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Structural Analysis of Excavator Bucket with Different Design Modifications

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ABSTRACT:
Excavators (hydraulic) are heavy construction equipment consisting of a boom, dipper (or stick), bucket and cab on a rotating platform known as the house. The house sits atop an undercarriage with tracks or wheels. They are a natural progression from the steam shovels and often mistakenly called power shovels. All movement and functions of a hydraulic excavator are accomplished through the use of hydraulic fluid, with hydraulic cylinders and hydraulic motors. Due to the linear actuation of hydraulic cylinders, their mode of operation is fundamentally different from cable-operated excavators which use winches and steel ropes to accomplish the movements.

The objective of this paper is to design an excavator bucket by using CATIA V5 R20 software. Model is exported through ANSYS 15.0 for meshing in analysis software boundary conditions and the forces are applied at the tip of teeth of excavator bucket. Static analysis is done in ANSYS 15.0 analysis software. In this paper the stresses developed at the tip of excavator bucket teeth are calculated. Structural analysis was carried out on the excavator bucket at different widths of teeth such as 25 mm, 30 mm, 35 mm, 40 mm and 45 mm. And the analysis was carried out on three types of materials named Stainless Steel, AISI-1045 and TI Carbide and the action of various stress and strains on the excavator bucket at various loads were investigated.

The best combination of parameters like Von misses Stress and Equivalent shear stress, Deformation, shear stress and weight reduction for excavator bucket were done in ANSYS software. TI carbide with 25mm width has more factor of safety, reduce the weight, increase the stiffness and reduce the stress and stiffer than other material. With Fatigue analysis we can determine the lifetime of the excavator bucket.

Key words:
Excavator, Structural, catia, Teeth, Stiffness.

1. INTRODUCTION

1.1 Earth digging operation

Essentially most excavator buckets are intended for digging in medium which is reflected in specific features of a the design .these are shaft soils having short blunt teeth while for rock or frost they are pointed and longer to provide better concentration of force [1].

Fig.1.1. Earth digging operation

1.2 Trenching

In this type the excavator is used to trenched the materials like soil, mud ,sand ,rocks etc.., Even in a certain depth based on the excavator boom, bucket rod and the bucket teeth [2].

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The trenched material of load is based on the type of buckets. Bucket of load is in Capacity is Small or large.

Fig 1.2: loading truck

1.3 loading truck operation

In loading of trucks using excavator bucket to lift the required materials (sand ,mud ,rock) at certain height of a truck to pour the material [3].

Fig 1.3: Trenching operation

1.4 Parts of an excavator

1. Bucket
2. Rivet
3. Tooth

1.5 Bucket

Excavator buckets are made of solid steel and generally present tooth protruding from the cutting edge, to disrupt hard material and avoid wear-and-tear of the bucket [4].

Fig.1.4: Excavator bucket design

1.6 Rivet

A Rivet is a permanent mechanical fastener. A Rivet consists of a smooth cylindrical shaft with a head on one end. The end opposite to the head is called Tail.

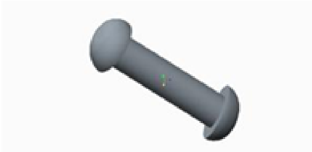

Fig 1.5: Rivet design

1.7 Tooth

The excavator bucket tooth have to bear heavy loads of materials like wet soil and rock and also subjected to abrasion wear due to the abrasive nature of solid particles when tooth acting to break up material Generally alloy steel is used to make an Excavator bucket tooth and hard facing of some wear resistant materials can be applied on the material of bucket tooth, so that its life will improve against abrasive wear [5].

Fig 1.6 Design of Teeth

2. LITERATURE REVIEW

Bhaveshkumaret.al.[1] :

Excavators are used primarily to excavate below the natural surface of the ground on which the machine rests and load it into trucks or tractor. Due to severe working conditions, excavator parts are subjected to high loads. The excavator mechanism must work reliably under unpredictable working conditions. Thus it is very much necessary for the designers to provide not only a equipment of maximum reliability but also of minimum weight and cost, keeping design safe under all loading conditions. It can be concluded that, force analysis and strength analysis is an important step in the design of excavator parts. Finite Element Analysis (FEA) is the most powerful technique in strength calculations of the structures working under known load and boundary conditions [6]. In general, computer aided drawing model of the parts to be analyzed must be prepared prior to the FEA. It is also possible to reduce the weight of the mechanism by performing optimization task in FEA. This paper provides the platform to understand the Modeling, FEA and optimization of backhoe excavator attachment, which was already carried out by other researchers for their related applications and it can be helpful for development of new excavator attachment.

