modeling is Solidworks 2018.

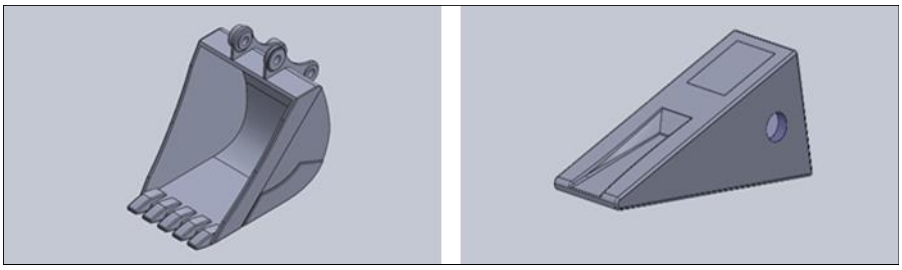

Figure 2 CAT 318 BL excavator bucket and bucket teeth design results

2.4. Static Force Analysis

Analysis of the bucket teeth there are three positions in the excavation process. To calculate the breakout force from the catalog, which is 157 kN at three positions, namely the maximum height reach with an angle of 33.570, the maximum reach on the ground at an angle of 7.280, and the maximum depth reach with an angle of 41.50.

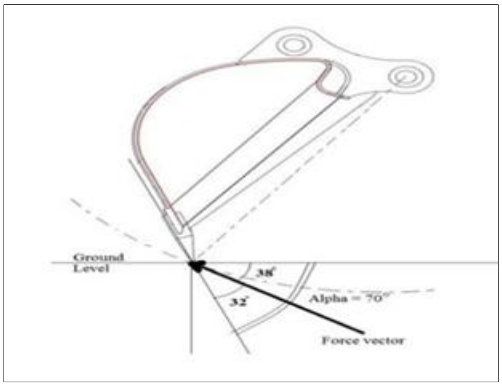

Figure 3 Load free body diagram

2.4.1. Bucket curling force (F_b)

$$F_b = 157{,}000 \text{ N}$$

The number of teeth on the bucket is 5, thus the load $F_b$received by teeth is $F_b$divided by 5:

$$F_b = 157{,}000 \text{ N}/5$$

$$F_b = 31{,}400 \text{ N}$$

2.4.2. Arm crowd force (Fs)

$$F_s = 139{,}000 \text{ N}$$

The number of teeth in the bucket is 5, thus the load Fs received by the teeth is Fs divided by 5:

$$F_s = 139{,}000 \text{ N}/5$$

$$F_s = 27{,}800 \text{ N}$$

From the above calculation, the value of bucket curling force (Fb) = 31,400 N and arm crowd force (Fs) = 27,800 N. The value of Fb is greater than Fs, therefore the value of Fb is used as the loading value in the simulation, namely F = 31,400 N. The force vector the critical value given during the linear simulation is shown in Figure 3.

2.5. Process Optimization Strategy

Simulation on bucket teeth with variations of 3 dredging angles. When the excavator reaches maximum distance, maximum height, and maximum depth reach. The optimization method used is topology optimization using Altair Optistruct software.

2.5.1. Mesh control

At this stage, the determination of the meshing method for 3D modeling is carried out by determining the parameters as shown in Figure 4.

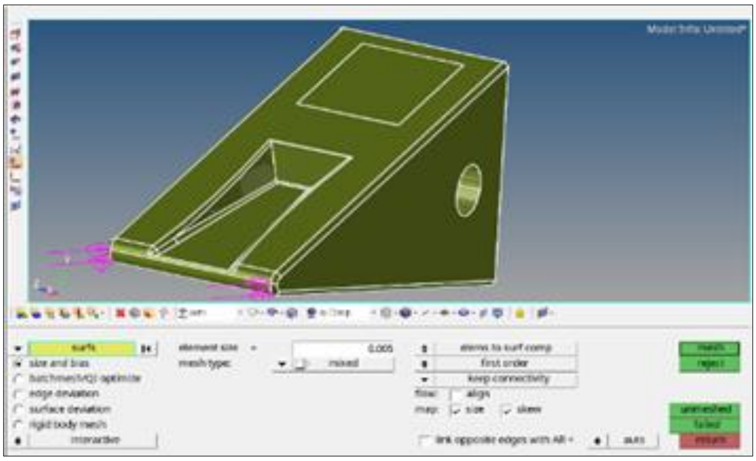

Figure 4 Parameters of meshing surface on teeth

2.5.2. Meshing volume

To make topological optimization required 3D meshing with the tetra meshing method using TET1 elements which can be seen in Figure 5.

