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Design & Analysis of Excavator Bucket with different design modification

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Abstract - *An excavator bucket is a specialized container attached to a machine as compared to a bucket adapted for manual use by a human being excavator bucket is the most used heavy tool because it can handle other heavy tool such as sloping and dumptruck loading. The analysis of excavator bucket lugs is carried over two steel alloy materials such SM50A (Steel Alloy) and SCNCr2B. The main aim of this project work is designing bucket excavator using Catia V5 software and doing analysis with ANSYS R14.5 software using finite element analysis (FEA) method. The project work emphasize about the development that is done in the tip of excavator bucket teeth based on the calculation and analysis.This methods gives the force calculation and further it is used for the carrying out the fatigue analysis to calculate fatigue life of bucket and its failure. Further the work regarding the optimization of modified bucket to give maximum fatigue life compared with existing bucket model for the digging at the desired force conditions.*

Key Words: Excavator bucket, Fea analysis, Catia V5

1.INTRODUCTION

A bucket is a specialized container attached to a machine, as compared to a bucket adapted for manual use by a human being. It is a bulk material handling component. The bucket has an inner volume as compared to other types of machine attachments like blades or shovels. The bucket could be attached to the lifting hook of a crane, at the end of the arm of an excavating machine, to the wires of a dragline excavator, to the arms of a power shovel or a tractor equipped with a backhoe loader or to a loader, or to a dredge. The name "bucket" may have been coined from buckets used in water wheels, or used in water turbines or in similar-looking devices. Buckets in mechanical engineering can have a distinct quality from the traditional bucket (pail) whose purpose is to contain things. Larger versions of this type of bucket equip bucket trucks to contain human beings, buckets in water-hauling systems in mines or, for instance, in helicopter buckets to hold water to combat fires. Two other types of mechanical buckets can be distinguished according to the final destination of the device they equip: energyconsumer systems like excavators or energy-capturer systems like water bucket wheels or turbines. Buckets exist in a variety of sizes or shapes. They can be quite large like those equipping hulett cranes, used to discharge ore out of cargo ships in harbours or very small such as those used by deep-sea exploration vehicles. The shape of the bucket can vary from the truncated conical shape of an actual bucket to more scoop-like or spoon-like shapes akin to water turbines. The cross section can be round or square. Excavator buckets are digging attachments with teeth that can be fixed to the arm of an excavator. The buckets are controlled by the excavator operator using controls in the cabin. There are different types of excavator buckets that are used depending on where the digging has to be done. Excavator buckets can also be used to move dirt or load dump trucks for transportation to dumping sites. Excavators are used in conventional trenching methods for laying pipelines and also used for digging trial pits for geotechnical investigation. The construction industry is wider than what you have imagined it was. By simply looking at the machineries and equipment being used in it, you can definitely say that it is a huge world to work into. But no matter what tasks are needed to be done, the presence of heavy machines like the excavator and excavator attachments can it all easy and simple to complete.

1.1 Typesof Bucket

A. Digging Bucket: The most common excavator bucket is the digging bucket. It is the standard bucket that comes with every excavator. These all purpose buckets are used to plough through hard soil, rocks or even frost covered soil. They come in various sizes and shapes with short blunt teeth, to break through hard soil. These teeth may be longer and sharper, depending on the hardness of the soil.

Fig -1: Digging Bucket

B. Rock Bucket: This excavator bucket is meant to work with hard rocks. They are similar in design to digging buckets but have reinforced structural parts for strength. They have longer, sharper teeth, narrow V-shaped cutting edge, and can push with more power. They can break through hard rock while maintaining their structural integrity.

Fig -2: Rock Bucket

C. V-Bucket: The V bucket is a special excavator bucket. It has a V shaped structure that helps it penetrate easily through the soil. The angled sides make it easier to dig. This saves costs on power while digging. Work that involves laying pipes is ideally suited to this type of excavator bucket.

Fig -3: V-Bucket

D. Skeleton Bucket: A skeleton bucket is a modified digging bucket. It accomplishes an additional task while digging. The bucket is made up of bars that have gaps. Small particles fall through these gaps during excavation. This utility is helpful in segregating coarser soil with finer particles.

Fig -4: Skeleton Bucket

1.2 Problem Statement

The excavator mechanism must even work under unpredictable operating conditions. Poor strength properties of the excavator parts like boom, arm and bucket limit the life of the excavator. Therefore, excavator parts should be robust enough to cope with caustic operating conditions of the excavator. The skilled operator is unaware of condition of road, soil parameter and sand force transmitted from soil during excavation process. These forces should consider for better design of tools, other parts of excavators, and for planning trajectory motion. In today's world, weight is one of the major concerns while planning and designing any machine parts. So for reducing the overall price further as for smoothing the performance of machine, modification is required.

