Static structural analysis of backhoe excavator loader bucket teeth

Jayaswamy S.,
PG Scholar
Manufacturing Science and Engineering
Department of Mechanical Engineering
Ghousia College of Engineering
Ramanagara, Karnataka India
jssgowda@gmail.com

Mohammed Imran.,
Assistant professor
Department of Mechanical Engineering
Ghousia College of Engineering
Ramanagara, Karnataka India
mechmdimran@gmail.com

ABSTRACT

Heavy construction machinery such as an excavator is frequently used in mining, construction, and other industries. The JCB loader market in India is continuously expanding, according to off-highway research about equipment analysis. The bucket tooth of the machine is one of the factors affecting its productivity. An inadequately designed set of teeth will ultimately result in less effective excavation. The excavator's teeth are among the parts that receive very little consideration from the industry that makes them. The bucket teeth is one of the most important parts of an excavator. It is normally composed of a steel alloy and has projecting teeth on its cutting side to break down difficult materials and guard against hard material and bucket damage. Due to the nature of abrasive fields, excavator bucket teeth must support a particular geometrical shape in order to penetrate and withstand the digging process on the ground, gravels, stones, or any other abrasive field.

The purpose of this paper is to design and analyze the excavator bucket teeth. The model is made using ANSYS Design Modeler, by using ANSYS Workbench 2023 R2 software mesh is performed, and boundary conditions are applied. Calculated forces are applied at the tip of the excavator bucket teeth and static analysis is carried out to analyze the structural strength [3]. In this study, it has been observed that the maximum stresses are developed at the tip and fixed boundary conditions. Structural analysis of teeth has been carried out without and with slots. In addition to the slot, on the right side of the teeth, a 2 mm thick extension is used to add stiffness to withstand the load. The results observed that the von Mises stresses and total deformation of the teeth under the resultant load 8285 N (f_x= 7026.1 N, f_y= 4390.2 N) [3], these results were examined during the analysis for two different types of materials structural steel and alloy steel Hardox 450.

Keywords— excavator, bucket teeth, steel mixture, boundary condition, structural analysis, structural steel, alloy steel hardox 450.

I. INTRODUCTION

Modern knowledge and technology are expanding quickly with the help of many sophisticated devices and human resources. There is a huge need for knowledge development to meet the demands of the global market and harsh competition. To meet those demands, engineers are working to invent and discover new solutions. By fostering a sophisticated environment and inspiring the workforce to develop effective machines, materials, tools, and other equipment, academics, researchers, and businesses are attempting to meet market needs. These tools can assist in streamlining work procedures, cutting down on working hours, and increasing the plant's overall efficiency. for the construction of large projects like roads, bridges, flyovers, skyscrapers, airports, shipyards, buildings, operations for moving materials, etc. Therefore, we require machinery that can do rigorous tasks more quickly and effectively, such as excavating, digging the earth, loading it onto conveyors, tractors, or trucks, or transporting the material. An excavator is one of the heavy machinery that is frequently used for excavating. It is a part of handling bulk materials and is available in a variety of sizes and forms. An excavator is a large piece of machinery used to dig holes, lay foundations, and perform other tasks in the mining, building, and excavation sectors. The cutting side of an excavator bucket is often equipped with protruding teeth to break down hard material and prevent wear and damage to the bucket. It is constructed of steel, alloy steel, and structural steel. The abrasiveness of soil particles in the field brought on by the nature of the ground when the bucket teeth break down the material requires the excavator bucket teeth to have a supportive loading capacity of materials like damp ground, pebbles, and other abrasive materials. Excavator bucket teeth are frequently made of alloy steel. Therefore, it is crucial for designers to produce equipment that is not only highly reliable but also efficient. The most effective method for calculating structural strength and stress as well as buckling analysis, total deformation, wear, and fatigue analysis under known load and boundary conditions is finite element analysis (FEA). In this study utilizing ANSYS Workbench software and finite element analysis, a thorough examination has been conducted to comprehend the stress and total deformation developed in the teeth before and after design modification of structural steel and alloy steel hardox 450. With the use of the Ansys workbench that can be solved for an approximate answer.

