Static structural analysis of excavator bucket teeth

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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 teeth are among the parts that receive very little consideration from the industry that makes them. One of the most crucial components of an excavator is the bucket tool, which is typically made of a steel mixture and has protruding teeth on its cutting side to break down tough materials and prevent dryness and damage to the bucket. Excavator bucket teeth must have a supporting geometrical shape to penetrate and endure the digging process on the ground, gravels, stones, or any other abrasive field due to the field's inherent characteristics.

The purpose of this paper is to use the ANSYS Workbench 2023 R1 software to design excavator bucket teeth. The model is made using ANSYS Design Modeler, mesh is performed and boundary conditions applied. Calculated forces are applying at the tip of the excavator bucket teeth and static analysis carried out to analyze the structural strength. In this study, the stresses created at the tip of the bucket teeth of an excavator are calculated. The excavator bucket's structural analysis was done after various design changes. The action of various stresses and deformations on the excavator bucket under various loads was examined during the analysis, which was done on two different types of materials are structural steel and AISI-1040 compared.

Keywords—excavator, bucket teeth, steel mixture, structural analysis

# INTRODUCTION

In the modern era, fast-growing knowledge and technology are assisted by a large number of intelligent machines and human resources. Much need for the development of knowledge to accomplish tough competition and global market needs. The Engineers are trying to create and find a new method to fulfill those needs. The academicians, researchers, and industries are trying to fulfill the market by creating a sophisticated atmosphere and motivating the personnel to create efficient machines, materials, tools, and other equipment. Those resources can help to minimize the working time, ease the work processes, maximizing the overall efficiency of the plant. For the building of big projects such as highways, bridges, fly over, skyscrapers, airports, shipyards, buildings, material transport operations and etc. therefore, we need equipment that has the ability to do rigid works such as excavating, digging the ground, loading it into conveyors, tractors, or trucks, transporting the material and many others with less time and more efficiency. One of the heavy equipment which is commonly used in digging is an excavator. It is a bulk material handling component and comes in a range of sizes and shapes. An excavator is heavy equipment used in excavating hills, construction, and mining industries to excavate holes and build foundations and other things. An excavator bucket is made of steel, alloy steel, and structural steel and is generally equipped with protruding teeth on its cutting side to break down hard material and prevent wear and damage to the bucket. Excavator bucket teeth must have a supporting loading capacity of materials such as wet ground, rocks, and the abrasive nature of soil particles in the field caused by the nature of the ground when the bucket teeth breakdowns the material. Alloy steel is commonly used to make excavator bucket teeth. Thus, it is very much needed for the designers to provide not only equipment of maximum reliability, and efficiency but also of minimum weight and cost, keeping the design safe under all loading conditions. Finite Element Analysis (FEA) is the most efficient technique in strength and stress calculations of the structures, buckling calculation, deformation wear, and fatigue calculation working under known load and boundary conditions. A detailed investigation has been carried out by finite element analysis using ANSYS workbench software to understand the stress developed in the excavator’s teeth for all design considerations. The FEM provides a standard process for converting governing energy principles or governing differential equations into a system of matrix equations to be solved for an approximate solution.

**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'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.Set 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 is 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 economic. 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. Bhaveshkumar 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, he 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

## **Objective**

This project aims to enhance the working life of excavator bucket teeth. This work aimed to accomplish the following objectives.

1. To enhance the durability of the excavator bucket teeth. This could involve exploring different materials.
2. Optimize the design of the excavator teeth, the project aimed to analyze the existing tooth design and identify areas for improvement. This could involve determining the teeth shape, size, and configuration to ensure maximum efficiency and longevity.
3. Analyzing the tooth performance, the study could analyze factors such as boundary condition, load capacity, impact resistance, and design characteristics to understand how the teeth behave over time and examine areas for improvement.