Manisha.p et.al. [2]:

In this paper he discussed as excavator is a typical hydraulic heavy-duty human operated machine used in general versatile construction operations, such as digging ,ground leveling, carrying loads, dumping loads and straight traction. After doing such operation, there is possibility of breaking of pin in tooth adapter assembly as well as bending of tooth point. The objective of this paper is to design an excavator bucket by using CREO-parametric 2.0software. Model is exported through IGES file format for meshing in analysis software Boundary conditions and the forces are applied at the tip of teeth of excavator bucket. Static analysis is done in ANSYS13.0 analysis software. In this paper the stresses developed at the tip of excavator bucket teeth are calculated. Percentage error between stress Analytical result and stress ANSYS result are calculated.

Kalpak.Set.al.[3]:

The Excavator bucket tooth have to bear heavy loads of materials like soil, rock and subjected to abrasion wear due to the abrasive nature of soil particles. Its tooth got damaged due to abrasive wear and impact load. This paper deals with review of Excavators bucket tooth analysis to find out its actual failure.

Jonas Helgessonet.al.[4] :

An optimized bucket design is important for increasing productivity and loading performance for underground loaders. Design theories are today difficult to evaluate due to lack of verification methods. Later year's development of simulation software and computers has made it possible to verify the design by simulating the loading process. The purpose with this thesis has been to both develop and use a simulation model of the loading process for one of Atlas Copco's underground loaders. A simulation model was developed in the program EDEM. EDEM uses the Discrete Element Method for simulating granular materials, which in this case was blasted rock. A factor such as particle flow, particle compression and loading setup adds complexity and uncertainty to the task. Nevertheless was a model that was able to detect force variations from small design changes developed. The tractive effort is the horizontal force the loader can generate. This the critical factor when loading rocks, with use of EDEM different bucket designs could be evaluated by studying the horizontal force in the simulations. The simulation model was compared with practical tests. The edge thickness of the bucket lip was the individual design parameter that had the largest influence on the horizontal force; a thin edge generated lower force. In general a bucket with sharp and edgy shape gave lower forces. The attack angle (bottom angle) had low influence on the horizontal force.

Yang.Cet.al.[5]:

The hydraulic excavators are widely used in construction, mining, excavation, and forestry applications. Its diversity and convenient operability make it popular.

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The performance of hydraulic excavator is depending on its performance of the backhoe front attachment. This paper focuses on the research work of excavator attachment, which mainly includes those aspects, such as the kinematic analysis, dynamic analysis, structural analysis, trajectory planning and control, fatigue life analysis and structural optimization design. and the development trends of excavator attachment, in the near future, are forecasted.

Mehul Kumar A Patel et.al.[6]:

The Hydraulic excavator machines are heavy duty earth mover consisting of a boom, arm and bucket. It works on principle of hydraulic fluid with hydraulic cylinder and hydraulic motors. The Hydraulic excavator backhoe operation require coordinated movement of boom, arm and bucket to control the bucket tip position by following a desired trajectory and to use the excavator machines effectively in the dark, sever weather, worst working condition, hazardous or unhealthy environment and dirty areas this can be achieved only through the automatic control of the hydraulic excavator machine. Controlling of hydraulic excavator machine is possible if the kinematics and dynamics of the excavator machine are understood. To achieve this goal different reviews related to kinematics of excavator machine are discussed in this paper which is helpful to doing the kinematic modeling of the excavator machine. Kinematic modeling is helpful for understanding behavior and improving the operating performance of the hydraulic excavator machine.

3. CATIA MODELING

3.1 GEOMETRIC MODELLING

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Assault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Assault Systems product lifecycle management software suite.

CATIA competes in the CAD/CAM/CAE market with Siemens NX, Pro/E, Autodesk Inventor, and Solid Edge as well as many others. Initially named CATI (Conception Assisted Tri dimensionally Interactive - French for Interactive Aided Three-dimensional Design) - it was renamed CATIA in 1981, when Dassault created a subsidiary to develop and sell the software, and signed a non-exclusive distribution agreement with IBM [7].