II.LITERATURE REVIEW

Sujitlomate et. al.[1], The evaluation process of bucket capacity and the digging forces necessary to prepare the ground for light- and heavy-duty construction work are the main topics of this paper. This technique can be used for autonomous excavation task operations and provides the prediction of digging forces. The excavator mechanism's finite element analysis can be used to analyze strength and stress using the evaluated digging forces as boundary conditions and loading conditions. For the static force analysis of the mini hydraulic excavator attachment, an analytical method is provided. This study's goal is to develop an excavator bucket with a smooth material flow and powerful digging forces. Kalpak. S et.al.[2], Due to the abrasive nature of soil particles, the excavator bucket tooth must support heavy loads of materials like soil and rock while also being subjected to abrasion wear. Due to impact load and abrasive wear, it lost a tooth. This essay examines the bucket teeth analysis performed on excavators to determine where failure actually occurred. Sumar Hadi Suryo et.al.[3], The main findings of this paper are to penetrate and withstand the digging process on the ground, gravel, stones, or any other abrasive field, an excavator bucket tooth must have a supporting geometrical shape. The bucket tool grinds the material because that is a property of the field naturally. Mixed iron is frequently used as the material for excavator bucket tools because it is convenient to obtain and economical. The surface that transports hard materials, such as mining machinery, also needs to have a high hardness value. To find the appropriate material in this area, a precise analysis should be conducted. According to the simulation results, the portion of the bucket tooth that is directly in contact with the soil at its end is under the most stress. During use, it may result in bucket tooth end failure due to wear, bending, cracking, and fracture. It has been discovered that the finite element method can be used to improve the quality of geometry forms. The calculation of bucket curling force yielded the largest force value for the excavator. The maximum force that can be measured is 8285.06 N in magnitude.209.3 MPa is the maximum stress value for bucket teeth. The bucket tooth form is regarded as safe because this value is still below the permissible stress value. The bucket tooth's right angle has the highest stress value. The bucket tooth's largest deformation value in the under-pressure area is 0.0681 mm. Bhavesh Kumar et al. [4], Excavators are primarily used to remove material from below the ground's natural surface so that it can be loaded onto trucks or tractors. Excavator parts are subjected to heavy loads as a result of difficult working conditions. The excavator's mechanism must function consistently in a variety of working situations. Therefore, it is imperative that the designers produce a piece of machinery that is not only highly reliable but also lightweight and inexpensive, with a design that is secure under all loading scenarios. Conclusion: Analysis of forces and strengths plays a significant role in the design of excavator parts. The most effective method for calculating a structure's strength under known load and boundary conditions is finite element analysis (FEA). A computer-aided drawing model of the parts that will be analyzed should typically be created before the FEA. It is also possible to lighten the mechanism's weight by FEA optimization task performance. In order to develop new excavator attachments, this paper provides a platform for understanding the modeling, finite element analysis, and optimization of backhoe attachments that have already been done by other researchers for related applications. Manisha et al. [5], in this paper, discussed how an excavator is a typical heavy-duty hydraulic machine that is operated by a person and used for a variety of general versatile construction tasks, including digging, leveling the ground, carrying loads, dumping loads, and straight traction. After performing such an operation, there is a chance that the pin in the tooth adapter assembly will break and the tooth point may bend. This paper's goal is to create an excavator bucket using the CREO-parametric 2.0 software. IGES file format is used to export the model for meshing in the analysis software. Forces and boundary conditions are applied at the tip of the excavator bucket's teeth. The analysis program ANSYS13.0 is used for static analysis. This paper calculates the stresses created at the tip of the bucket teeth of an excavator. Error percentage when comparing stress analyses and stress ANSYS results were calculated.