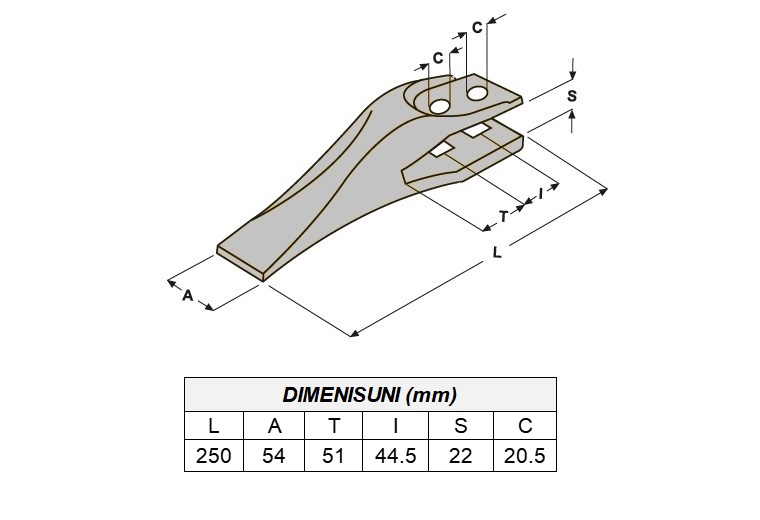
## **Methodology**

1. Study about Backhoe loader Bucket teeth.
2. Software-Assisted Three-Dimensional Modeling
3. Data observation and calculation.
4. Material used
5. Analysis of Backhoe loader Bucket teeth by ANSYS WORKBENCH 2023 R1.
6. Study about Backhoe loader Bucket teeth

In the earth-moving machine, one of the main frequently replaceable parts is bucket teeth which experience breakage, wear tear, and buckling when the excavator is working because this part makes direct contact with the ground under the work by using the excavator. Improper design of bucket teeth and composition of bucket teeth material will lead to an inefficient working process and also cause high wear and damage on the teeth, which loss in time and overall cost, and a downfall of productivity. Before analysis or simulation, the dimension of the bucket tooth can take direct measurement, and then from that dimension size three-dimensional model of the bucket tooth can be made by using ANSYS design modeler.

1. Software-Assisted Three-Dimensional Modeling

Loading simulation and application of boundary conditions need to be done by using computer software so that the work can be easier and more accurate. The finite element analysis (FEA) used in this research was Ansys Workbench 2023. With the usage of this software, all of the points of bucket teeth can be analyzed with certain loading. The type of bucket tooth modeled for the simulation process is the standard JCB bucket tooth. The standard type was chosen because of its broad usage and is commonly used in excavation works. This bucket tooth was modeled as resembling its actual shape and size. Modeling was done by using the same software. The bucket tooth was designed after getting the dimensional data such as the length, width, and height of the bucket tooth from the measurement. The overall dimensional size of the bucket tooth could be seen in Table.



**Fig 1 Dimension of bucket teeth [8]**

**Table 1 Dimension of bucket teeth [8]**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 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.

1. Data observation and calculation.

In actuality, the dynamic angle configuration of the excavator arm and bucket causes its angle to change constantly. It should not, however, examine every excavator orientation or configuration. Therefore, the static configuration is set to maximize power before being used in this study [8].

* Bucket Curling Force (Fb)

According to SAE J1179, the cylinder provided the maximum radial force for the bucket tooth (also known as the bucket curling force) Fb. As a result of the cylinder bucket and radius tangent dD, there is a digging force of 1. The bucket should be placed to receive the greatest moment output from the bucket cylinder and connecting component. Since the other ranges in equation (2) are constant [9], Fb becomes maximum when the dA range is maximum.

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Bucket cylinder force = (working stress) × (cylinder bucket longitudinal section)

Equation 3 can be illustrated as follows if the cylinder bucket piston's diameter is DB (mm), the working force is P (MPa), and all other ranges are in mm:

(3)

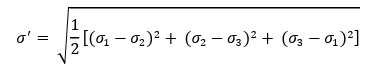
* Bucket Crowd Force (Fs)

The digging force known as the bucket crowd force Fs is produced by the tangent radius df and arm cylinder. The position of the arm should maximize the moment of the arm cylinder and bucket. The following equation is used to determine the maximum value FS if the arm cylinder center is parallel to the connecting line between the pin cylinder arm and the boom nose pin:

(4)

* Von Mises Stress Theory

This theory makes a larger assumption regarding friction stress failure than the maximum friction stress theory does. Utilizing Von Mises stress, an equation with stress on three axes makes planning analysis simpler.



