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Structural Optimization of Excavator Bucket Link

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Abstract : *The excavators are heavy duty earthmoving machines and normally used for excavation task. During the excavation operation unknown resistive forces offered by the terrain to the bucket teeth is transformed to the other parts. Excessive amount of these forces adversely affected on the bucket link and may be failed during excavation operation. Thus, it is very much necessary to provide not only a better design of parts having maximum reliability but also of minimum weight and cost, keeping design safe under all loading conditions. This paper deals with the optimization of bucket link of heavy duty hydraulic excavator (320D/D L Series 2). A 3D model of a bucket link is drawn in Catia V5. Meshing is carried out in Hypermesh. Ansys is used for preprocessing, solutions, post processing. According to Ansys results topology optimization will be carried out by determining the regions where there is less stress concentration by using software Optistruct. After achieving desirable results, model of bucket link will be manufactured and heat treatments will be carried out for improving its mechanical properties, strength, load carrying capacity then testing will be done using UTM to validate the results.*

Keywords – *Excavator bucket link, Maximum breakout force, Optimization*

1. INTRODUCTION

A pivotal boom of an excavator is attached to the pivotal arm. The positions of the boom relative to the vehicle and the arm relative to the boom are controlled by hydraulic cylinders. The one end of idler link or bucket link is directly pin jointed to bucket and at the other end to intermediate link and hydraulic rams. This is done to avoid the bending of the idler link due to,

1. The force from the bucket cylinder piston rod directly transfers to the bucket link.
2. The width of the bucket link is less compared to intermediate links.

Material Selection for bucket link - The bucket link is usually made of the material IS 2062[1]. The mechanical properties of IS 2062 are mostly used for the different parts of the Excavators such as collars and bushes and bucket links. IS 2062 is a high tensile strength steel made by India's largest steel manufacturer called SAIL (Steel Authority of India Limited, 2003) having the yield strength is 1030 MPa and Poisson's ratio is 0.3 [5]. The scope of this project is to finding the alternate design which will reduce in weight and cost and to determine the design solution which can withstand high level of stresses that are induced in the bucket link without compromising its strength.

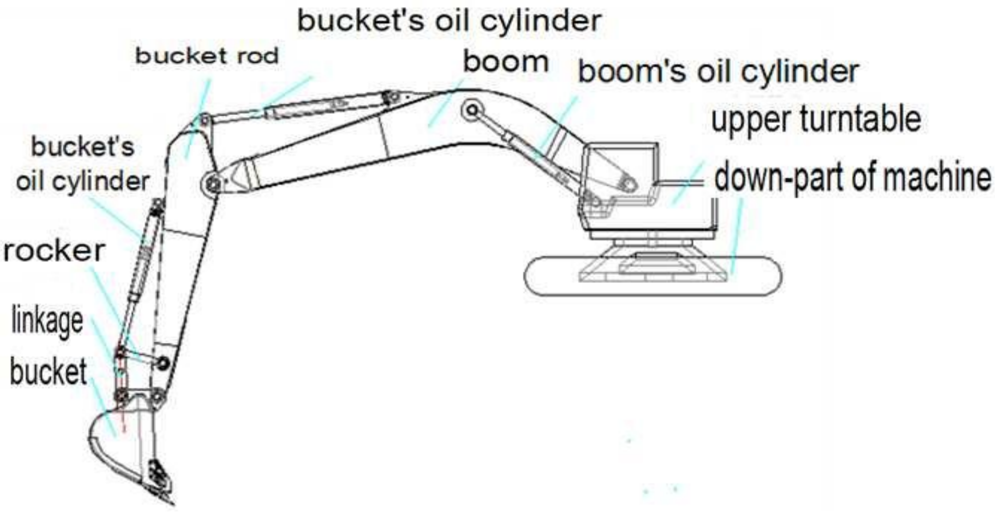

Fig.1. Typical hydraulic excavator

Bhaveshkumar P. Patel, Jagdish M. Prajapati [2], weight optimization of backhoe excavator attachment by using FEA approach by trial and error method. Shape and weight optimization is carried out and results are compared which shows identical results. Rahul Mishra, Vaibhav Dewangan [3], to analyze the force calculation of excavator bucket and calculation of excavator bucket capacity has been calculated according to SAEJ296 and the breakout force is calculated by SAEJ1179. The SAE provides improved bucket geometry for efficient digging and loading of material along with heavy duty robust construction for increased strength and durability. Mr. Suneet J. Mehta,Mr. Nilesh B. Nagare [6], To analyze the existing design and redesign the parts of attachments which are failing under the given operating conditions due to the varying stresses induced in the attachment. Use of a finite element analysis to understand the behavior of the structure which provides specified breakout force. Finally optimization will be done to minimize the weight, deformation and stress of the bucket.

