STATIC STRUCTURAL ANALYSIS OF BACKHOE LOADER EXCAVATOR BUCKET TEETH

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 machine bucket tooth is one factor affecting its productivity. An inadequately designed set of teeth will ultimately result in less effective excavation. The excavator teeth are among the parts that receive very little consideration from the industry that makes them. The bucket teeth are 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 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 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. 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 stress and total deformation of the teeth under the resultant load 8285 N (F_X = 7026.1 N, F_Y = 4390.2 N), 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, alloysteel hardox 450.

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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 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, designers must 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

Sujit Lomate 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 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 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 work examines the bucket teeth analysis performed on excavators to determine where the failure 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 right angle has the highest stress value. The bucket tooth 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 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 mechanism must function consistently in a variety of working situations. Therefore, the designers must 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. Analysis of forces and strengths plays a significant role in the design of excavator parts. The most effective method for calculating a structure 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 weight by FEA optimization task performance. 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 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 teeth. The analysis program ANSYS 13.0 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.

Liu. Y [6] carried out through static analysis, impact analysis, and modal analysis, the effects of element size on the accuracy of finite element models and simulation results were carefully examined in this study. It was discovered that to achieve satisfactory results while using fewer computing resources and less time, each side of a plate model should be discretized into 10 divisions for static analysis that assumes steady loading and response conditions. A thin-walled beam model must have meshed into 80 divisions along its axis to effectively and accurately simulate its crash response for impact analysis that includes fast, transient loading and takes into account dynamic structural response. Even FEA models with the finest mesh take no longer than 20 seconds to complete a modal analysis when using a small number of elements to accurately predict the natural frequencies. To accurately simulate the box beam model mode shapes at the lowest natural frequencies, it is advised to apply 10 divisions. The presented results show that various structural analysis types call for suitable mesh generation techniques. For other finite element models for structural analysis, which will result in precise and effective computer simulations, the optimal mesh density for static, impact, and modal analysis can be used as guidelines. Bilal Pirmahamad Shaikh et al. [8], For general purposes, the von Mises stress and total deformation of an excavator bucket tooth are observed according to this study, tiger, modified tiger, twin tiger, and modified twin tiger are unsafe teeth, whereas general and modified teeth like std. bolted, modified std. bolted, fanggs dig, modified fanggs dig, long, modified long, abrasion, and modified abrasion, are safe. Results show that stresses are still below safe stress levels, Allowing for additional Material removal. Tiger and twin tiger teeth are used forthe excavation of densely compacted soil or material even though their stresses are above safe limits.

B. P. Patel et al. [9], carried out a thorough analysis of the kinematics of the backhoe attachment on a hydraulic excavator. The FEM approach was used by researchers to create an angle arrangement for the excavator arm safe operation. Excavator parts are subjected to heavy loads because of the harsh working environment. To keep the design safe under all loading conditions, the designers must provide equipment that is not only highly reliable but also lightweight and inexpensive. To calculate the arm crowd force and bucket curling force at an angle of 38.23º for the configuration of the maximum breakout force condition, they also developed formulas. They also came up with the equation for bucket capacity. According to Sonkar Digvijay [10], Backhoe excavators are used for excavation and light construction work. Digging forces acting on the bucket teeth are calculated, and finite element analysis uses these forces as boundary conditions. A cap has been created to lessen the strain on the teeth and thelikelihood of tooth damage. After performing a finite element analysis, it was discovered that the stresses in the bucket, cap, and rivet were within the permitted stress range. Because the cap and rivet are made of Hardox 450 and the remaining portion of the bucket is made of structural steel rather than Hardox 500 and structural steel. It has been found that values of von Mises stress and deformation are lower in the rivet type of joints as compared to the bolted type of joints. The von-misses stress, deformation, maximum shear stress, life, and other parameters for each cap and rivet separately for various types of materials and joints are also included in the analysis. In every case, the riveted type of joint made of hardox 450 and structural steel was found to be effective and durable in comparison to other types of joints.