III. OBJECTIVE AND METHODOLOGY

A. Objective

This project aims to enhance the working reliability of teeth. This work aimed to accomplish the following objectives.

a. To enhance the durability of the excavator bucket teeth. This could involve exploring different materials.

b. Optimize the design of the teeth, the project aimed to analyze tooth design. Analyzing the tooth performance on factors such as boundary condition and load capacity to understand how the teeth behave under static loading condition and examine areas for improvement.
c. Finally based on without slot design teeth condition, teeth will be modified by providing slot and added a stiffness to improve the strength of teeth under static loads.

B. **Methodology**

a) Study about backhoe loader excavator bucket teeth.
b) Software-Assisted Three-Dimensional Modeling
c) Data observation and calculation.
d) Material used
e) Analysis of backhoe loader excavator bucket teeth by ANSYS WORKBENCH 2023 R2.

a. Research on backhoe loaders tooth buckets

Bucket teeth are one of the most often replaced components in an earth-moving machine because they come into close contact with the ground when the excavator is operating, leading to breakage, wear and strain, and buckling. Inadequate bucket teeth design and material composition will result in an ineffective working process, significant wear and damage to the teeth, a waste of time and money overall, and a decline in production. Direct measurements of the bucket tooth's dimensions can be taken prior to analysis or simulation, and an ANSYS design modeler can then be used to create a three-dimensional model of the bucket tooth based on that size.

b. Software-Assisted Using three dimensions to model

Software must be used for loading simulation and boundary condition application in order to make the process simpler and more precise. Ansys Workbench 2023 was the finite element analysis (FEA) program utilized in this study. All of the bucket teeth's points may be examined using this program under certain loading conditions. The typical JCB bucket tooth is the sort of bucket tooth that was modeled during the simulation procedure. Since it has a wide range of applications and is frequently employed in excavation operations, the standard type was chosen. This bucket tooth's true size and form were taken into account when modeling it. Utilizing the same program, modeling was completed. The bucket tooth's dimensions, including its length, breadth, and height, were determined by measuring before being built. The table shows the bucket tooth's total dimensional dimensions.

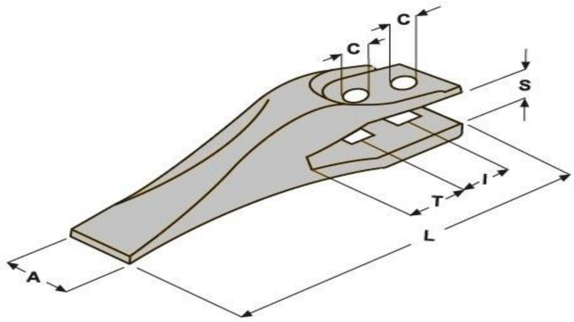

Fig 1 Size of the bucket's teeth

Table 1 Size of the bucket teeth

Dimension (mm)					
L	A	T	I	S	C
240	67	62	44	22	20

After determining the bucket tooth geometry's fixed dimensions, the design process was carried out using the ANSYS workbench software. The software created the bucket tooth design as displayed in Fig 1.

c. Data observation and calculation.

In actuality, the dynamic angle configuration of the excavator arm and bucket causes its angle to change constantly. Hence it is difficult to examine every tooth's orientation or configuration. Therefore, the static structural state analysis was carried out according to Liu, Y [6]. Force vector components are used according to Sumar Hadi Suryo et. al [3] and these force components are used to apply in the present scope of work such as resultant force F=8285.06 N, and resolved components are F_X = 7026.12 N, and F_Y = 4390.4 N [3] and shown in the fig.2.

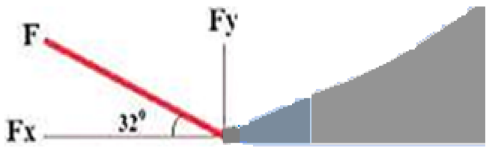

Fig 2 Diagram of force application

d. Material used

Material selection is one of the most crucial and significant steps in the structural or mechanical design process. The bucket teeth continue to operate under challenging circumstances, such as extremely high-impact loads acting on the bucket while it is in use and increased component wear. The choice of material is influenced by factors such as density, Poisson's ratio, yield strength, and ultimate strength. The following materials, including structural steel, and alloy steel Hardox 450 have been used to make excavator bucket teeth. Based on cost and performance, the best material for a tooth is selected for the application. For this study, structural steel and alloy steel Hardox 450 were employed as well as bucket teeth from the casting process. Table 2 shows the properties of the materials used to create teeth.