Used Catia Tools:

Circle, Rectangular Pattern, Circular Pattern, Pad, Pocket and Plane.

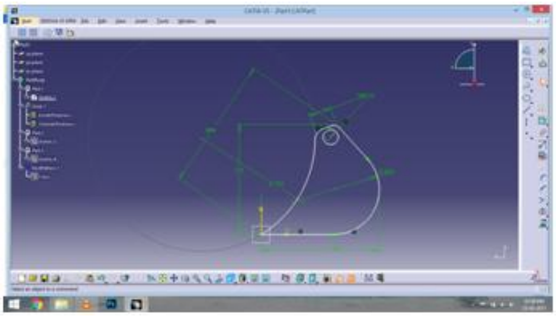

Fig.3.1 CATIA model of excavator bucket

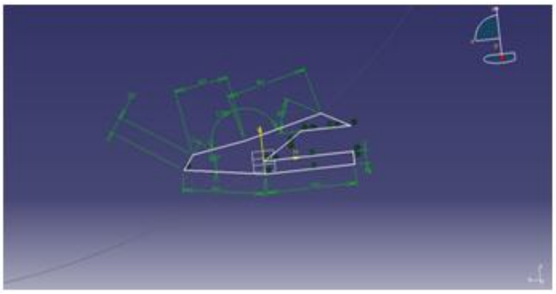

Fig 3.2 Model of Excavator bucket

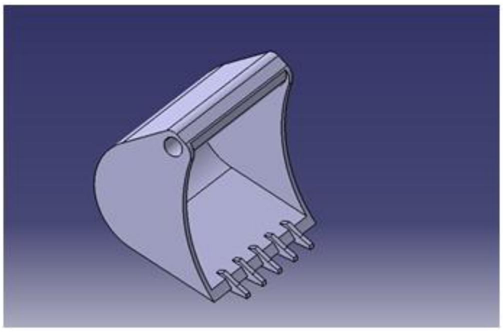

Fig 3.3 Designed CATIA model of excavator bucket with teeth

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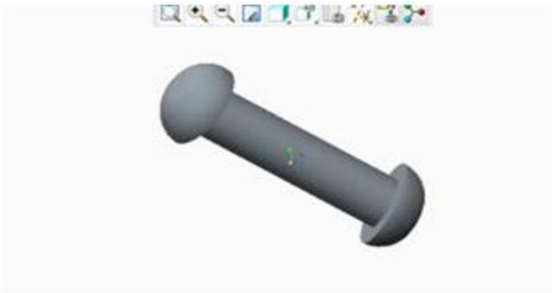

Fig 3.4 Designed CATIA model of rivit

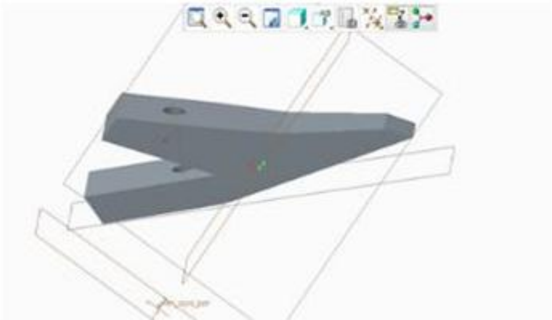

Fig 3.5 Designed Catia model of Teeth

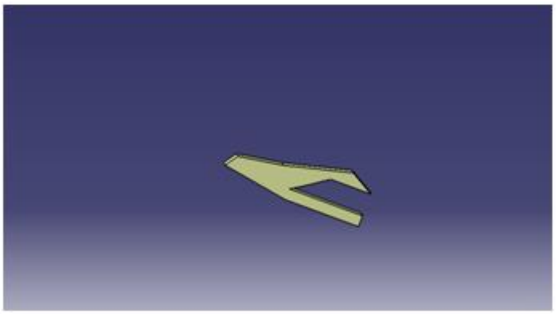

Fig 3.6 Designed Catia model of Teeth

4. Overview of ANSYS:

ANSYS is a general-purpose finite element computer program used for solving several classes of engineering analyses. The analysis capabilities of ANSYS include the ability to perform static and dynamic structural analyses, steady-state and transient heat transfer problems, mode- frequency and buckling analysis, Eigen value problems analysis, magnetic analyses and coupled- field analysis. The program contains many special features which allow nonlinearities or secondary effects to be included in the solution, such as plasticity, large strain, hyper elasticity, creep, swelling, large deflections, contact, stress stiffening, temperature dependency, material anisotropy and radiation.