Sharanagouda A Biradar et al. [11], Utilizing the CATIA V5 R21 and ANSYS 18.1 software, an excavator bucket was designed. According to the SAE J1179 standard, the forces acting on the excavator bucket teeth are calculated to be 60 KN, and the SAE J296 standard determines the bucket capacity to be 0.75 m^3. Calculations are made to determine the stress at an excavator bucket teeth tip. According to the analysis, it is advised that the bucket used for excavation should be carefully examined for its suitability based on the soil strata. An excavator bucket underwent static structural analysis to determine whether the stresses were within acceptable bounds. By reducing the thickness of the various bucket parts, the weight of the bucket can be successfully optimized. Utilizing AISI 4140 material results in a weight reduction of the bucket of about 14.90%. By using AISI 1040 material, the bucket's weight is reduced by about 15.60%. By using Sailma 450HI material, the weight of the bucket is reduced by roughly 15.90%. By using hardox 400 material, the weight of the bucket is reduced by about 15.33%. The analysis findings indicate that the Sailma 450HI material can reduce weight more than the other four materials. Useless material during the manufacturing process as a result, which is revolutionary in the excavator industry. J.E. Fernandez et al. [12], in the mining industry, hard alloys are typically used as the material for excavator teeth. The majority of the time, these alloys don't have enough anti-wear properties, so coatings are used as a good substitute. This project aims to test the abrasive wear resistance of various cast irons alloyed with various elements. Examining the performance of excavator teeth under actual working conditions in mines was done in comparison to laboratory tests based on the ASTM G105-89 standard. The best choice for abrasion-resistant materials is not low-carbon content cast irons (MR14). Cr-Nb-based coatings have a high dispersion and poor performance. The strength of the coating process is clearly what determines the abrasive wear resistance. It was found that the test results could be significantly impacted by the surface state. The mass losses can be very high when a specimen has some visible flaws, like minor cracks or any other kind of discontinuity. Swapnil. S et al. [13], the analysis of the backhoe excavator bucket revealed that the von Mises stresses in both the existing and optimized versions are quite similar. However, the optimized bucket shows a reduced stressed area compared to the original design. The optimized bucket, made of Hordox-400, exhibits lower deformation and stress intensity, measuring at 2.138 mm and 201 MPa, respectively, which are superior to other materials tested. The existing bucket material has a lifespan of 22,760 minutes of cycles. After comparing various materials, the optimized Hordox-400 excavator bucket demonstrated an impressive lifespan of 66,102 minutes, outperforming both the existing and optimized 500 materials. Additionally, the cost of using Hardox 400 material is more affordable. Consequently, adopting Hordox-400 for the entire bucket structure appears to be the most feasible and advantageous option.

Mohammed Imran et al. [14], project focuses on analyzing the landing gear structural integrity and its ability to withstand shock spectrum loads. The process begins with creating the geometry using Catia software and then importing it into Hyper Mesh for high-quality meshing. Hyper Mesh offers advantages in maintaining aspect ratio, skew angle, warpage, and Jacobian, all of which contribute to the accuracy of the solution. The use of tetrahedral elements is minimized in Hyper Mesh. The analysis starts with static structural analysis, which examines extreme loads to assess deflection and von Mises stress development. The results indicate a maximum stress of 168 MPa, well below the allowable stress limit of 360 MPa. Moving on to shock spectrum analysis, modal analysis is conducted first to obtain 10 modal frequencies, essential for identifying resonant conditions. The analysis of the spectrum reveals a stress development of 54.6 MPa at the time of maximum response. Overall, the study demonstrates that composite materials exhibit higher strength compared to conventional materials, making them more suitable for landing gear construction.

