International Journal of Core Engineering & Management (ISSN: 2348-9510)
Special Issue, NCETME -2017, St. Johns College of Engineering and Technology, Yemmiganur

DESIGN AND ANALYSIS OF EXCAVATOR ARM

P.Govinda Raju[1],Md.Salman Ahmed[2],Md.Bilal[3].
P.Govinda Raju[1], Asst. Professor, Department of Mechanical Engineering, BITS, Kurnool.
Md.Salman Ahmed[2], IV B.Tech , Department of Mechanical Engineering, BITS, Kurnool.
Md.Bilal[3], IV B.Tech , Department of Mechanical Engineering, BITS, Kurnool.
DEPARTMENT OF MECHANICAL ENGINNERING
BRINDAVAN INSTITUTE OF TECHNOLOGY AND SCIENCE (JNTUA ANANTAPURAMU)
KURNOOL CITY, INDIA.
govinda.gdas05@rediffmail.com[1], fizasallu@gmail.com[2],
md.bilal371@gmail.com[3]

Abstract

An excavator is a typical hydraulic heavy-duty human-operated machine used in general versatile construction operations, such as digging, ground levelling, carrying loads, dumping loads. The present work concentrate on the arm of an excavator and bucket in order to replace the material, which they are usually made of, with another material. In particular, the study wants to substitute the existing structural steel and replace with aluminium alloy for excavator arm and steel alloy for bucket. This change lightens the components of the arm, and so it is possible to increase the excavator productivity per hour. Study of the components of the excavator in order to identify the problems faced while performing the lifting and digging operations. Due to severe working conditions, excavator parts are subjected to high loads and must work reliably under unpredictable working conditions. Excavator Arm shows stresses are under allowable limit. As the present mechanism used in excavator arm is subjected to loads and bending stresses during lifting and digging operation respectively, because of which failure occurs frequently at the bucket end of the arm. So, the excavator arm is modelled in solidworks software and static structural analysis is done in ANSYS workbench.

Keywords: *Excavator arm, lifting, material, productivity, Solid Works, ANSYS.*

I. INTRODUCTION

A hydraulic shovel of a bucket type excavator is an earth moving machine comprising an upper rotatable chassis mounted on a drivable body with wheel or track and hydraulically powered mechanism consisting of boom, arm and bucket. Applications for excavator in India used as a utility machine at large construction sites and urban infrastructure projects as well as the loading of hoppers and trucks, trenching, the cleaning of canals and ditches, general excavation, solid waste management and even demolition and mining work. The useful task of hydraulic excavator is to free and/or remove surface materials such as soil from its original location and transfer it to another location by lowering the bucket, digging, pushing and/or pulling soil then lifting, swinging The excavation of this task is usually performed by a human operator who controls the motion of the machine manually by using the visual feedback provided through his or her own eyes.

Normally excavators are working under worst working conditions. Due to severe working conditions, excavator parts are subjected to high loads and must work reliably under unpredictable working conditions. Thus, it is necessary for the designers to provide not only an equipment of maximum reliability but also of minimum weight and cost, keeping design safe under all loading conditions. The force analysis and strength analysis is important steps in the design of excavator parts.In this paper, 3D modeling is done in SOLIDWORKS. Analysis is carried out in ANSYS respectively. Stress and deformation is the output of analysis. Re-designing the arm with different materials following the same procedure for 3D modeling, Analysis. Stress values must be below critical value to ensure that the new design is safe.

Fig.1. A typical Excavator of CAT

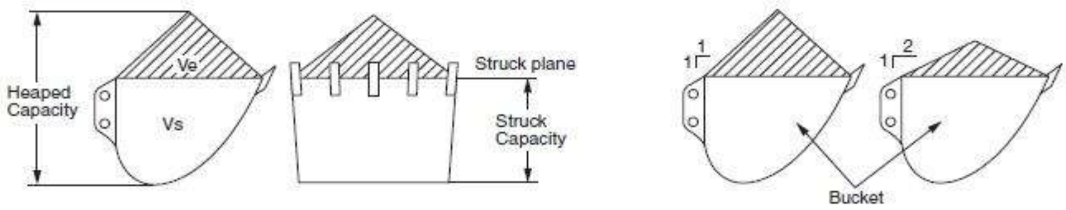
II. BACK GROUND INFORMATION

Bucket Capacity

In this calculations of the excavator bucket capacity, bucket crowd force or breakout force, arm curl or digging force according to standards of SAE (Society of Automotive Engineers) are presented. Static force analysis, considering the maximum breakout force condition, is done for the excavator arm as a boundary condition for static FEA , the static model presented in is according to resistive force condition which is lesser than breakout force, so breakout force has been taken as the boundary condition for static FEA. The bucket capacity calculations are carried out in section 2.1, digging forces according to SAE standard is presented in section 2.2, generalized breakout and digging force model is presented in section 2.3, presents the comparison of proposed excavator attachment with the other standard models available in the market for all technical specifications.