It will fail if:

From trials that have been done, it reveals that distortion energy theory (von Mises) assumes failure with the highest carefulness in all quadrants [7]

* Bucket Curling Force (Fb) and Bucket Crowd Force (Fs)
* Bucket curling force (Fb)

The numbers of the tooth in the bucket are 5, thus loading of Fb accepted by a tooth is Fb divided by 5:

Fb = 41425.34752/5 = 8285.06 N

The numbers of the tooth in the bucket are 5, thus loading of FS accepted by the tooth is FS divided by 5:

* Force Vector

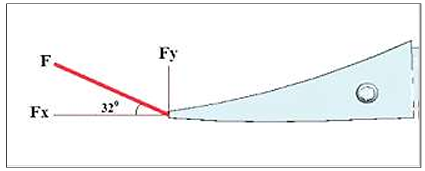
F=8285.06 N

= cos32

FX = 7026.12 N

= sin32

FY = 4390.4 N



**Fig 2 Diagram of free-pressuring object [5]**

1. 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 AISI 1040 have been used to make excavator bucket teeth. Based on cost and performance, the best material for a tooth is selected for the application.

This research uses bucket teeth from the casting process in which the material used was included in structural steel and AISI 1040. Specification of the material used to make bucket tooth is shown in Table 2.

**Table 2 Properties of structural steel material**

|  |  |  |
| --- | --- | --- |
| **Particulate** | **Structural Steel** | **AISI 1040** |
| Density ton/mm3 | 7.85× 10-9 | 7.845× 10-9 |
| Coefficient of Thermal Expansion /oC | 1.2× 10-5 | 1.2× 10-5 |
| Specific Heat MJ /ton oC | 4.34× 108 | 4.34× 108 |
| Thermal Conductivity W/ mm oC | 6.05× 10-2 | 6.05× 10-2 |
| Compressive Yield Strength MPa | 250 | 250 |
| Tensile Yield Strength MPa | 250 | 435 |
| Tensile Ultimate Strength MPa | 460 | 670 |
| Young's Modulus MPa | 2.0 × 105 | 2.05 × 105 |
| Poisson's Ratio MPa | 0.3 | 0.29 |
| Bulk Modulus MPa | 1.6667 × 105 | 1.627 × 105 |
| Shear Modulus MPa | 76923 | 79457 |

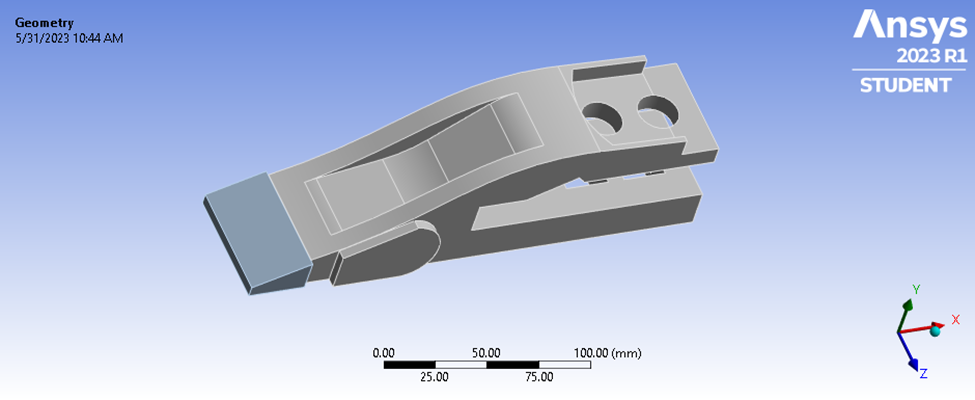
The property of the material used in bucket tooth modeling is attached to Table. Property of material was obtained from test results which have been done in laboratory tests.