B. Govinda Reddy. et al. [15],The Excavator bucket was designed using CATIA V5 software, and its analysis was performed using ANSYS 15.0 software. The results showed a percentage error of 13.69% and 6.72% between the analytical and ANSYS results, indicating the need for careful consideration of the bucket application based on soil strata. It was found that altering the inclination and thickness of the tooth could prevent failure due to impact loading, proving to be a cost-effective solution. The structural analysis examined different tooth width (25 mm, 30 mm, 35 mm, 40 mm, and 45 mm) and three materials (Stainless Steel, AISI-1045, and TI Carbide) to assess various stresses and strains on the excavator bucket under different loads. The ANSYS software helped identify the optimal combination of parameters, such as von mises stress, Equivalent shear stress, Deformation, shear stress, and weight reduction for the bucket. Among the materials tested, TI Carbide with a width of

25 mm exhibited the highest factor of safety, reduced weight, increased stiffness, and lower stress compared to other materials. The TI Carbide material was found to be the most suitable choice for the bucket.

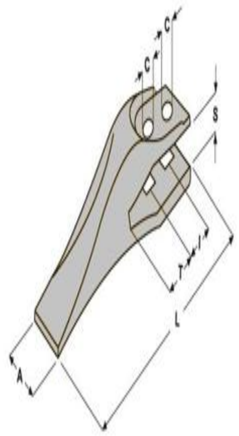
III. OBJECTIVE AND METHODOLOGY

1. **Objective:** This project aims to enhance the working reliability of teeth. This work aimed to accomplish the following objectives.
   - To enhance the durability of the excavator bucket teeth. This could involve exploring different materials.
   - 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 be have under static loading conditions and examine areas for improvement.
   - Finally, based on with slot design teeth condition, teeth will be modified by providing a slot and adding stiffness to improve the strength of teeth under static loads.

2. **Methodology**
   - Study about backhoe loader excavator bucket teeth.
   - Software-Assisted Three-Dimensional Modeling
   - Data observation and calculation.
   - Material used
   - Analysis of backhoe loader excavator bucket teeth by ANSYS WORKBENCH 2023 R2.

     - **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 dimensions can be taken before 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.

     - **Software-Assisted Using Three Dimensionol Modeling:** Software must be used for loading simulation and boundary condition application 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 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 true size and form were taken into account when modeling it. Utilizing the same program, modeling was completed. The bucket tooth dimensions, including its length, breadth, and height, were determined by measuring before being built. The table 1 shows the tooth total dimensional dimensions.



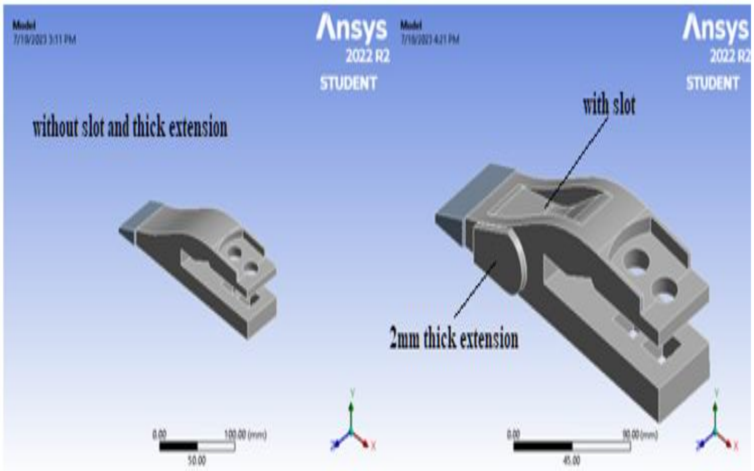


Figure 1: Size of the bucket teeth **Figure 2:** without slot teeth **Figure 3:** with slot and thick extension

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, 2, and 3.

- **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 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 fig.4.

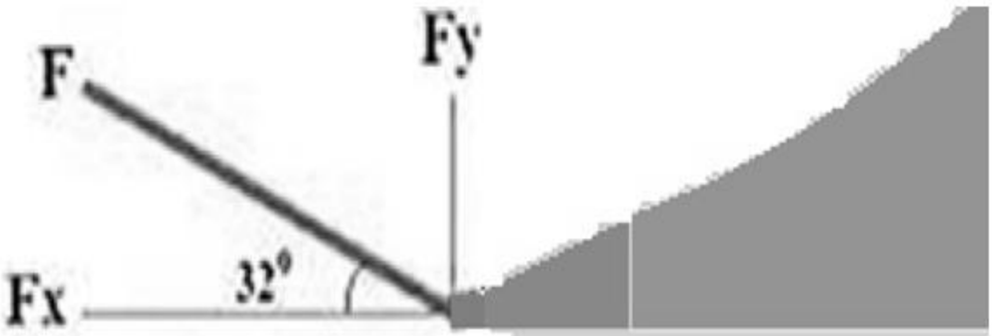


Figure 4: Diagram of force application

- **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

- **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 5 was created by using an ansys design modeler and this structure is constructed from a different type of steel.