Table 2 Properties of structural steel material [7]

Properties	Structural Steel	Alloy steel Hardox 450
Density kg/m^3	7850	8050
Coefficient of Thermal Expansion /^{o}$_C$	1.2×10^{-5}	1.5×10^{-5}
Specific Heat MJ /ton ^{o} $_C$	4.34×10^{8}	5.20×10^{8}
Tensile Yield Strength MPa	250	1350
Tensile Ultimate Strength MPa	460	1663
Young's Modulus MPa	2.0×10^{5}	2.1×10^{5}
Poisson's Ratio MPa	0.3	0.3

e. Analysis steps

One method for solving natural problems numerically is the finite element method. A differential or integral equation could be used to explain an event in nature. Due to this, one method for solving partial and integral differential forms is the finite element method. The finite element approach typically allows users to determine how a physical system has evolved through time or space using one or more variables. There are five basic steps to using finite element technique software, and they are as follows:

- Creating a 3D model

In this study a finite element model to analyze the stresses and total deformation in the bucket tooth. As shown the solid object in Fig 3 was created by using an ansys design modeler and this structure is constructed from a different type of steel.

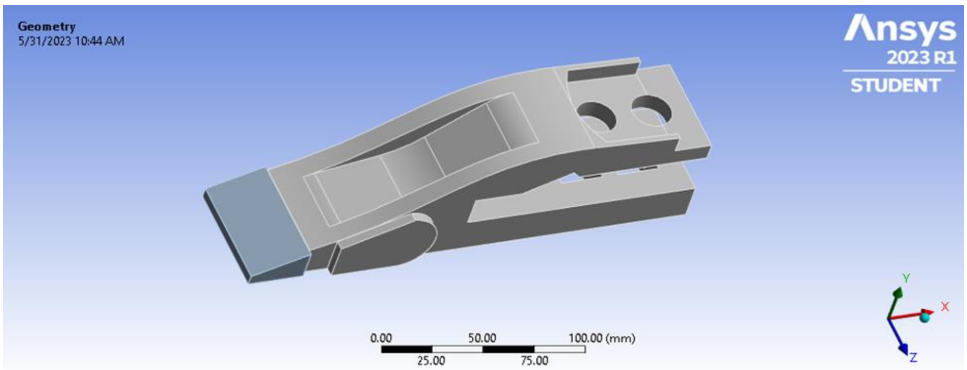

Fig 3 Finite Element Analysis Geometrical Model.

- Define the materials

Specify the materials for the 3D simulation model of teeth. Structural steel and Hardox 450 alloy steel were used in this study.

- Application of forces

Applying loads is necessary in order to perform static structural analysis for teeth initially. Forces that are applied on the teeth face, and these forces develop the stresses and deformations in the teeth have been discussed in the results section and different figures explain the stress distribution and deformation.

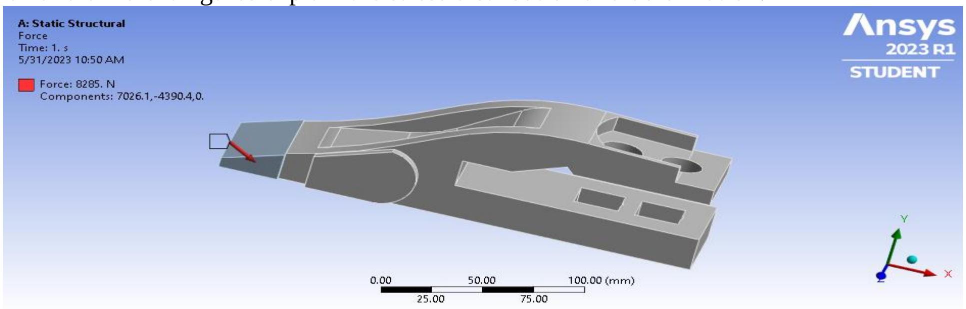

Fig 4 Finite Element Analysis Geometrical Model of the loading condition

- Mesh plot

The mesh of bucket teeth in figure 5 contains 7337 elements with an 8 mm element size, and 19754 nodes. An element of the teeth model for the backhoe loader is a solid tetrahedron.