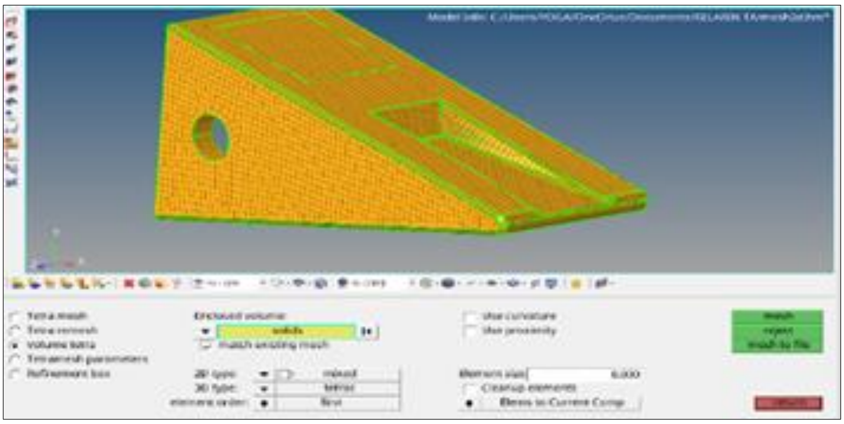

Figure 5 Mesh volume result

2.5.3. Material determination

At this stage, the determination of the type of material used is carried out with the test results and the provision of properties as shown in Figure 6.

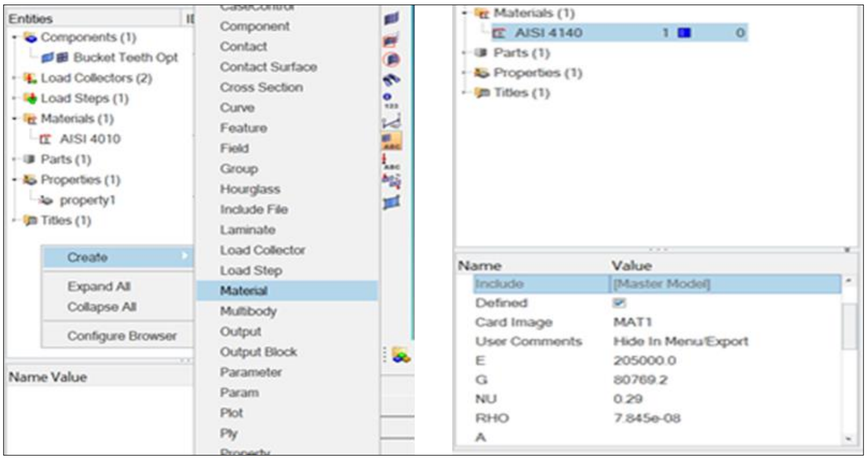

Figure 6 Material parameters

2.5.4. Constraint distribution

Supporting the modeling teeth is required on the adapter section by using a fixed constraint as shown in Figure 7.

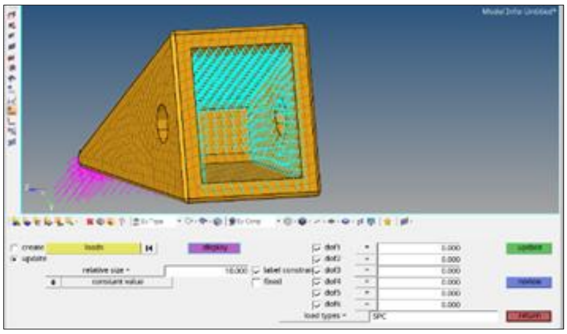

Figure 7 Result of giving constraint

2.5.5. Force distribution

After the support is made on the adapter part, force is applied to the bucket teeth with the size and direction as shown in Figure 8.