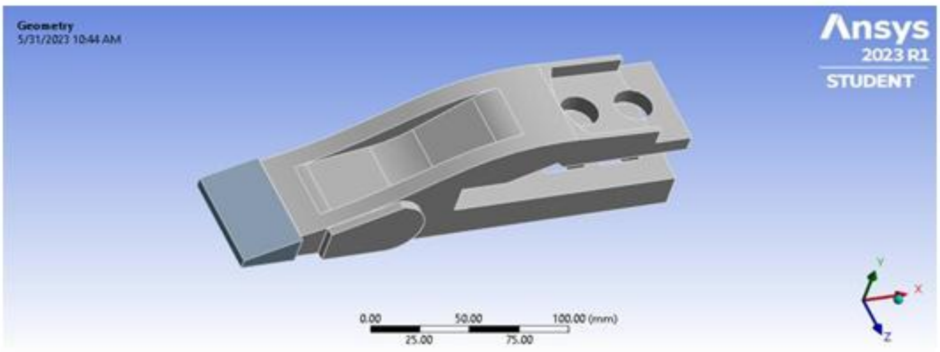


Figure 5: Finite Element Analysis Geometrical Model

- **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 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.

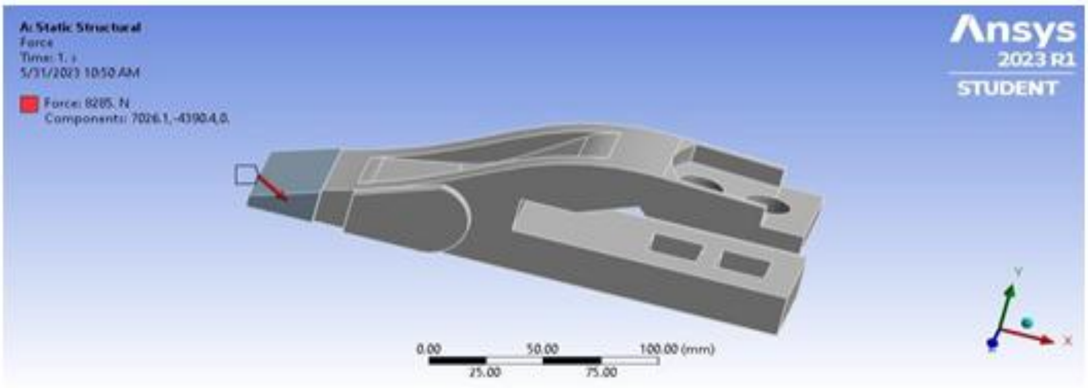


Figure 6: Finite Element Analysis Geometrical Model of the loading condition

- **Mesh Plot:** The mesh of bucket teeth in Fig 7 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.