2. PROBLEM DEFINATION

To understand the causes of failure of bucket link it is necessary to walk through the mechanisms and forces acting on the excavator bucket link very carefully. Excavators are intended for excavation task such as digging foundations, mining, rock piles and truck loading. During the excavation operation unknown resistive forces offered by the terrain to the bucket teeth are transformed to the other parts via bucket link. Excessive amount of these forces adversely affect on the bucket link and even it fails during excavation operation. The excavator mechanism must work reliably under unpredictable working conditions. Poor strength properties of the excavator parts like bucket, bucket linkages limit the life expectancy of the excavator. Therefore, these parts must be strong enough to withstand working conditions of the excavator. The skilled operator also cannot know about the terrain condition, soil parameters, and the soil-tool interaction forces exerted during excavation operation are required to find because these forces helpful for better design of the tool, excavator parts and for trajectory planning. Normally, the excavator is working under cyclic motion during excavation process. Due to this repetitive nature of work, cyclic stresses are developed in the bucket link. That high level of stresses can cause the crack in bucket link of excavators and it will adversely affected on productivity of machine. Now a day weight is major concern while designing the machine components. Therefore, for reducing the overall cost as well as for smoothing the performance of machine, optimization is needed.

3. CALCULATION OF STATIC FORCES ON BUCKET LINK

In this section calculation for the static force analysis of the excavator for the condition at which the mechanism produces the maximum breakout force [1] has been done. The force analysis is done for any of the position and orientation of the mechanism from the available breakout forces, in static analysis one configuration of the mechanism has to be decided first for which the analysis is to be carried out. The maximum breakout force condition is the most critical one as it produces the highest breakout force and will be used as a boundary condition for FEA. Fig.2. shows the configuration in which the mechanism is producing the maximum breakout force. The free body diagram of bucket, bucket link, with directions and magnitudes of the forces are explained in this section. It can be seen that reaction force on the bucket teeth at point A1 due to the breakout force (F_B) acts at the angle 38.23°[1] for configuration of the maximum breakout force condition .According to SAE the maximum breakout force is considered to be 54 KN [4] which is acting at a joint A1.

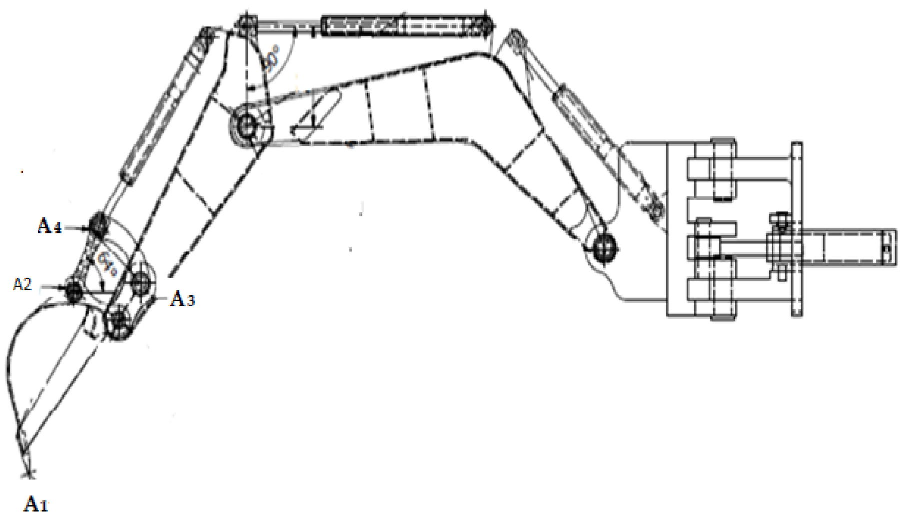

Fig.2. Maximum breakout force configurations

So, the forces acting on bucket link are calculated by resolving forces in the horizontal (X) and the vertical (Y) directions as shown in fig 3.