4.1 Steps involved in analysis using ANSYS:

The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis.

A typical ANSYS analysis consists of the following steps:
Build the model using key points, lines, areas and volume commands.

- Giving material properties.
- Choosing proper element.
- Meshing the model to discrete elements.
- Applying the given loads.
- Applying the boundary conditions.
- Running the solution phase.
- Review the results using the post processor.

4.2 GEOMETRY:

Heat exchanger is built in the ANSYS workbench design module. It is a counter-flow heat exchanger. First, the fluid flow (fluent) module from the workbench is selected [8]. The design modeler opens as a new window as the geometry is double clicked.

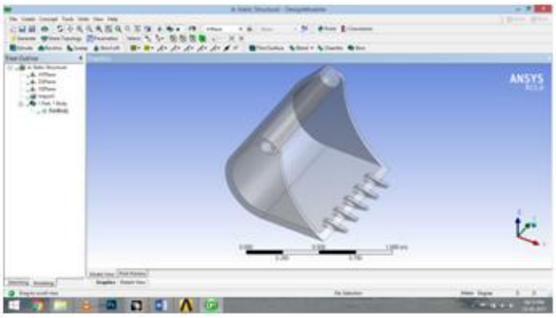

Fig. 4.1 Imported model in geometry

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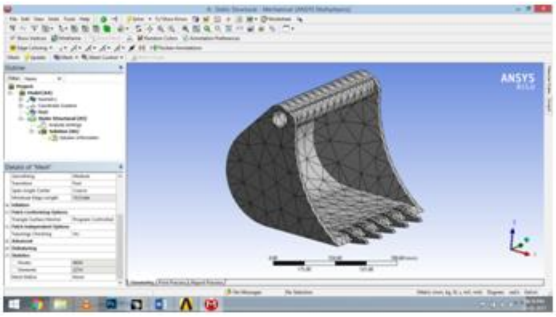

Fig. 4.2 Meshed model of Excavator

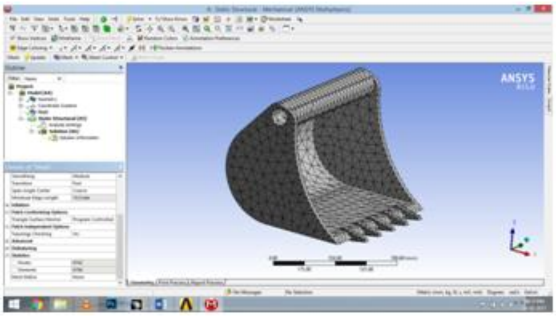

Fig. 4.3 Excavator bucket geometry

4.1.1 The Main Solver

The solver is the heart of CFD software. It sets up the equation set according to the options chosen by the user and meshes points generated by the pre-processor, and solves them to compute the flow field. The process involves the following tasks:

- selecting appropriate physical model,
- defining material properties,
- prescribing boundary conditions,
- providing initial solutions,
- setting up solver controls,
- set up convergence criteria,
- solving equation set, and
- saving results

Once the model is completely set up, the solution starts and intermediate results can be monitored in real time from iteration to iteration. The progress of the solution process is displayed on the screen in terms of the residuals, a measure of the extent to which the governing equations are not satisfied.

4.2 MESHING

Initially a relativelycoarser mesh is generated. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries. Care is taken to use structured hexahedral cells as much as possible. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region. Later on, a fine mesh is generated. For this fine mesh, the edges and regions of high temperature and pressure gradients are finely meshed. Save project again at this point and close the window [9]. Refresh and update project on the workbench. Now open the setup. The ANSYS Fluent Launcher will open in a window. Set dimension as 3D, option as Double Precision, processing as Serial type and hit OK. The Fluent window will open.