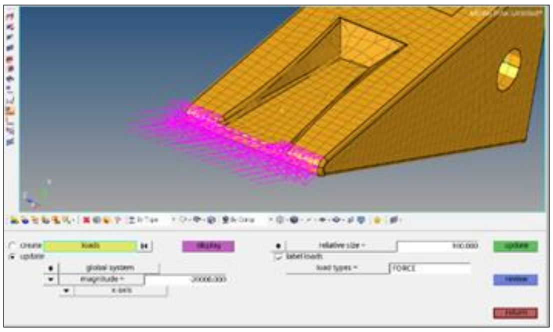

Figure 8 Force result

2.5.6. Variable design determination

Determination of design variables aims to determine the part of the design that can be changed and adjusted which can be seen in Figure 9 with orange color while the blue color shows the part of non-design variables where that area is an area that cannot be changed.

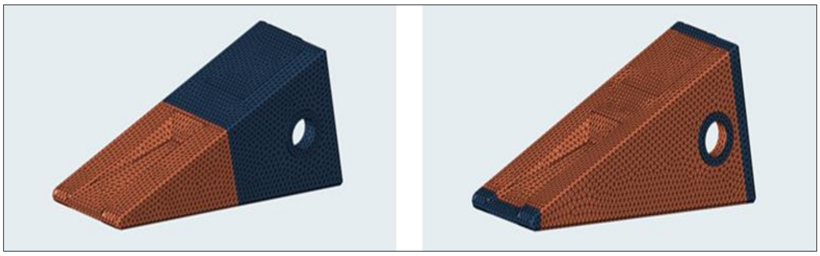

Figure 9 Variable design

2.5.7. Determination of structural response

In this optimization process, the response used is in the form of weight compliance and volume fraction. The process of making a response by clicking on the response menu click create by selecting the desired response as shown in Figure 10.

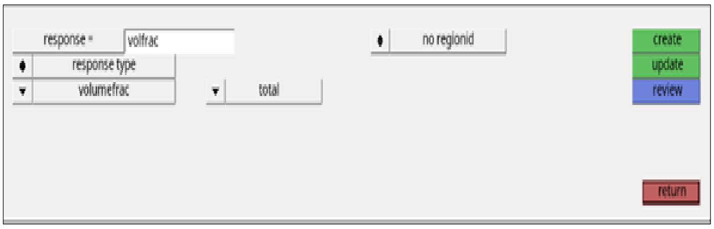

Figure 10 Parameters volume fraction

2.5.8. Determination of design constraints

In this optimization the design constraint is a volume fraction of 70%. The constraint design update is done by clicking create on the constraint design menu by first specifying the desired constraint as shown in Figure 11.

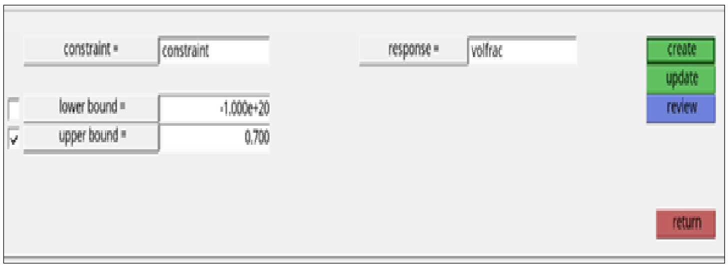

Figure 11 Constraint design parameters

2.5.9. Final objective determination

*Objective*is each response function to be optimized, the response is a variable of the design. In this optimization the objective is to minimize weight compliance.

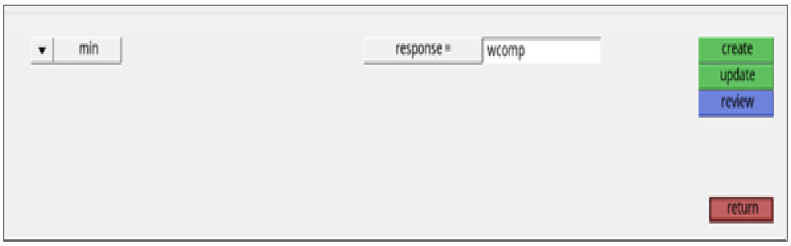

Figure 12 Objective parameters

2.5.10. Running optimization

After all the required parameters are inputted, the simulation process can be run by changing the run option to optimization as shown in Figure 13.