2.1 Bucket capacity calculations

Bucket capacity is a measure of the maximum volume of the material that can be accommodated inside the bucket of the excavator. Bucket capacity can be either measured in struck capacity or heaped capacity as described below:



(a) **(b)**

Fig. 2.1 Bucket struck and heaped capacities

Struck capacity is defined as: The volume capacity of the bucket after it has been struck at the strike plane. The strike plane passes through the top back edge of the bucket and the cutting edge as shown in Fig. 2.1 (a). This struck capacity can directly be measured from the 3D model of the bucket excavator.

On the other hand the calculation of the heaped capacity is done by following the standard. Standard used to determine the heaped capacity, are:

- SAE J296:"Mini excavator and, backhoean American standard bucket (Mehta Gaurav K., 2006), (Komatsu, 2006)

Heaped capacity is defined as: The sum of the struck capacity plus the volume of excess material heaped on the bucket at a 1:1 angle of repose (according to SAE), as shown in the Fig. 2.1 (b). This in no way implies that the hoe must carry the bucket oriented in this attitude, or that all material will naturally have a 1:1 angle of repose.

As can be seen from the Fig. 2.1 the heaped capacity V_h can be given as:

$$V_h = V_s + V_e \qquad \text{.... (2.1)}$$

Where, V_s is the struck capacity, and V_e is the excess material capacity heaped either at 1:1 angle of repose as shown in Fig. 2.1 (b).

Firstly, from Fig. 2.2 struck capacity Vs equation will be presented, then by using methodologies SAE , equation of excess material volume or capacity

Ve will be presented from Fig. 2.2. Finally bucket heaped capacity can be found from equation (2.1).

- Struck capacity Vs can be given from Fig. 2.2 as:

$$V_s = P_{Area} \times \frac{(W_f + W_r)}{2} \qquad \text{......(2.2)}$$

- Excess material capacity V_e for angle of repose 1:1 according to SAE J296 standard as shown in Fig. 2.2 (a).

$$V_e = \frac{L_B W_f^{\,2}}{4} - \frac{W_f^{\,3}}{12} \qquad \text{......(2.3)}$$

The description of the terms used in Fig. 2.2 is as follows:

- L_B: Bucket opening, measured from cutting edge to end of bucket base rear plate.
- W_f: Inside width front, measured at cutting edge or side protectors.
- W_r: Inside width rear, measured at narrowest part in the back of the bucket.
- P_{Area}: Side profile area of bucket, bounded by the inside contour and the strike plane of the bucket.

Fig. 2.3 shows the important parameters to calculate the bucket capacity for the proposed 3D model of bucket. The calculation done is based on SAE standard as this standard is globally acceptable and used.

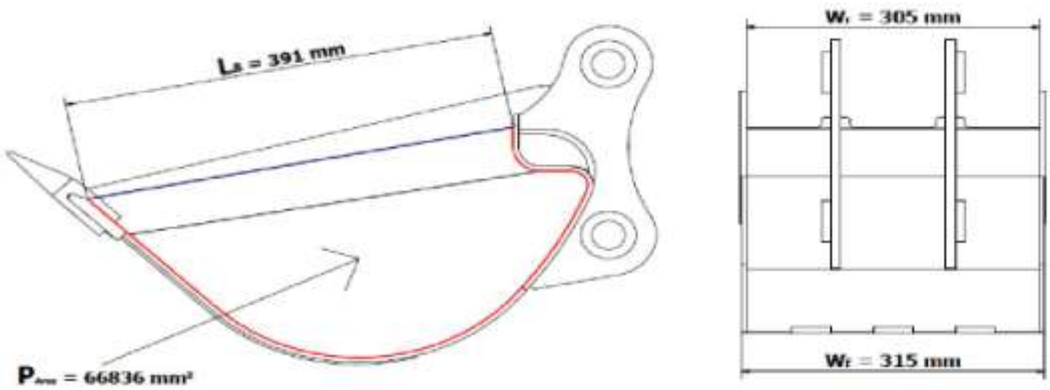


Fig. 2.3 Parameters of the proposed 3D bucket model to calculate the bucket capacity

As can be seen from the left side of the Fig. 2.3 P_{Area} is the area bounded by struck plane (blue line) and side protector (red curve), and it is 66836 mm^2.