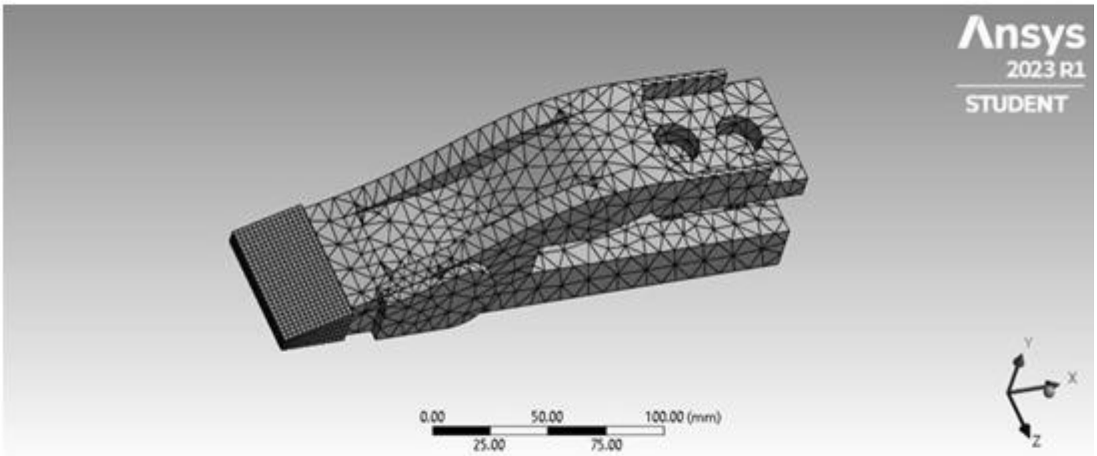


Figure 7: Finite Element Analysis Geometrical Model of the Meshing Tooth

- **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 fixed support and squared holes displacement applied. The calculated resultant force shows 8285 N [3] shown in Figure 8.

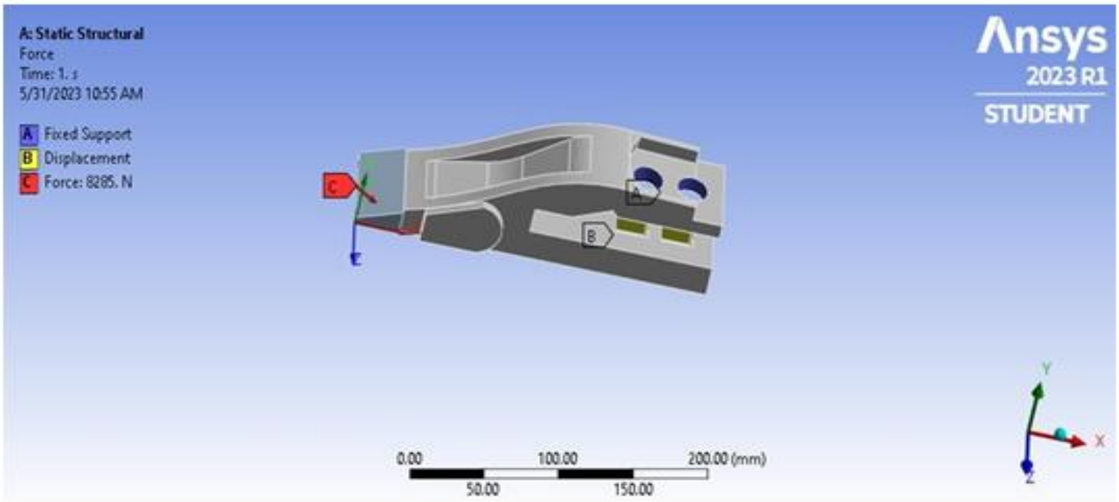


Figure 8: Finite Element Analysis Geometric3al Model of the boundary condition

- **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 thelimit 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 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