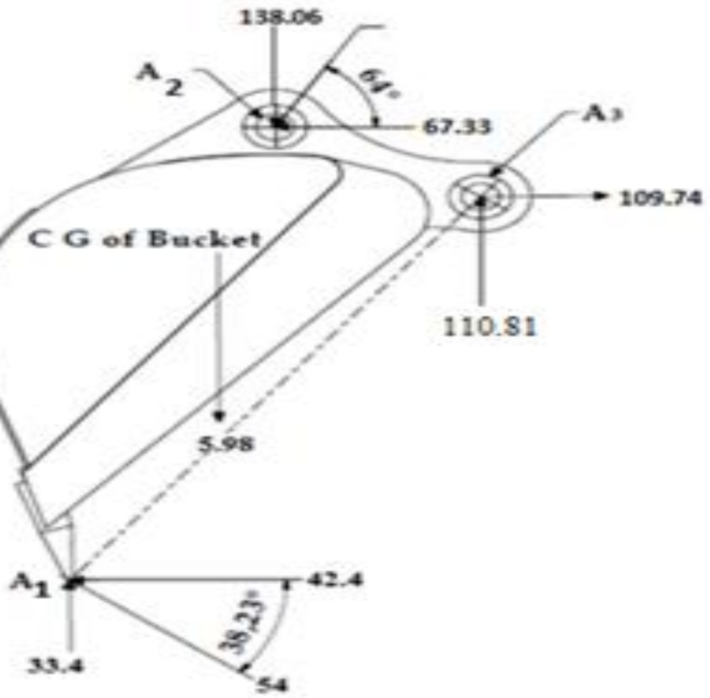

Fig.3. Free body diagram of bucket

The horizontal and vertical component of reaction force 54 KN at point A1 is using equations (1) and (2), as - 42.4 KN, and 33.4 KN respectively.

$$F_{1H} = F_B \cdot \cos \alpha \quad (1)$$

$$F_{1V} = F_B \cdot \sin \alpha \quad 2)$$

Where, α is the angle between the breakout force of bucket and the ground level as horizontal reference surface of 38.23º at joint A1 as shown in Fig.3, Now considering the bucket in equilibrium $\Sigma M_{A_3} = 0$, taking moment about the bucket hinge point A_3.

$$F_1 \cdot L_1 - Fcg \cdot Lcg = F_2 \cdot L_2 \quad (3)$$

Where,

F_1 = 54 KN [4], the force acting at bucket tool tip at point A1 when the bucket approaches to the earth in the maximum breakout force condition which is equivalent to the bucket breakout force F_B.

L_1 = 1620 mm, the perpendicular distance between the tool tip A1 of the bucket and the bucket hinge point A3.

Fcg = 5.98 KN, the gravitational force acting on bucket.

Lcg = 660 mm, the perpendicular distance between the C.G. of the bucket to the bucket hinge point A3.

F_2 is the force acting on hinge point A2 of the bucket link which can be found by using equation (3) and acting at an angle (β = 64º)

L_2 = 543 mm, the perpendicular distance of the bucket hinge point A2 to the idler link or bucket link hinge point on bucket in mm.

By substituting all values in equation (3) the resultant force F_2 = 153.83 KN

The resultant force F_2 can be resolved in horizontal (X) and the vertical (Y) directions by using the following equations,

$$F2H = F2 \cdot \cos \beta$$

$$F2V = F2 \cdot \sin \beta$$

This gives,

F_{2H} = - 67.33 KN and F_{2V} = -138.06 KN

F_{3H} = 109.74 KN and F_{3V} = 110.81 KN respectively.

The negative sign indicates the horizontal component of the force acting in the leftward direction and vertical component of the force in the downward direction.