By using equations (2.1), (2.2) and (2.3) the bucket capacity for the proposed 3D bucket model comes out to be 0.02781 m^3 = 0.028 m^3.

III. MAIN RESULTS

2.2 Static force analysis

In this section calculation for the static force analysis of the excavator for the condition in which the mechanism produces the maximum breakout force has been explained. Unlike the previous section's flexibility where the force analysis could be done for any of the position 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. From all the configurations, 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 static FEA.

International Journal of Core Engineering & Management (ISSN: 2348-9510)
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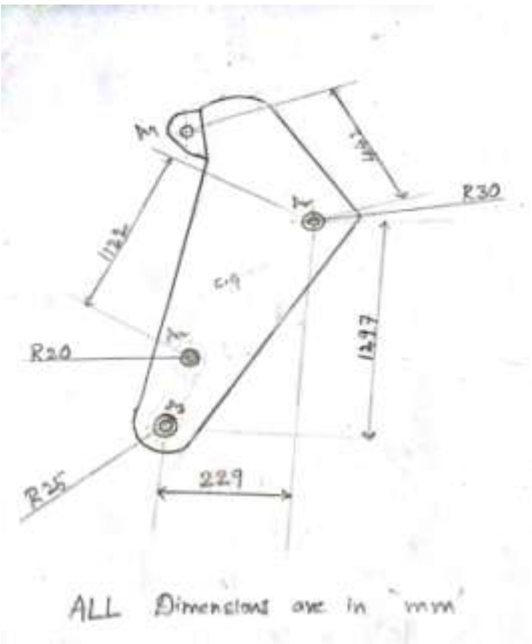
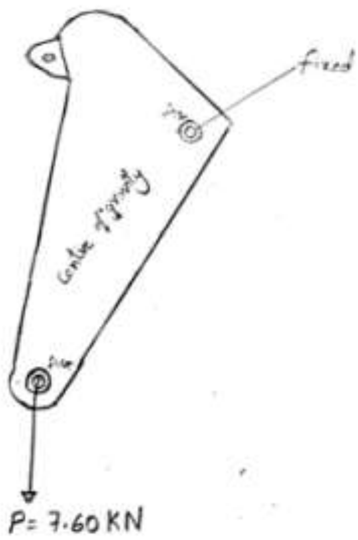
2.3 Arm static force analysis

In Fig. (a) shows the important dimensions for the moments and the resolution of forces respectively. Fig. (b) shows the static force acting at the point on the arm is taken from Reference [10].
The A_2 point is fixed and the A_4 point is having a different forces as shown in figure.

Fig. Free body diagram of arm



(a) Dimensions



(b) Load

III. MODELING

3.1 Solid Works modelling

Solid Works technology is very important while designing Excavator Mechanism.
Following are advantages of Solid Works technology:

- To increase the productivity of the designer
- To improve the quality of the design

CAD/CAE softwares for Excavator mechanism design

- Solid Works is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs on Microsoft Windows. Solid Works is published by Dassault Systemes.
- Solid Works provides mechanical engineers with an approach to mechanical design automation based on solid modelling technology and the features such as 3D modelling, parametric design, feature-based modelling, associatively, capturing design intent, combining

features into parts, and assembly. The three dimensional model of the assembly of Excavator arm is shown in the fig.