1. Static Structural Results

- Case 1- Without slot for structural steel material

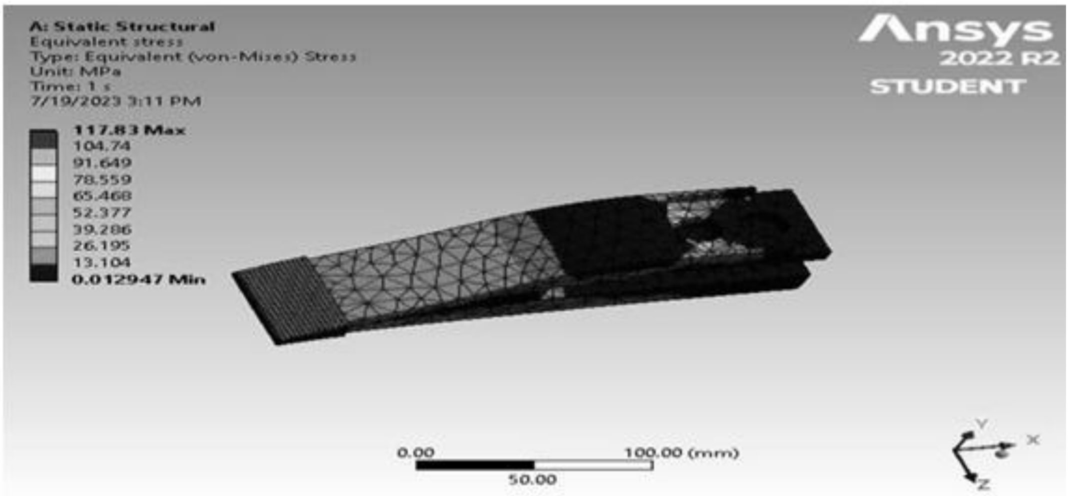


Figure 9: Stress in the Bucket Teeth of Structural Steel Material

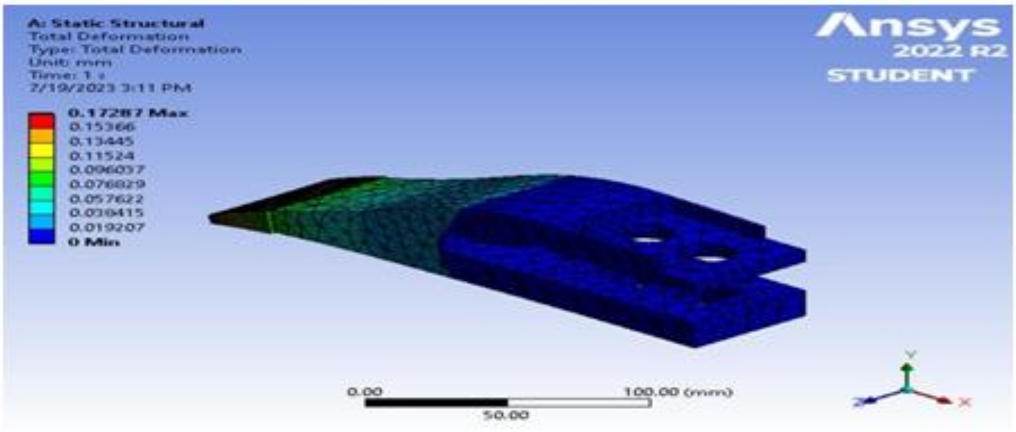


Figure 10: Displacement in the Bucket Teeth of Structural Steel Material

- Case 2 Without slot for Alloy steel Hardox 450 material

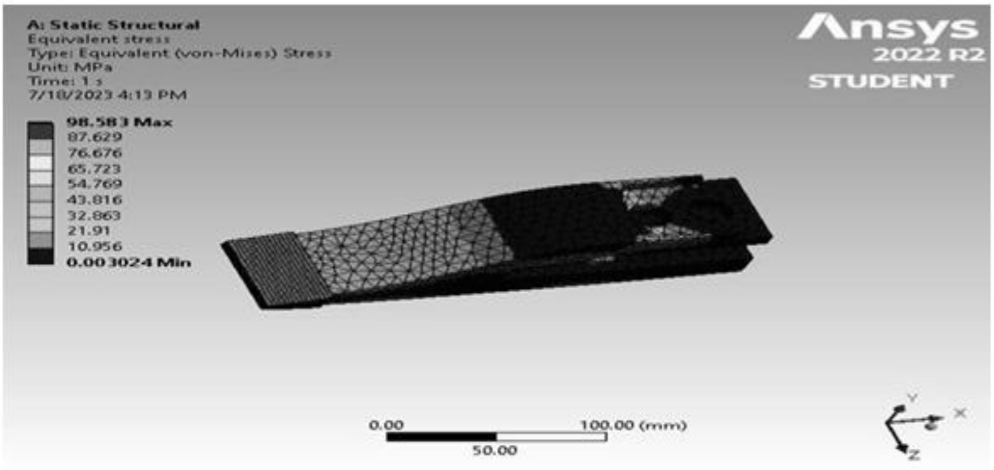


Figure 11: Stress in the bucket teeth of alloy steel Hardox 450 material

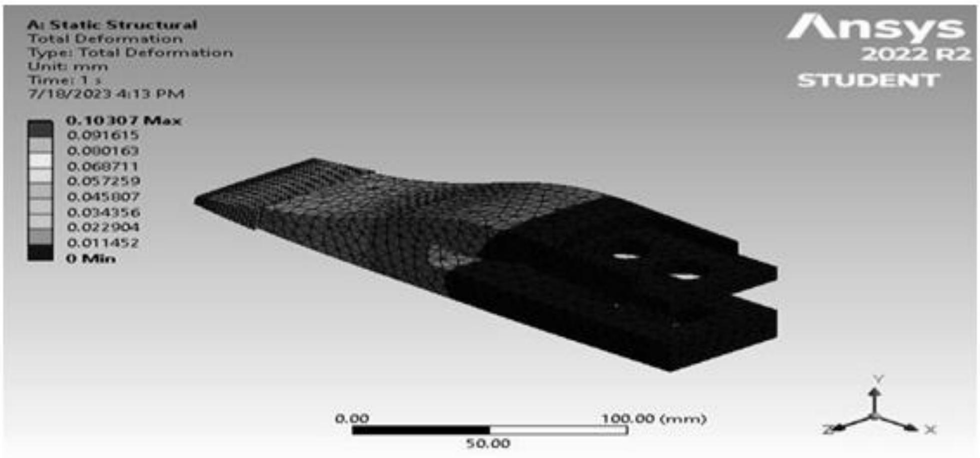