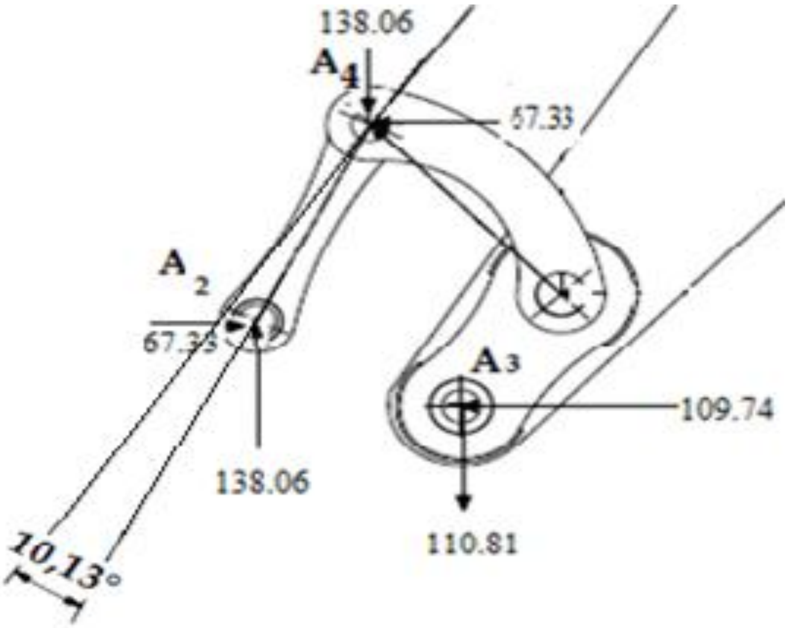

Fig.4. Free body diagram of bucket link

Therefore, the condition at which mechanism produces the maximum breakout force, the forces acting on bucket link are calculated. The forces on joint A4 are exactly equal and opposite forces acting on joint A2.

4. FINITE ELEMENT ANALYSIS

Analysis is done by selecting appropriate solver and carrying out the operations in various stages to obtain solution. Particularly analysis is carried out in three stages by performing various operations in software.

4.1 Meshing

Cad model is generated in part design module of Catia V5. This parametric generation of drawings will help to get the dimensions useful in forces calculations in static loading conditions.

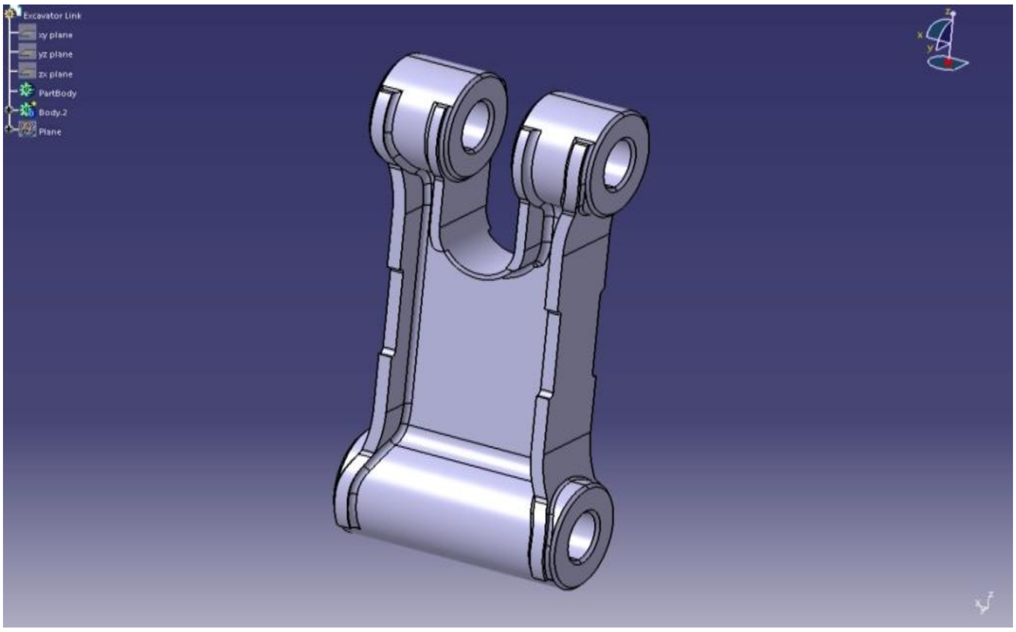

Fig.5. Three-dimension (3D) model of bucket link

In this stage .igs file is imported to the meshing software like Hypermesh. The CAD data of the bucket link structure is imported and the surfaces were created and meshed. Since all the dimensions of bucket link are measurable (3D), the best element for meshing is the tetra-hedral.