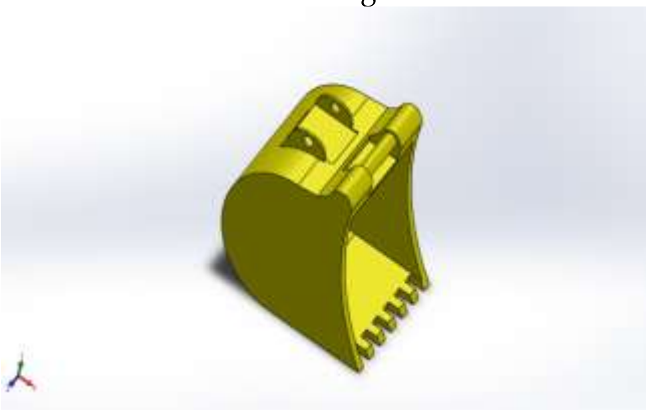


Fig. Bucket of Excavator

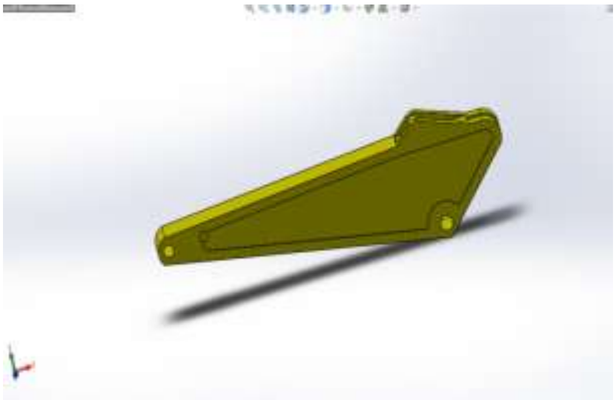


Fig. Arm of Excavator

IV. FINITE ELEMENT ANALYSIS

The finite element method (FEM), sometimes referred to as finite element analysis (FEA), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Simply stated, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. Boundary value problems are also sometimes called field problems. The field is the domain of interest and most often represents a physical structure.

The field variables are the dependent variables of interest governed by the differential equation. The boundary conditions are the specified values of the field variables (or related variables such as derivatives) on the boundaries of the field. Depending on the type of physical problem being analyzed, the field variables may include physical displacement, temperature, heat flux, and fluid velocity to name only a few.

4.1 Analysis of bucket

After the digging operation the bucket will lift the material. So, the total load acting on bucket will be the sum of self weight of bucket and total weight of material in the bucket. The load acting on bucket while working is 570 N.

The steps involved in Static analysis are as follows :

- Defining the geometry of bucket.
- Meshing of the geometry is done. The component is divided into 2147 elements having 4457 nodes.
- Providing fixed support at one end of the bucket.
- Applying force on the bucket.

International Journal of Core Engineering & Management (ISSN: 2348-9510)
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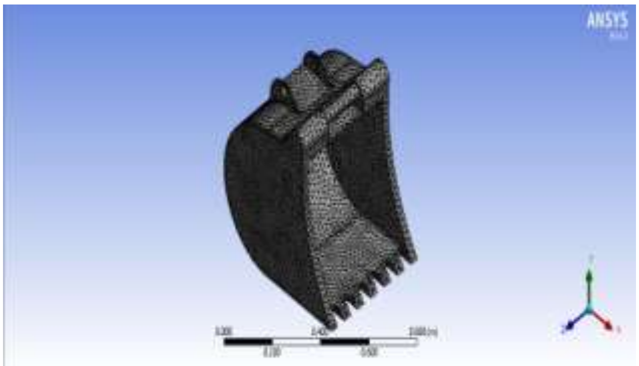
- Solution involves determination of the stresses occurred due to the application of load and also finding out the total deformation.

The fig shows equivalent (Von-Mises) stress, Maximum Shear stress and total deformation respectively which are developed because of the 570N force applied.