Figure 12: Displacement in the bucket teeth of alloy steel Hardox 450 material

- Case 3- With slot for structural steel material

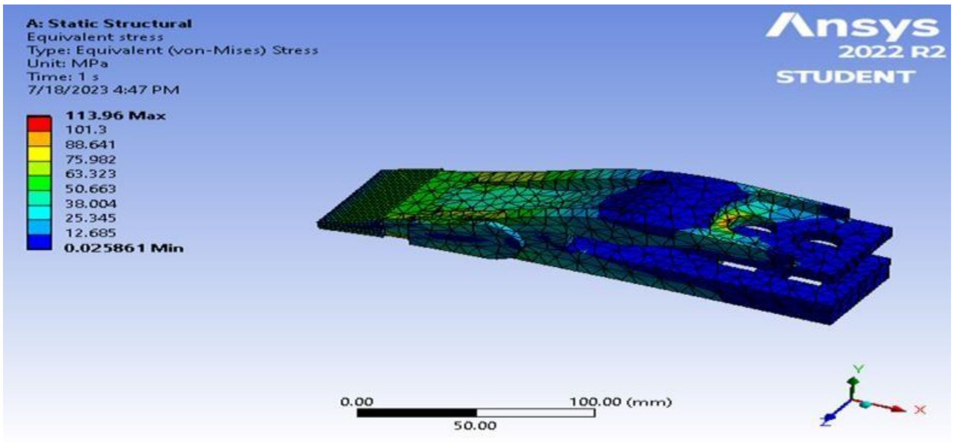


Figure 13: Stress in the bucket teeth

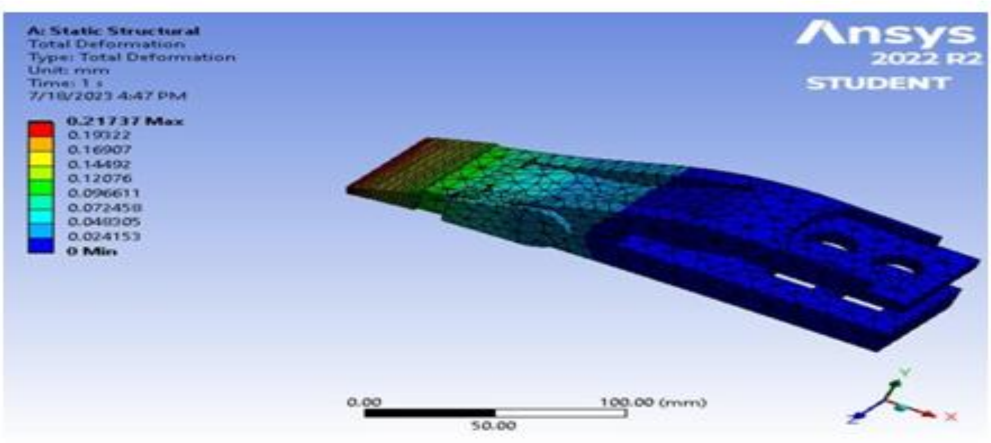


Figure 14: Displacement in the bucket teeth

- Case 4 with a slot for Alloy steel Hardox 450 material

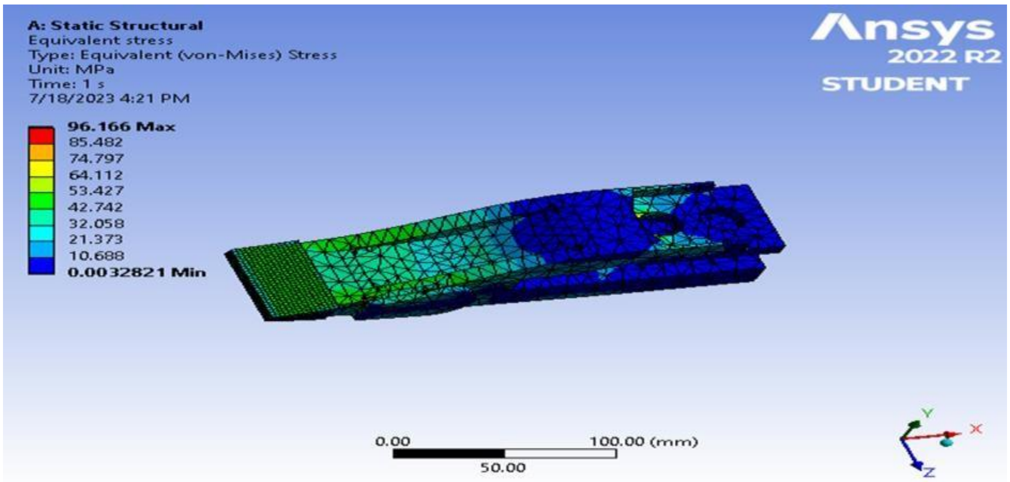


Figure 15: Stress in the bucket teeth

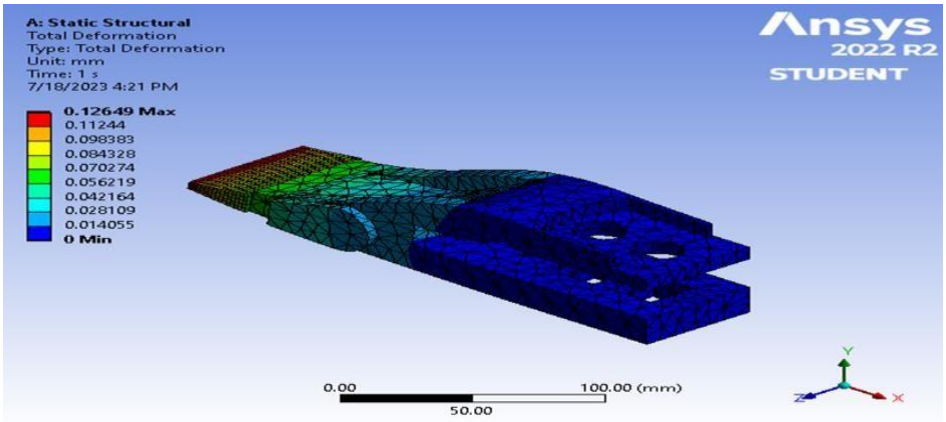


Figure 16: Displacement in the bucket teeth

- **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 a minor decrease in the results around 7 to 9 % 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 future analysis should be carried out, 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 andhence 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 reducesthe 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, making it a better material for producing teeth and their applications.

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