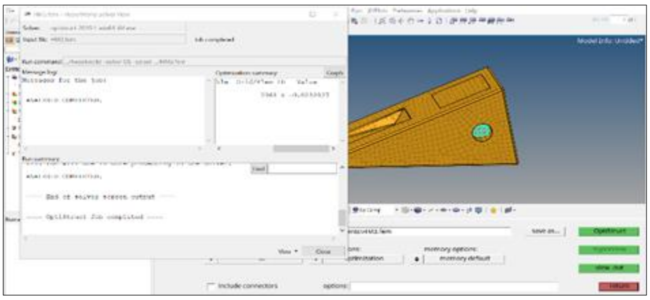

Figure 13 Optimization running process

2.5.11. Converting optimized elements into surfaces

To convert the optimization results into a Computer Aided Design (CAD) form, the OSSmooth feature on hypermesh is used by specifying the format used as shown in Figure 14.

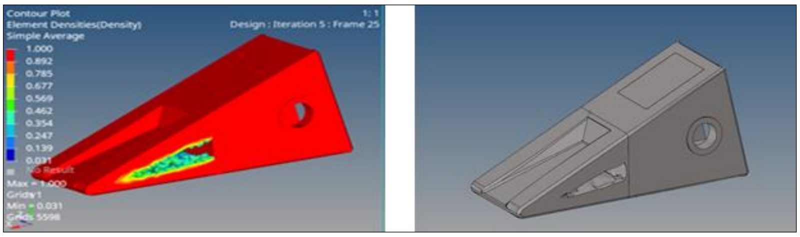

Figure 14 Optimization using OSSmooth

3. Results and discussion

3.1. Static linear simulation results

Static linear simulation using Hyperworks Altair software aims to determine whether the material used does not fail and can be optimized by linear static analysis to obtain von Mises stress on the excavator bucket teeth. In the results of this simulation, which can be seen in Figure 15 for bucket teeth, the von Mises stress value is 301.42 MPa.

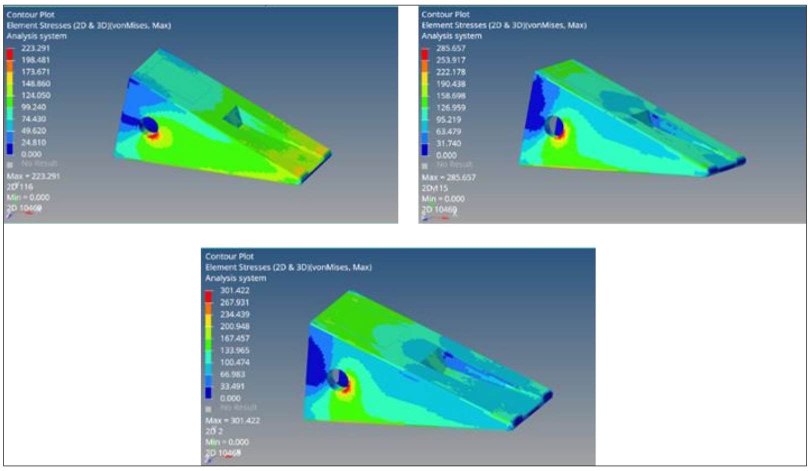

Figure 15 Result of von Mises stress on bucket teeth

Table 2 Results of linear static simulation on bucket teeth

Material Type AISI 4140		Von Mises (Mpa)		Displacement (mm)	
No	**Position**	**Min**	**Max**	**Min**	**Max**
1	Maximum Altitude	0.715	223.291	0	0.170
2	Maximum Reach	0.077	285.657	0	0.288
3	Maximum Depth	0.757	301.422	0	0.319

3.2. Convergence test

Convergence test is used to determine the appropriate number of elements to be continued with the optimization process which can first be seen in Table 3. Until convergent results are obtained for each element increase by gradually improving the mesh and in certain areas.

Table 3 Convergence test results

No	Maximum Voltage (MPa)	Number of Elements
1	164.550	33295
2	201.748	50988
3	266.633	87849
4	269.287	124185
5	268.324	189235