Existing Model | **Proposed Model**

□□□□eshing



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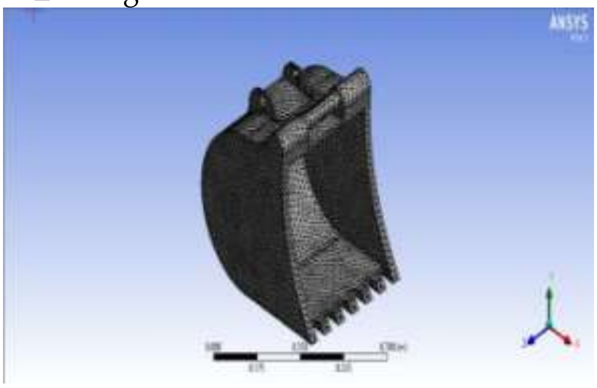
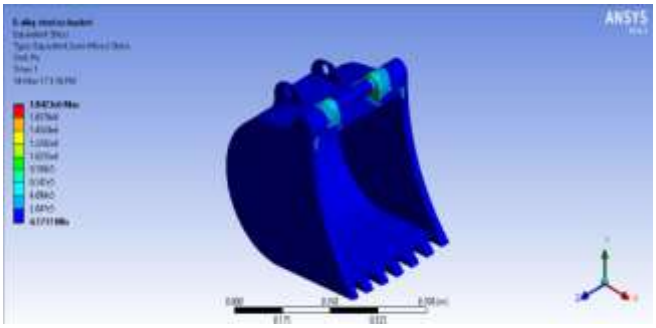
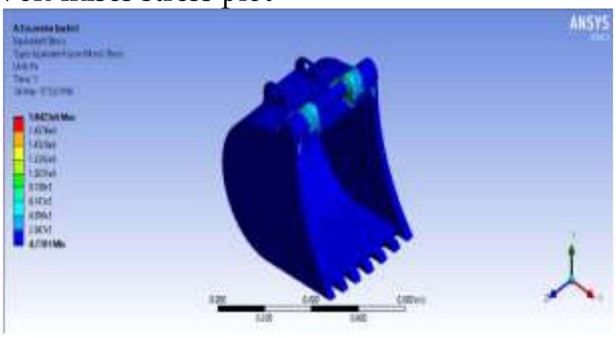