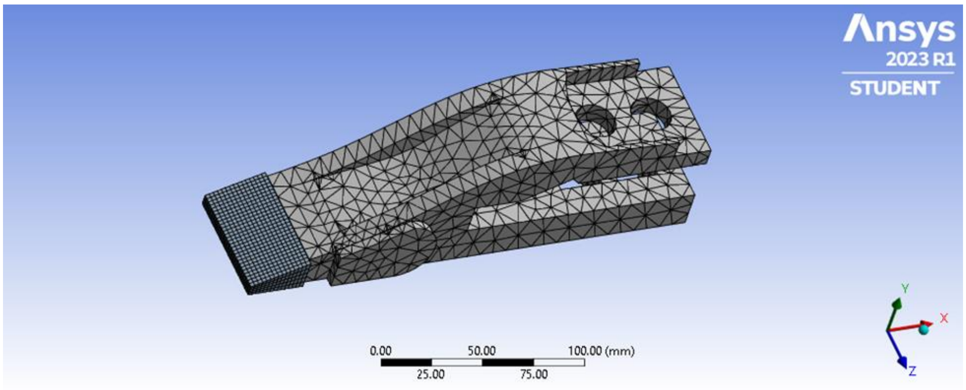

Fig 5 Finite Element Analysis Geometrical Model of the Meshing Tooth

- Boundary condition and loading

Constraining the degrees of freedom on a model is what boundary conditions do. Real-world circumstances serve as the basis for the boundary condition. At circular holes applied fixed support and squared holes displacement applied. The calculated resultant force shows 8285 N [3] shown in Fig. 6.

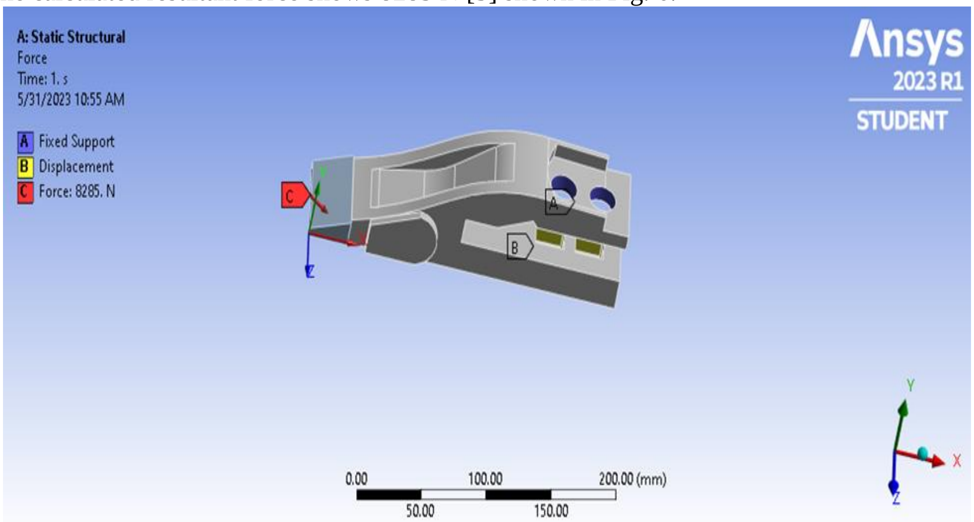

Fig 6 Finite Element Analysis Geometrical Model of the boundary condition

- Analysis of the bucket teeth from a backhoe loader

Static structural analysis was performed for bucket teeth to see if the stresses were within the limits or beyond the limit under the static loading condition, according to Sumar Hadi Suryo et. al [3]. Structural design modification was performed for a backhoe loader bucket teeth to increase the strength. This means that the following requirements must be met for a part's design to be safe or to work under safe stress. Safe working stress = Yield stress/Factor of safety. Consider factor of safety is 1.5 [3]