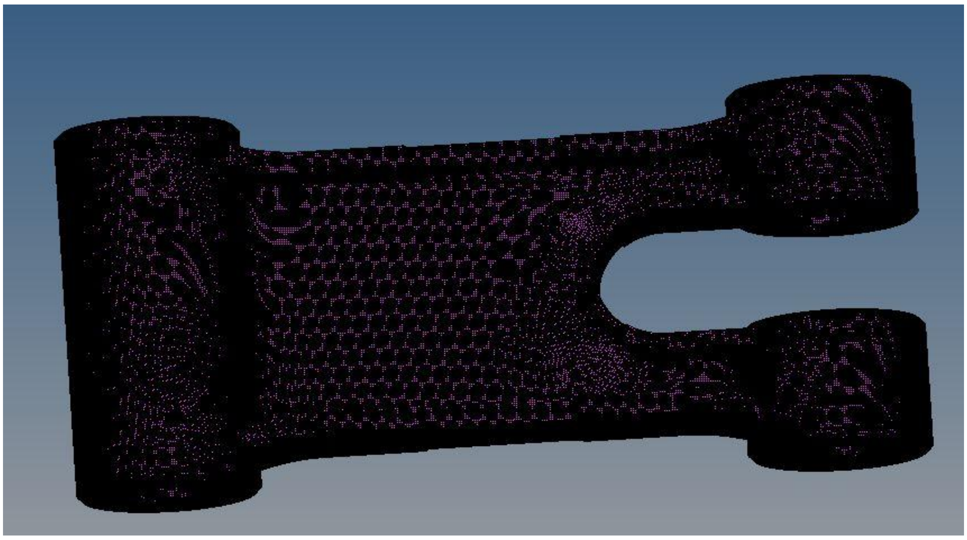

Fig.6. Meshing

A structure or component consists of infinite number of particles or points hence they must be divided in to some finite number of parts. In meshing the component is divided into finite number of elements. Dividing helps us to carry out calculations on the meshed part. Then the meshing is done by selecting tetra-hedral elements.
Number of nodes: 686595
Number of elements: 3314792
Element size = 2 mm

4.2 Boundary conditions

After meshing is completed boundary conditions are applied. These boundary conditions are the reference points for calculating the results of analysis. Here the different load steps are created which are to be applied during analysis. Elements are defined by their material properties such as density, modulus of elasticity, poisson's ratio etc. is assigned to the elements. The proper arrangements are made so the analysis can run in solver software. After the completion of process model is exported to the solver.

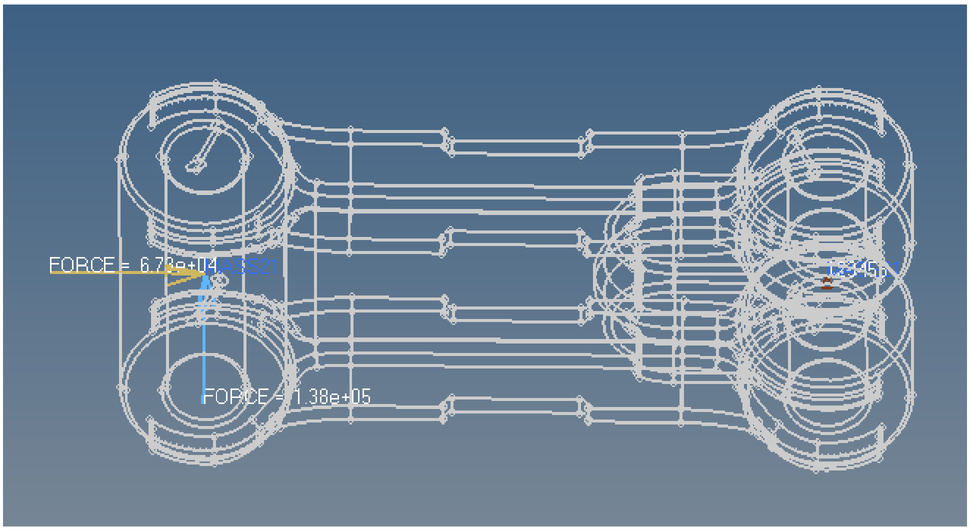

Fig.7. Boundary conditions

As shown in above fig 7, the joint A4 is fixed during the analysis and horizontal and vertical loads are applied to joint A2 as 67 KN and 138.23 KN respectively.

4.3 Structural Properties

Table 1 shows the properties of material - IS2062 (Hardened and Tempered).

Table 1 Properties of Material - IS2062

Young's modulus	210 Gpa
Poisson's ratio	0.3
Density	7850 kg/m³
Yield tensile strength	1030 MPa
Ultimate tensile strength	1420 MPa

4.4 Analysis

Meshed and boundary condition applied model is imported to the solver. Software first calculates the deflection with respect to the boundary conditions applied. Then on the basis of deflection it calculates strain. Once the strain is calculated the modulus of elasticity is known then the stress values are calculated.