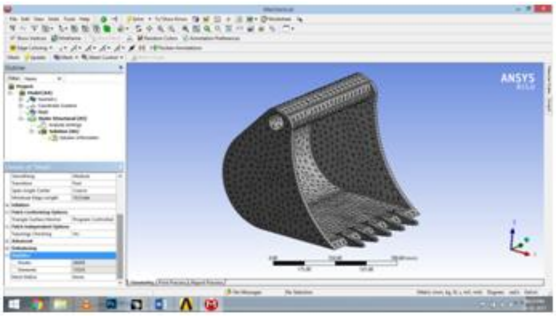

Fig. 4.4 Excavator bucket geometry Fine mesh

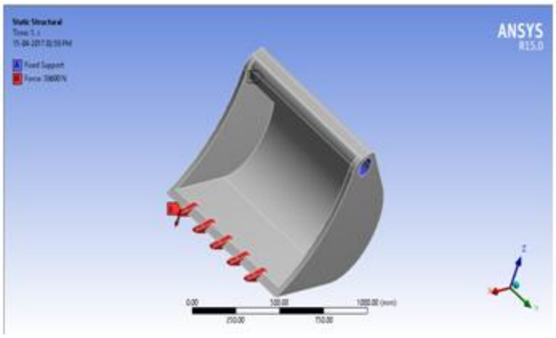

Fig. 4.4 Excavator bucket Named Sections

4.3 SETUP:

The mesh is checked and quality is obtained.

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4.3.1 MATERIALS:

The create/edit option is clicked to add water-liquid, steel and copper to the list of fluid and solid respectively from the fluent database.

4.4 SOLUTION:

RUN CALCULATION:

After giving the boundary conditions to the inner and outer fluid, finally we have to run the calculations. The number of iteration is set to 500 and the solution is calculated and various contours, vectors and plots are obtained.

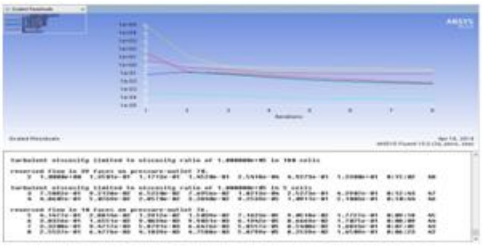

Fig 4.10 Calculations was running

4.5The Post-processor

The post-processor is the last part of Ansys software. It helps the user to examine the results and extract useful data. The results may be displayed as vector plots of velocities, contour plots of scalar variables such as pressure and temperature, streamlines and animation in case of unsteady simulation. Global parameters like drag coefficient, lift coefficient, Nusselt number and friction factor etc. may be computed through appropriate formulas. These data from a Ansys post-processor can also be exported to visualization software for better display [10]. TASCFLOW and FINE/TURBO for turbo machinery and ORCA for mixing process analysis are some examples. Most ANSYS software packages contain their own grid generators and post processors. Software such as ICEM CFD, Some popular visualization software used with ANSYS packages are TECPLOT and FIELDVIEW.

4.6 OVERVIEW OF ANSYS

The input data for an ANSYS analysis is given using a pre-processor. The pre-processor contains solid modeling and mesh generation capabilities and is also used to define all other analysis data like geometric properties (real constants), material properties, constraints, loads, etc., with the benefit of data base definition and manipulation of analysis data. Extensive graphics capability is available throughout the ANSYS program, including isometric, perspective, section, edge, and hidden-line displays of three-dimensional structures. Graphical user interface is available throughout the program, to guide new users through the learning process. The analysis results are reviewed using post processor, which has the ability to display distorted geometries, stress and strain contours, flow fields, safety factor contours, contours of potential field results (thermal, electric, magnetic), and vector field displays mode shapes and time history graphs.

5. RESULTS AND DISCUSSIONS

The main objective of this investigation is to do the Structural analysis on excavator bucket with different materials at various loads and find out the behavior of the excavator bucket at various inclinations and widths. Here in this analysis various factors were calculated by applying loads at appropriate sections of the excavator bucket. Structural analysis was carried out on the excavator bucket at different inclinations 25, 30, 35, 40,45mm on three types of materials Stainless Steel, AISI-1045 and TI Carbide and the action of various stress and strains on the excavator bucket at various loads were investigated. In this research different widths also considered for teeth.