IV. RESULTS AND DISCUSSION

A. Static structural results

- Case 1- Without slot for structural steel material

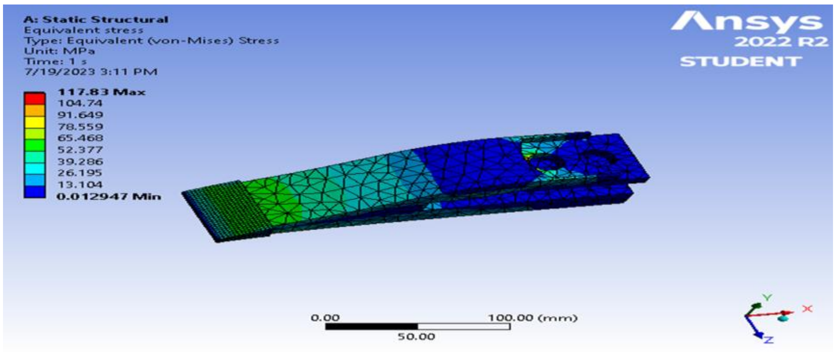

Fig 7 Stress in the bucket teeth of structural steel material

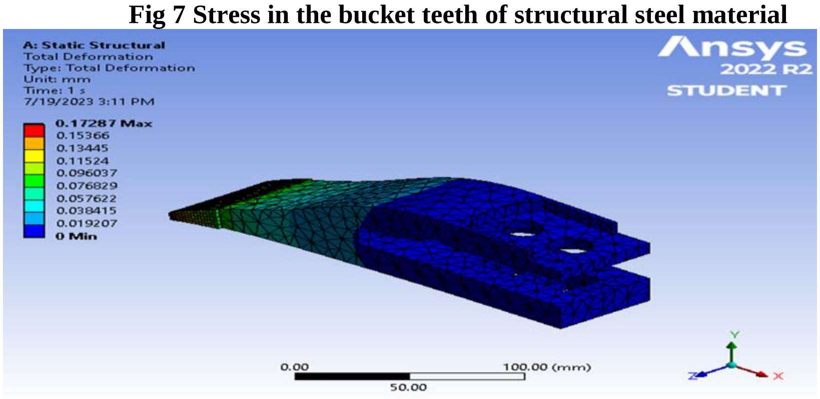

Fig 8 Displacement in the bucket teeth of structural steel material

- Case 2 Without slot for Alloy steel Hardox 450 material

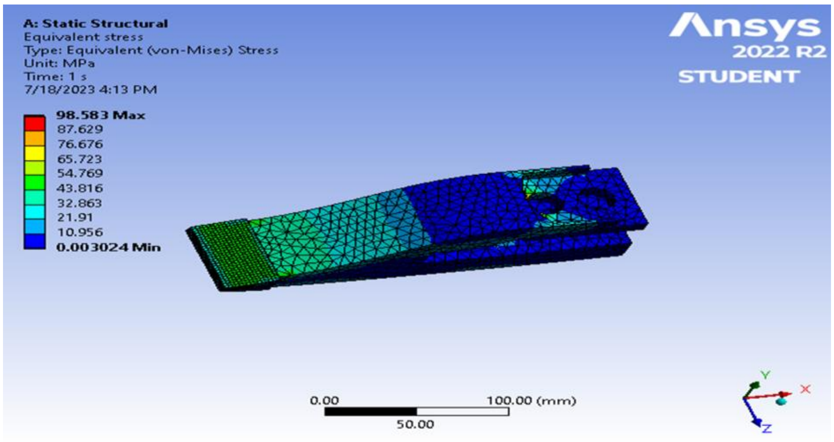

Fig 9 Stress in the bucket teeth of alloy steel Hardox 450 material

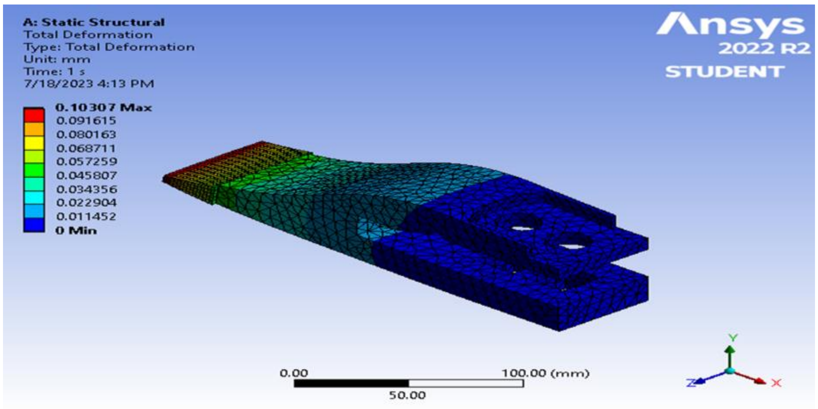

Fig 10 Displacement in the bucket teeth of alloy steel Hardox 450 material

- Case 3- With slot for structural steel material

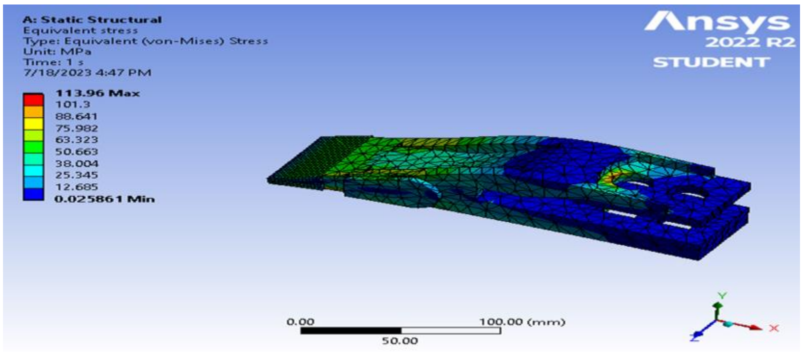

Fig 11 Stress in the bucket teeth

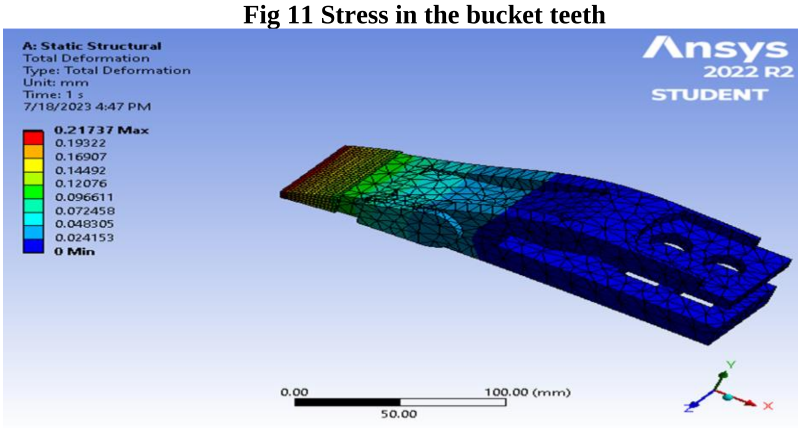

Fig 12 Displacement in the bucket teeth

- Case 4 with slot for Alloy steel Hardox 450 material

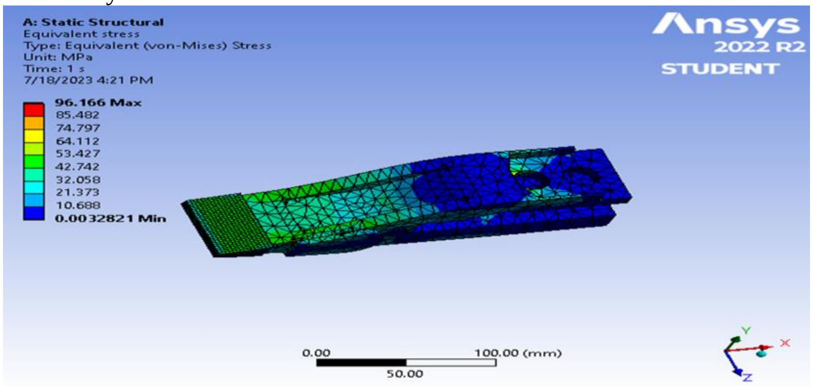

Fig 13 Stress in the bucket teeth

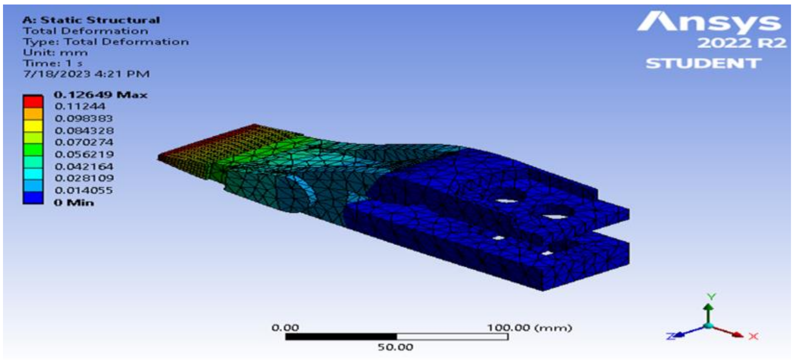

Fig 14 Displacement in the bucket teeth

B. **Discussion**

Table 4 Observation of results without and with slots for Structural Steel and Alloy Steel Hardox 450