1. 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. The finite element method is a good approach for estimating displacement, stress, and tension on a structure when applying load. In order to tackle some engineering problems that are closely associated to computer development and other aspects like computer-aided design (CAD) and computer-aided engineering (CAE), the finite element method is one of the numerical approaches that is used. 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 distribution of stresses in the cutting tooth. As shown the solid object in Fig 3 consists of a holder, a component from the cutting tooth with an improved edge. The cutting teeth are attached to the holder by a joint and are a separate component. It is true that the holder is a rectangular steel structural tube, but it is also feasible that the other components of the structure are constructed from a different type of steel.



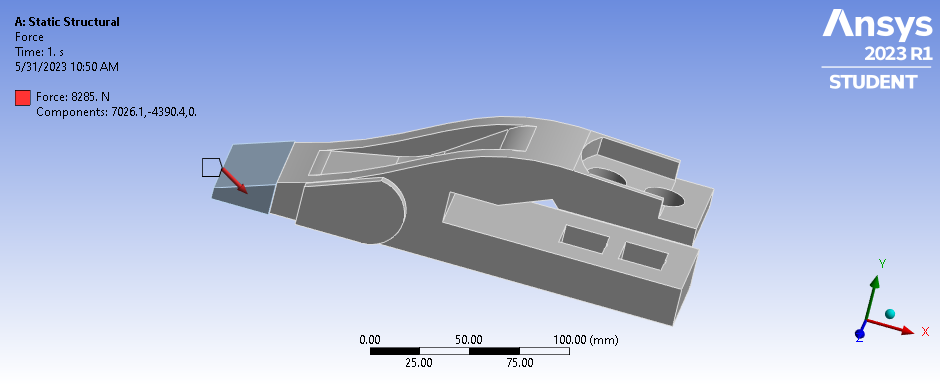
**Fig 3 Finite Element Analysis Geometrical Model.**

* Define the materials

Specify the materials for the 3D simulation model of an excavator bucket. For conducting various simulations, ANSYS offers the option to alter the material for each part.

* Application of forces

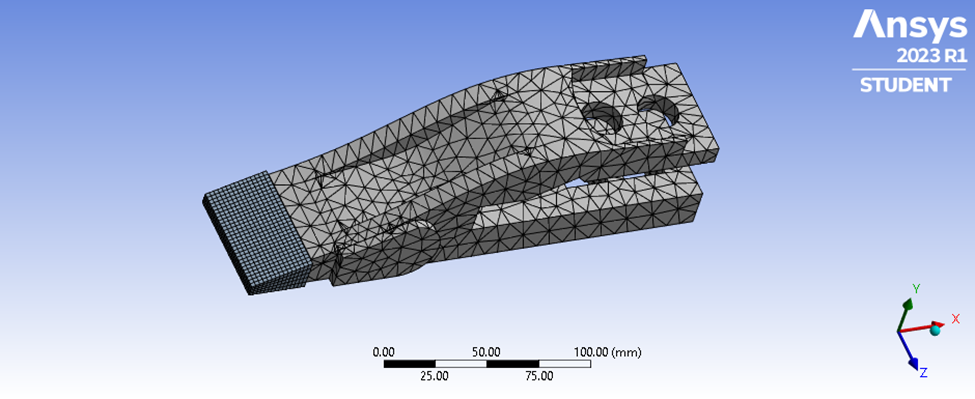
Applying loads is necessary in order to perform static structural analysis for an excavator bucket initially. Forces are loads that are applied to an assembly for simulation purposes, and these forces cause stresses and deformations in the assembly.