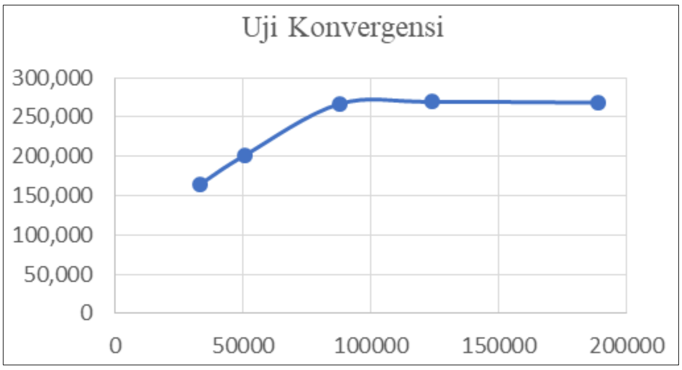

Figure 16 Convergence test results

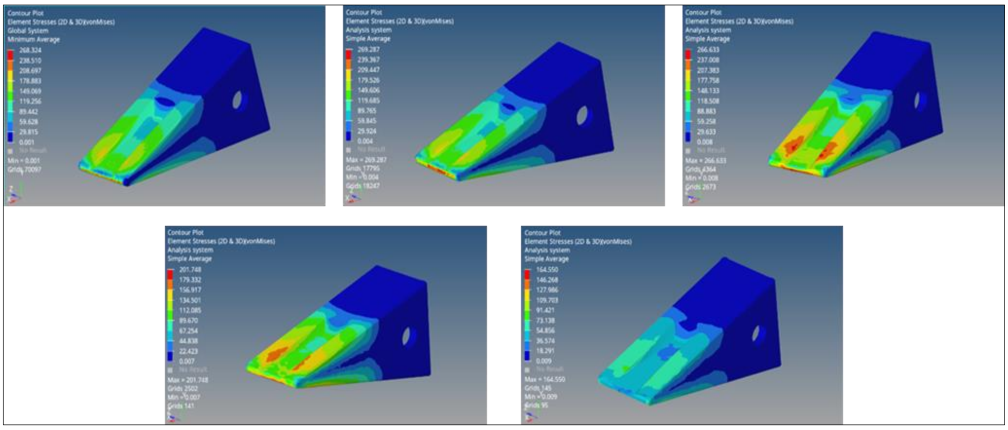

Figure 17 Von mises voltage value

3.3. Optimization result analysis

The optimization results can be illustrated in Figure 18 with elements > 0.5 where the material is removed from the part that is not too affected by the applied force so that a lighter bucket tooth is obtained with stresses that are not much different. In the optimization results of design variable 2, there is a slight increase in the maximum von Mises stress but it is still below 5% so it is still acceptable. The comparison between the design before and after optimization can be seen in Table 4.2. From the weight compliance graph, the results of the optimization of design variable 1 with design variable 2 are shown in Figure 19.

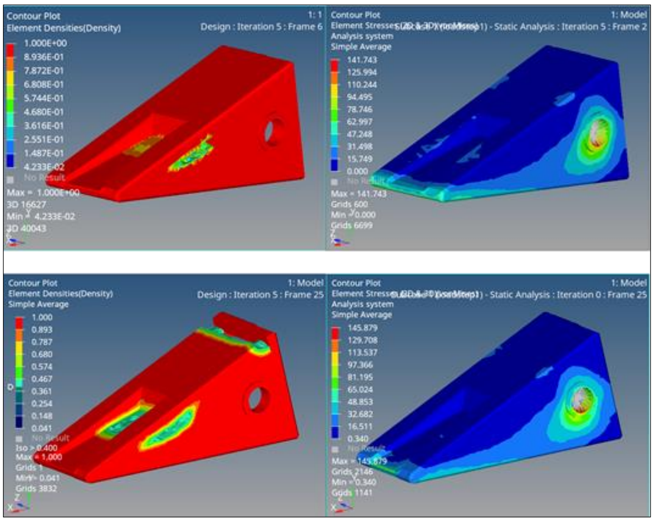

Figure 18 The results of the optimization of variables 1 and 2

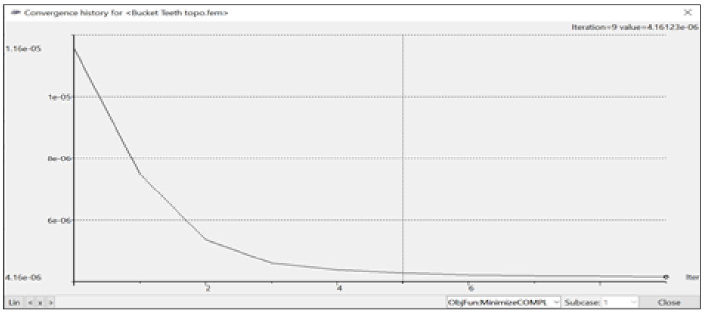

Figure 19 Compliance result graph

Table 4 Comparison of initial and post-optimization designs

Variable design	1	2
Initial mass	3.5 kg	3.5 kg
Mass after optimization	3.23 kg	3.13 kg
Initial maximum stress	164.490 MPa	164.490 MPa
Maximum stress after optimization	141.743 MPa	145.879 MPa
safety factor	2.92	2.84