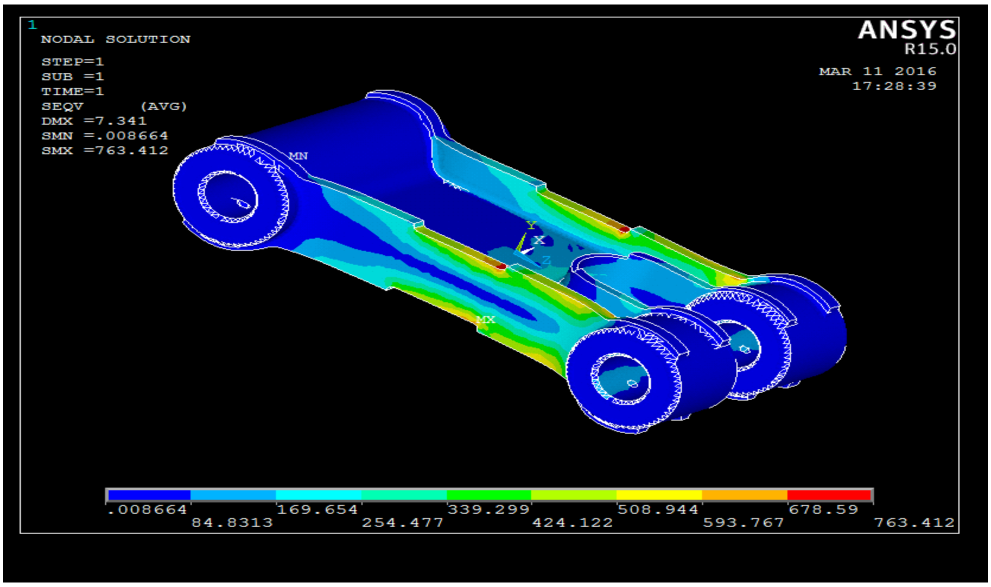

Fig.8. Maximum Principal Stress

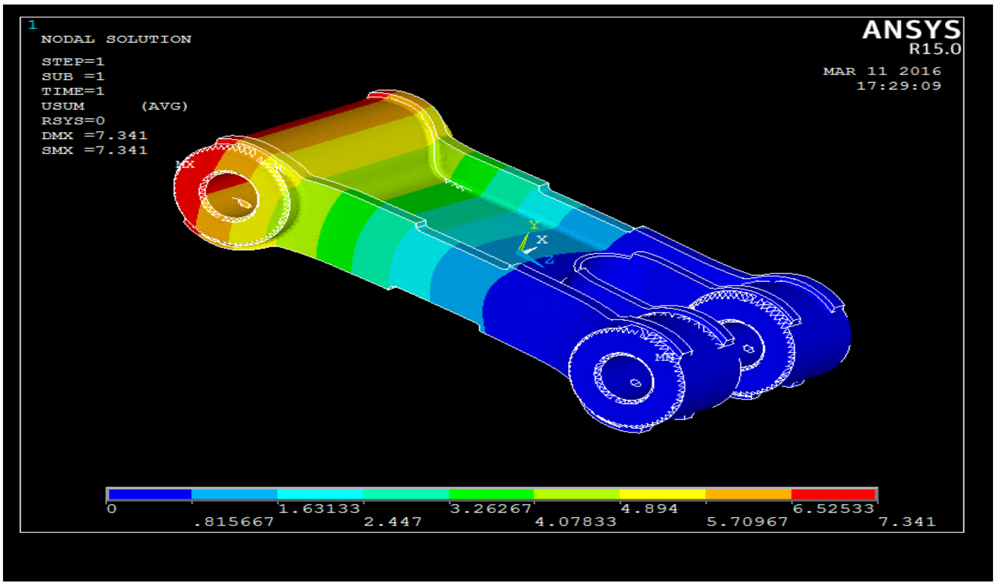

Fig.9. Maximum Deformation

Stress value for bucket link is 763.4132 N/mm^2 and deformation of link is 7.341 mm which is well below the critical value of 1030 N/mm^2. Hence, the design is safe. Results are viewed and accordingly modifications are suggested according to high stress regions obtained. If the stresses are beyond the permissible limits then changes such as, change in thickness of component or addition of ribs etc. are made according to suitability.

5. CONCLUSION

There is a future scope for optimization for further research work by removing material from the low stressed regions and re-designing the bucket link. To find out the effective design that will reduce the weight of bucket link without compromising the strength. After optimization, the bucket link will be manufactured and heat treatments will be carried out for improving its mechanical properties, strength, load carrying capacity then experimental testing will be done by using UTM. The experimental values of stress and deformation should be in-line with the Ansys results.

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