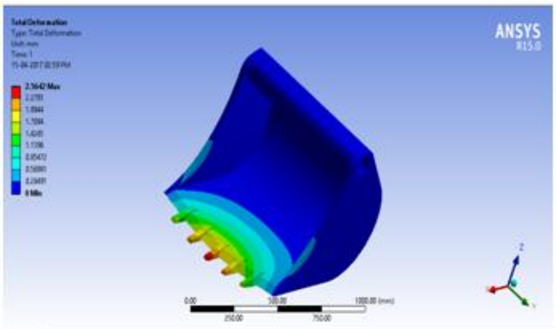

Fig 5.1 Structural analysis of stainless steel

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5.1 REPORTS:

Fig 5.2 verifying the reports.

5.2 Stainless Steel

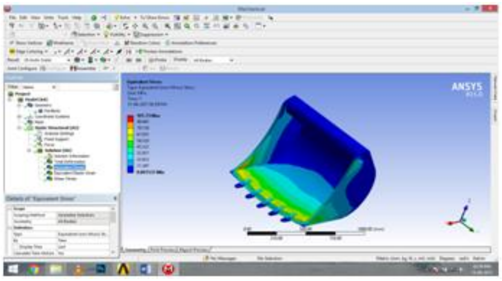

Fig 5.3 Equivalent stress of stainless steel

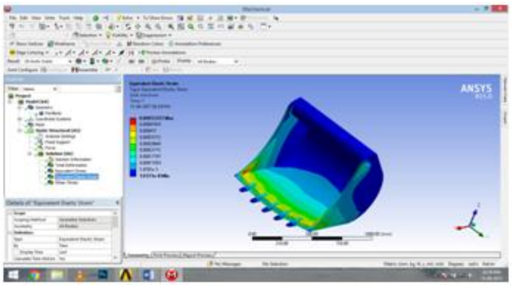

Fig 5.4 Equivalent elastic strain of stainless steel

Table.5.1 Maximum stresses developed

		Obtained Value	
S.No	Type Of Stress	Maximum	Minimum
1.	Total Deformation	2.5642	0
2.	Equivalent Von-Mises Stresses	101.75	0.001537
3.	Equivalent Shear Stress	0.00053357	1.9721e-8
4.	Shear Stress	39.748	-42.046

- **For AISI-1045**

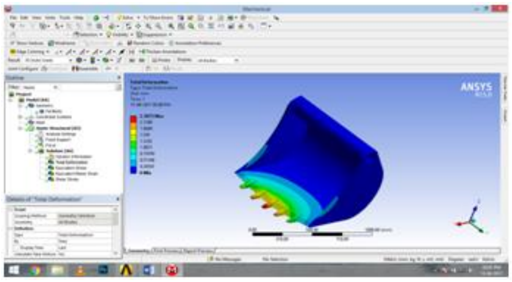

Fig 5.5 Total deformation in AISI-1045

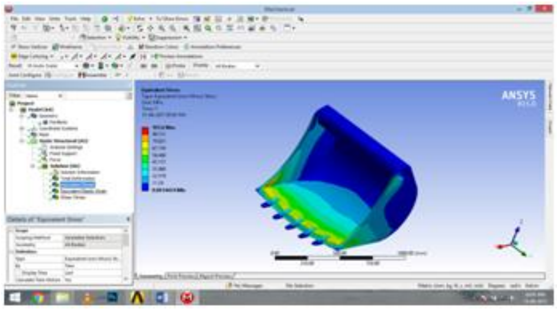

Fig 5.6 Equivalent stresses in AISI-1045

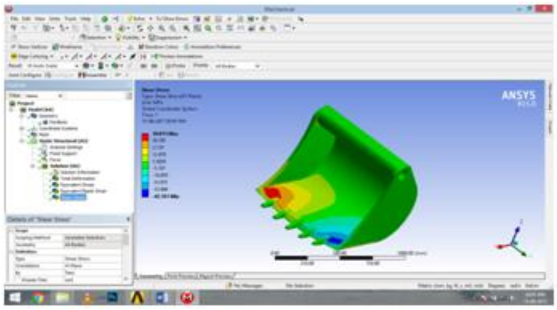

Fig 5.7 Shear stress in AISI-1045

Table 5.2 Deformations for AISI 1045

		Obtained Value	
S.No	Type of Stress	Maximum	Minimum
1.	Total Deformation	2.3925	0
2.	Equivalent Von-MisesStresses	101.6	0.0014474
3.	Equivalent Shear Stress	0.00050168	1.7542e-8
4.	Shear Stress	39.815	-42.197

TI Carbide

Here material TI carbide is used for this analysis. After applying the same boundary conditions for this material and run the solution. The post processor is used to calculate the total deformation.