3.4. Final design

The final design is obtained from the smoothing process from the optimization simulation results by changing the shape of the finite element into a surface with the OSSmooth feature which will later be converted into CAD format (Parasolid, IGES, and STEP). The design in CAD form can be seen in Figure 20.

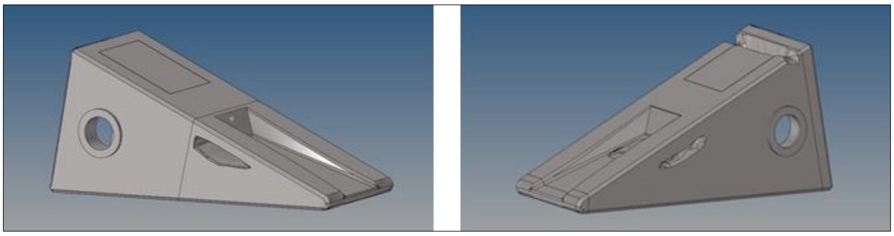

Figure 20 Optimized design

4. Conclusion

The results obtained after topological optimization were found that the mass reduction in the first variable design was 0.22 kg and in the second variable design was 0.32 kg. In addition, the maximum von misses stress in variation 1 is 141.743 MPa, while in variation 2 is 145.879 MPa. The safety factor value of the first design variable is 2.92 and the second design variable is 2.84 where it can be said that the value of the stress that occurs in both designs, although tends to increase, is still declared safe.

Compliance with ethical standards

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References

[1] Goelke M. Altair Optimization Guide Book: Practical Aspect of Structural Optimization. 2015.

[2] ASTM E18 – 3: Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials. June 1998.

[3] Shaikh BP. Analysis of Bucket Teeth of Backhoe Excavator Loader and its Weight Optimization. International Journal of Engineering Research & Technology. 2015; 4(5): 2278-0181.

[4] Beer FP, Johnstone ER, DeWolf JT, Mazurek DF. Mechanics of Materials. 7th Ed. New York: McGraw-Hill; 2015.

[5] Bendsøe, MP Sigmund, O. Topology Optimization: Theory, Methods and Applications. Berlin Heidelberg, Germany: Springer-Verlag; 2003; ISBN 3-540-42992-1.

[6] Budynas, Nisbett. Shigley's Mechanical Engineering Design. 8th Ed. New York: McGraw-Hill; 2008.

[7] Callister, William D, Rethwisch, David G. Materials Science and Engineering An Introduction. 8th ed. United State of America: Library of Congress; 2009.

[8] Caterpillar. Cat Bucket Teeth: Option & Replacement Parts for Excavator Buckets. USA: Caterpillar Inc; 2014.

[9] Christensen, Peter W. Klarbring, A. An Introduction to Structural Optimization. Berlin Heidelberg, Germany: Springer-Verlag; 2008; ISBN-13: 978-1402086656.

[10] Suryo SH, Bayuseno AP, Jamari J, Ramadhan MAR. Analysis of AISI material power of AISI 4140 bucket teeth excavator using influence of abrasive wear. AIP Conference Proceedings 1977. 2018; 030022. Available from https://doi.org/10.1063/1.5042942.

[11] Oñate, E. Structural Analysis with the Finite Element Method. Linear Statics Lecture Notes on Numerical Methods in Engineering and Sciences. Barcelona: Artes Graficas Torres SA; 2003.

[12] QH Le, CS Jeong, HK Kim, HL Yang, SY Yang, Study on modeling and control of excavators, in: MY Cho, K. Varghese, F. van Gassel (Eds.), Proceedings of the 28th ISARC (ISBN: 781510804296). Jun. 29–July 2. 2011; 969–974.

[13] SAE J1179: Hydraulic Excavator and Backhoe Digging Force. SAE International. Warrendale: SAE. 1990.