**Fig 4 Finite Element Analysis Geometrical Model of the loading condition**

* Mesh plot

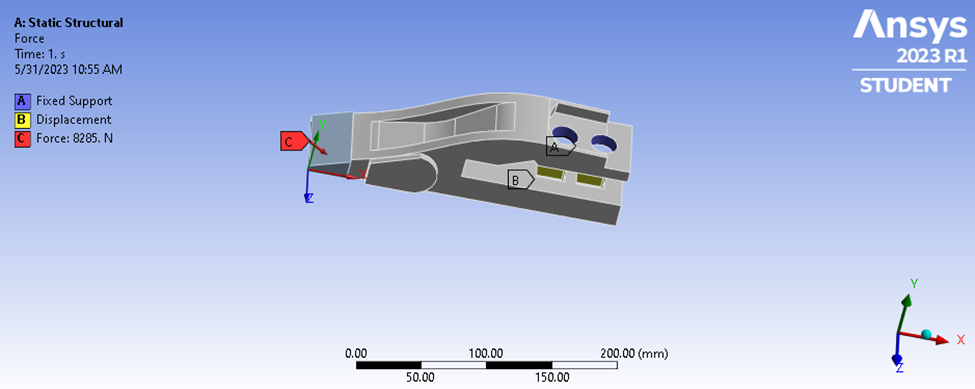
The mesh helps to cut down on the time and effort required to obtain accurate results. ANSYS contributes by creating better and more automated meshing tools because meshing typically takes up a significant portion of the time needed to obtain simulation results. Mesh of bucket teeth shown in fig 5 has number of nodes are 19754 and, number of elements are7337 and element size is 20 mm. The bucket teeth model for the backhoe loader uses a solid tetrahedron as an element.



**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 squired displacement is applied. Calculated resultant force shows 8285 N shown in fig.6.



**Fig 6 Finite Element Analysis Geometrical Model of the boundary condition**

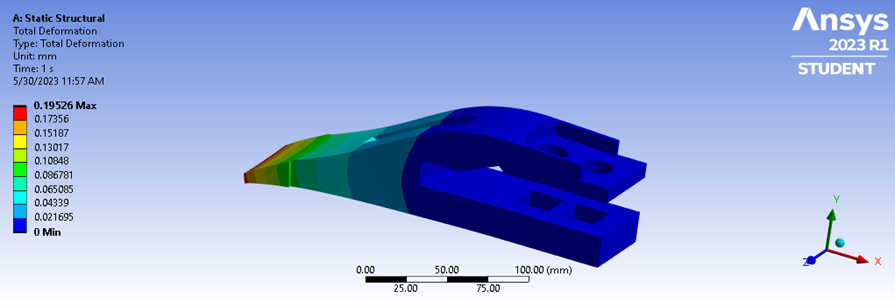
* Analysis of the bucket teeth from a backhoe loader

Von Misses stresses are used as a criterion in determining the onset of failure in steel materials, and the materials in the presented study for the parts of the bucket teeth are of steel materials, so the design of all parts should be on the basis of Von Misses stresses. Static structural analysis was performed for bucket teeth to see if the stresses are within the limits, and structural optimization was performed for a backhoe loader bucket teeth to reduce the weight. This means that the following requirement 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 1.5 [3]