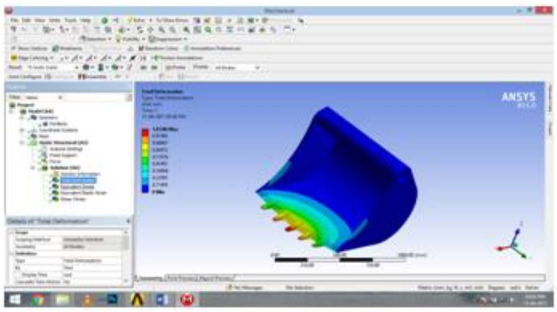

Fig 5.8 Total deformation in TI carbide

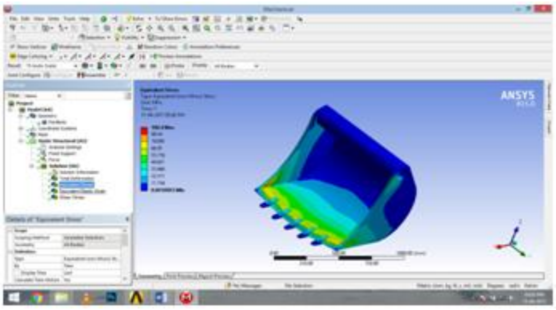

Fig 5.9 Equivalent stress in TI carbide

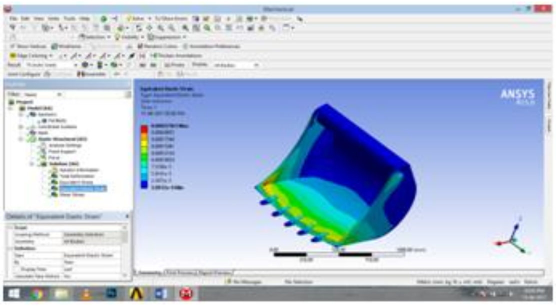

Fig 5.10 Equivalent elastic strain in TI carbide

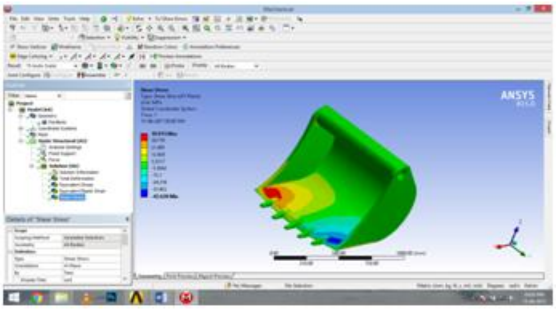

Fig 5.11 Shear stress in TI carbide

Table 5.3 Deformations in TI carbide

		Obtained Value	
S.No	Type Of Stress	Maximum	Minimum
1.	Total Deformation	1.0346	0
2.	Equivalent Von-Mises Stresses	100.4	0.0010993
3.	Equivalent Shear Stress	0.00022561	5.9912e-9
4.	Shear Stress	39.955	-42.628

Structural analysis of stress in different materials at 25mm

Here we are using different materials for this analysis with 25mm after applying the same boundary conditions for this material and run the solution. The post processor is used to calculate the total deformation.