Properties	Structural steel (SS)		Alloy steel Hardox 450 (ASH)		Average percentage improvement between SS and ASH	
	Without slot	With slot	Without slot	With slot	Without slot	With slot
Total deformation (mm)	0.084277	0.097166	0.042582	0.058205	49.42%	40.09 %
Von-mises stress (Mpa)	28.915	30.268	16.495	19.119	42.94%	36.83%
Safe working stress (Mpa)	166.67		900			

Table 4 it is observed that the average total deformation of the teeth without a slot under static loading condition for alloy steel Hardox 450 is improved by 49.42% when compared with structural steel and it is also been observed that von Mises stress is improved by 42.94% for alloy steel Hardox 450 when compared with structural steel under the same loading condition. Further, it is observed the average total deformation of the teeth with a slot under static loading conditions for alloy steel Hardox 450 is improved by 40.09% when compared with structural steel, and the von-mises stress is improved by 36.83% for alloy steel Hardox 450 when compared with structural steel under same loading condition. ASH material average stresses and deformation show that minor decrease in the results around 7 to 9 % when compared to structural steel. However, result in weight to weight-to-strength ratio of ASH material is high and the cost will be minimized. Further, the analysis should be carried out in the future such as modal, buckling, fracture, and fatigue analysis.

V. CONCLUSION

- Deformation in elastic limits occurs when stresses are below the yield strength according to Hook's law.
- From the results, it can be concluded that the stresses are below safe working stress hence design is safe.
- Total deformation changes slightly which is negligible.
- Before design modification, structural steel induces more stress than the alloy steel Hardox 450 material and hence second material is good for this application.
- After the design modification of the bucket teeth by providing a slot on the top surface of the tooth it reduces the weight of the teeth and the right side of the teeth, a 2 mm thick extension improved in stiffness to withstand the static load.
- Design modifications made on the alloy steel Hardox 450 material developed 36% less stress and 40% less deformation, behavior making it a better material for production of teeth and their applications.

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