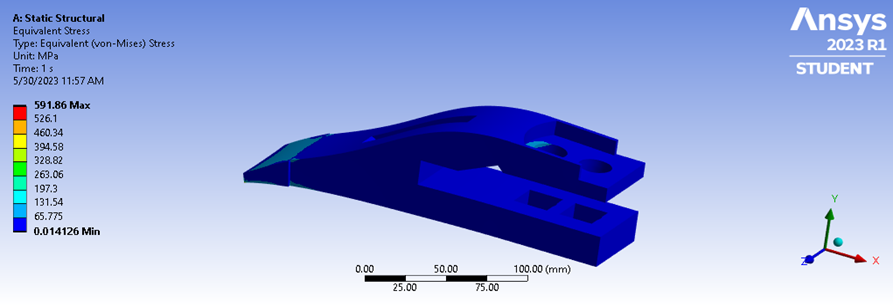
# IV. RESULTS AND DISCUSSION

1. **Static structural results**

## Case 1- Without slot for structural steel material

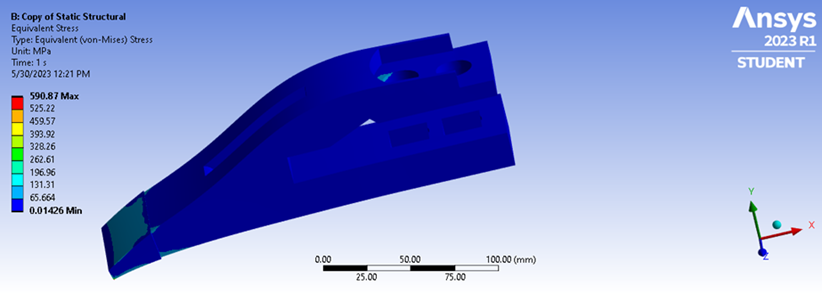


**Fig 7 Displacement in the bucket teeth of structural steel material**

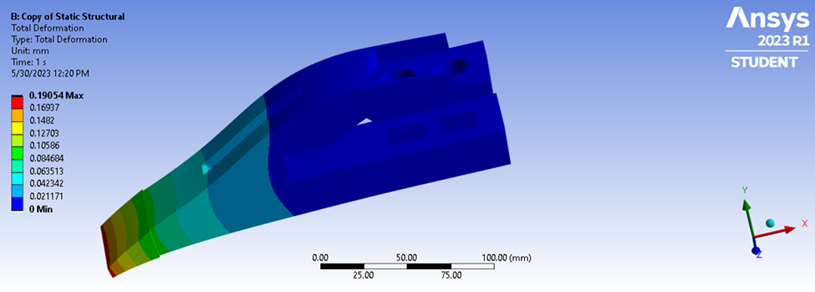


**Fig 8 Stress in the bucket teeth of structural steel material**

## Case 2- Without slot for AISI 1040 steel material

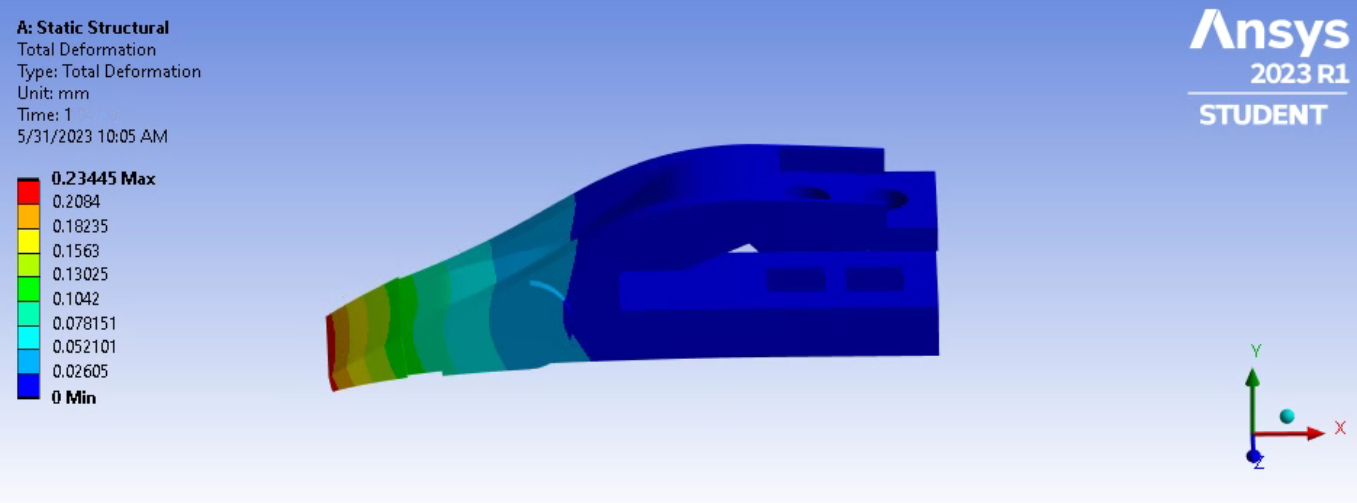


**Fig 9 Stress in the bucket teeth of AISI 1040 steel material**

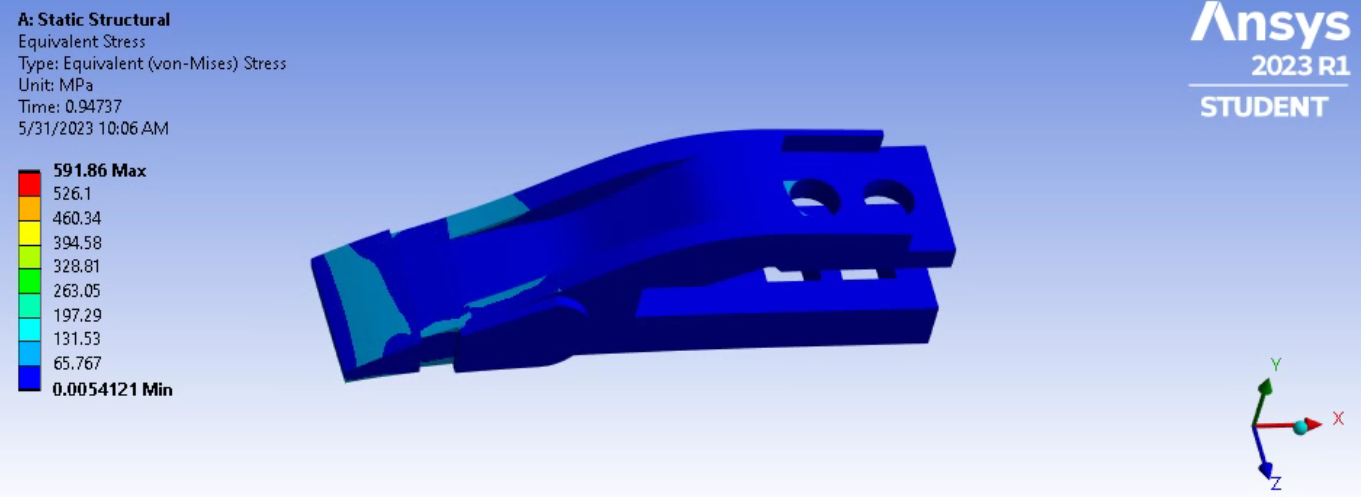


**Fig 10 Displacement in the bucket teeth of AISI 1040 steel material**

Case 3- With slot for structural steel material



**Fig 11 Displacement in the bucket teeth**



**Fig 12 Stress in the bucket teeth**

# Discussion

**Table 4 without slot (before design modification)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Type of material | Total deformation (mm) | | | Von-mises stress (Mpa) | | | Safe working stress (Mpa) |
| Min | Avg | Max | Min | Avg | Max |
| Structural steel | 0 | 0.09763 | 0.19526 | 0.014126 | 295.93 | 591.86 | 166.67 |
| AISI 1040 | 0 | 0.09527 | 0.19054 | 0.01426 | 295.43 | 590.87 | 290 |

**Table 5 With slot (after design modification)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Type of material | Total deformation (mm) | | | Von-mises stress (Mpa) | | | Safe working stress (Mpa) |
| Min | Avg | Max | Min | Avg | Max |
| Structural steel | 0 | 0.11722 | 0.23445 | 0.0054121 | 295.93 | 591.86 | 166.67 |

From the table 4 and table 5 can conclude that total deformation changes with changing of material and design of the tooth but stress remains the same for the same material even with modification of design.

**V. CONCLUSION**

* Deformation in elastic limits occurs when stresses are below the yield strength according to Hook's law.
* It has been discovered that the finite element method can be applied to improve the quality of geometry forms.
* The failure can be reduced by redesigning the tooth better, talking about force calculations, and improving the geometry of the bucket teeth for better material loading and digging.

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