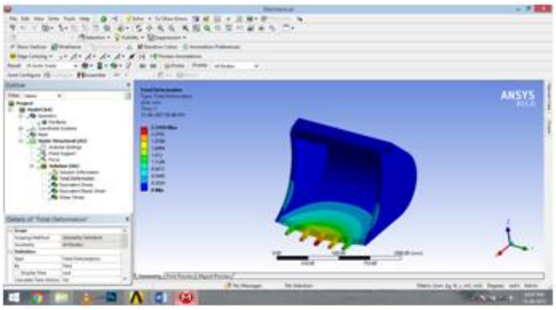

Fig 5.12 Total deformation at 25mm

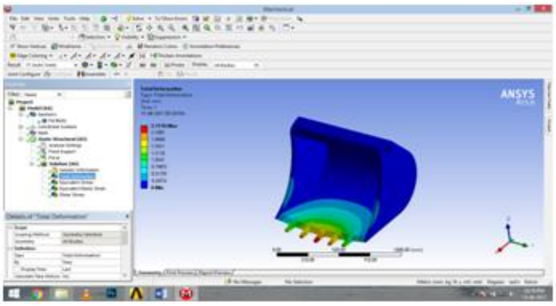

Fig 5.13 Total deformation at 30mm

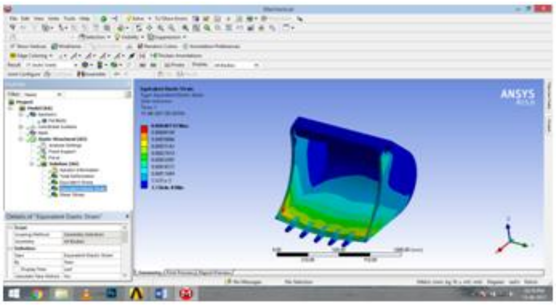

Fig 5.14 Total deformation at 35mm

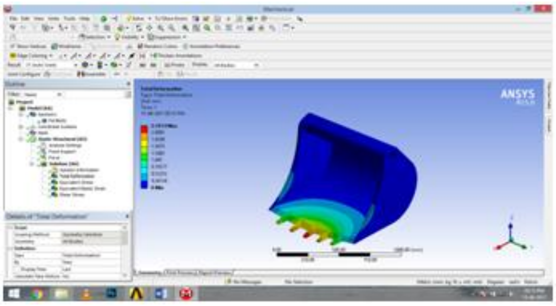

Fig 5.15 Total deformation at 40mm

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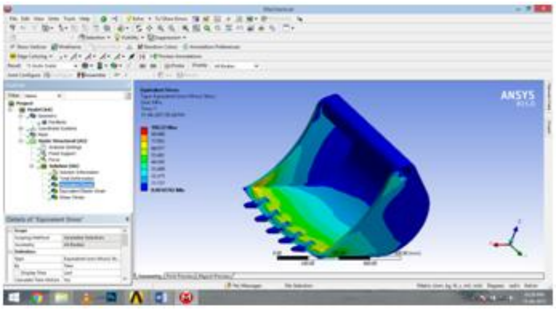

Fig 5.16 Total deformation at 45mm

Table 5.4 structural analysis values at 45mm

		Obtained Value	
S.No	Type Of Stress	Maximum	Minimum
1.	Total Deformation	2.4987	0
2.	Equivalent Von-Mises Stresses	101.99	0.0015094
3.	Equivalent Shear Stress	0.00053196	1.9621e-8
4.	Shear Stress	38.995	-39.705

6. CONCLUSION:

We designed an Excavator bucket by using CATIA V5 software and analysis is done by ANSYS 15.0 software. The stress at the Tip of teeth of an Excavator bucket is calculated 86.39 MPA and stress due to shearing of rivet is calculated 187.67 MPA by analytically. The stress at the tip of the teeth is calculated 112.98 MPA and stress due to shearing of rivet 157.47 is calculated. Percentage error between analytical result and Ansys result are 13.69 % and 6.72 %. As per the above analysis, it is suggested that the bucket used for the excavation purpose should be properly checked for its application on the basis of the soil strata. And considering the failure of the tooth and rivet due the impact loading, it is very much economical to change the tooth assembly and also the inclination and thickness of the tooth. Structural analysis was carried out on the excavator bucket at different widths of teeth such as 25 mm, 30 mm, 35 mm, 40 mm and 45 mm. And the analysis was carried out on three types of materials named Stainless Steel, AISI-1045 and TI Carbide and the action of various stress and strains on the excavator bucket at various loads were investigated. The best combination of parameters like Von misses Stress and Equivalent shear stress, Deformation, shear stress and weight reduction for excavator bucket were done in ANSYS software. TI carbide with 25mm width has more factor of safety, reduce the weight, increase the stiffness and reduce the stress and stiffer than other material. With Fatigue analysis we can determine the lifetime of the excavator bucket.

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