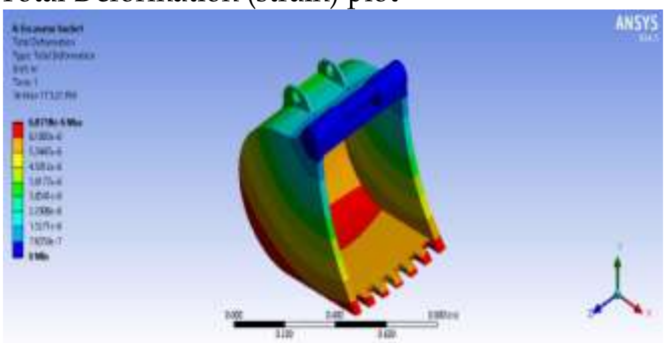
Von-mises stress plot



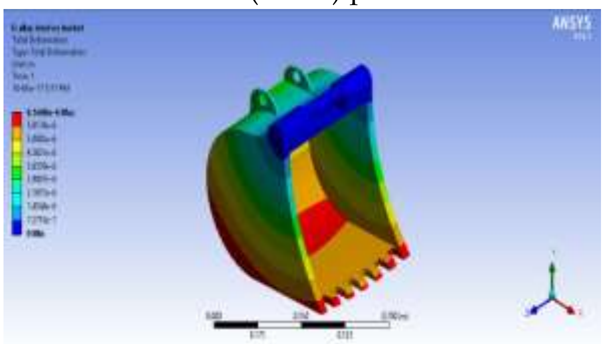
Von-mises stress plot



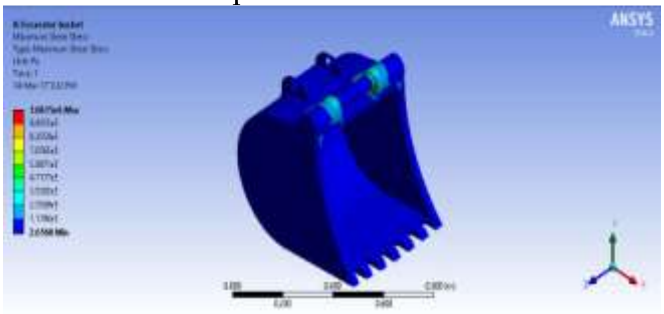
Total Deformation (strain) plot



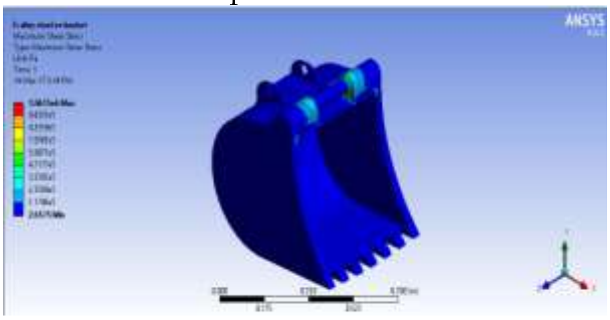
Total Deformation (strain) plot



Max. shear stress plot



Max. shear stress plot



4.1 Static structural analysis of Arm

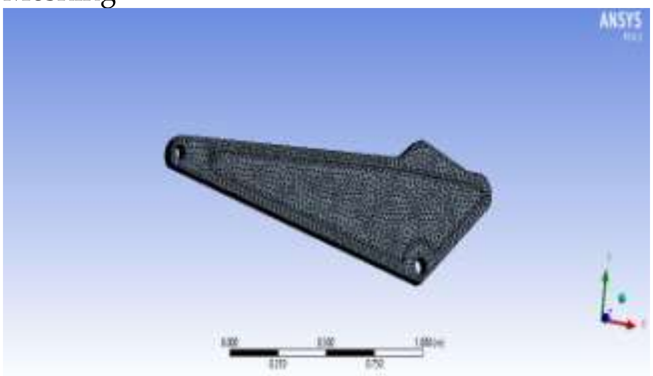
The steps involved in static structural analysis are as follows :

- The IGES file of the Excavator arm is imported and geometry is generated.
- The joint connection type used in the Mechanism Design to place a component in an assembly is specified.
- Meshing of the model is done.
- Fixed support is provided to the mechanism.
- The calculated digging force of 7600N is applied.

Solution of the problem is done in which the stresses induced due to the force applied is found.

Existing Model

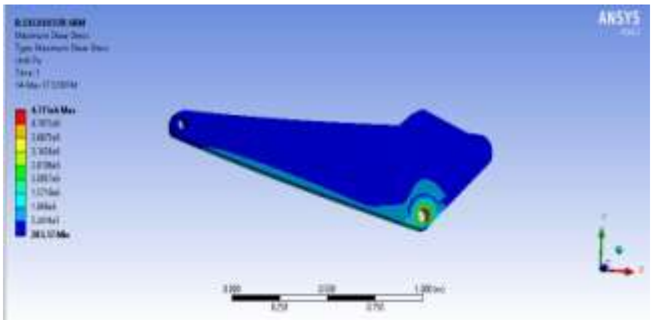
Meshing



Proposed Model

Meshing

Max. shear stress plot



Max. shear stress plot

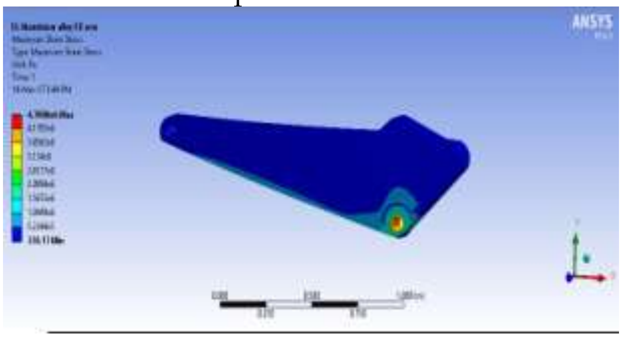


Fig : Max shear stress at 7600N

V. RESULTS AND DISCUSSIONS

The static structural analysis of the arm is done and the maximum shear stress developed in the model is shown. Also, the static structural analysis of the bucket is done and the stresses developed and deformation occurred are shown. Based on this study we achieve that the total weight of the arm is reduced nearly to 50% i.e; the existing weight of the arm is 2050 Kg and now the reduced weight is 1080Kg . The capacity of the existing bucket is 0.022m^3 and now the increased capacity of the bucket is 0.028m^3.

Material properties :

S.No.	Properties	Existing material Structural Steel (Bucket & Arm)	Proposed Material	
			Steel Alloy (Bucket)	Aluminium Alloy (Arm)
1	Density(1000Kg/m^3)	7.8	7.85	2.8
2	Elastic Modulus (GPa)	210	210	79
3	Poisons ratio	0.3	0.3	0.3
4	Thermal Expansion(10^{-6}/K)	12.5	15	25
5	Tensile Strength (MPa)	750	758	570
6	Yield Strength (MPa)	360	366	505

For Arm :

Description	Structural steel (existing)	Aluminium alloy (proposed)
Maximum shear stress	4.715e^6	4.70e^6

For Bucket :

S.No.	Description	Structural steel (existing)	Steel alloy (proposed)
1	Von-mises stress	6.141e^5	6.141e^5
2	Total deformation	6.870e^{-6}	6.544e^{-6}
3	Maximum shear stress	1.061e^6	1.061e^6

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