OBJECTIVES

1) To Reduction in material which will reduces weight of bucket by modification and ultimately reduces basic and operating cost.
2) Stress Analysis to find the possible deformation and stress concentrated areas.
3) To do the Structural analysis on excavator bucket with different materials at various loads.
4) To find behavior of the modified excavator bucket by comparing with exsiting bucket model.

2. METHODOLOGY

In our project work we have setup design procedure based on exsiting design data and past literature research papers. We have gone through the mathematical calculations and obtained the geometrical parameters for the 3D model of an excavator bucket.

1. First we will calculate the Bucket digging force form the following equation,

$$F_B = \frac{\text{Bucket cylinder force}}{d_D}\left(\frac{d_A \times d_C}{d_B}\right)$$

2. Next we will calculate the curling force by using following equation,

$$F_B = \frac{p \times \left(\frac{\pi}{4}\right) D_B{}^2}{d_D}\left(\frac{d_A \times d_C}{d_B}\right)$$

3. Then we will calculate the Bucket capacity by using following two eqations

$$V_B = Vs + Ve$$

Where,

V_B = Bucket capacity,
V_s = Struck capacity and
V_e = Excess capacity,

4. Next we will calculate forces which are acting on the bucket,

5. Design Parameters

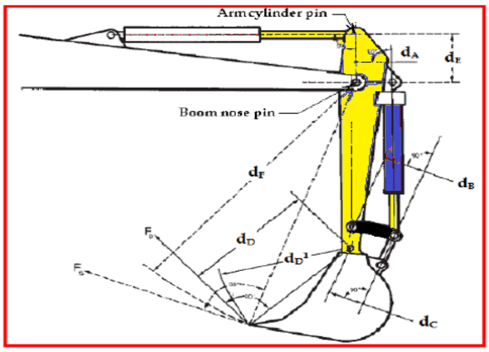

Fig -5: Bucket Forces

Where,

d_A = Distance between Boom and arm fixed point = 700 mm
d_B = Distance between arm and bucket cylinder fixed point = 470 mm
d_C = Distance between arm end and cylinder end fixed point = 290 mm
d_D = Distance between bucket end to the tip of teeth of bucket = 1150 mm
d_E = Distance between boom cylinder end and arm cylinder end = 450 mm

6. Next we have considered the existing bucket forces acting on bucket.

8. And then we design excavator bucket according to step 1 to 7

9. 3D Modelling of the excavator bucket is carried out using modelling software CATIA. And also we made some changes in new model by comparing with existing bucket model to increase the volumetric efficiency of bucket.

10 Bucket analysis is done with the help of Ansys software for comparing the result of stresses and total deformation.

11. Final result is compared with existing model of bucket.

3. Design & Force Calculations

3.1 Design Detail of modified bucket

Table-1: Design Detail of modified bucket

Plate Thickness	No. of Teeth	Height of Bucket	Width of bucket	Length of Bucket	Vol. Capacity
20mm	4	771.2mm	1000mm	1022mm	0.6279m³

A. calculating the digging force

$$F_S = \frac{35.3 \times \left(\frac{\pi}{4}\right) 122^2 \times 1202.2}{4002.5}$$

F_S = 123945.1768 N = **123.94KN**

Where,

d_F =bucket tip radius (d_D) + arm link length and D_A = end diameter of the arm cylinder

B. Calculating the curling force

$$F_B = \frac{35.3 \times \left(\frac{\pi}{4}\right) 136^2}{1396.4} \left(\frac{132.8 \times 456}{628}\right)$$

F_B = 35410.80 N = **35.41KN**

When the assembly of proposed model is placed in the position as shown in Fig. 5.4 it holds the values of the parameters as: d_A = 132.8 mm, d_B = 628 mm, d_C = 456 mm, d_D = 1396.4 mm, d_E = 1202.6 mm, and d_F = 4002.5 mm. The working pressure p = 35.3 MPa, D_A=122, D_B=136.

The bucket curl or breakout force F_B = 35.41KN and arm crowd force or digging force FS = 123.94 KN.

3.2 Bucket capacity calculations

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

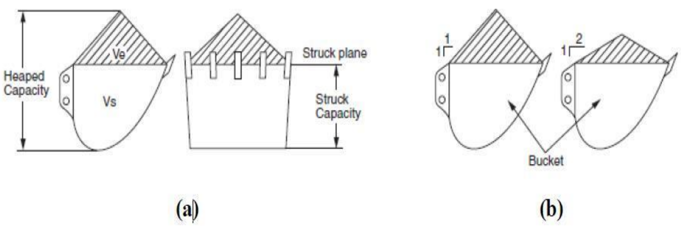

Fig -6: (a) Bucket struck (b) heaped capacities

2. Struck capacity

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.6 (b). This struck capacity can directly be measured from the 3D model of the backhoe bucket excavator.

$$V_s = 455582 \left[\frac{(1000+988)}{2}\right]$$

V_s = 452848508mm³ = **0.452848 m³**

Where,

p_{area}= area of inner surface of bucket,
W_r = inside width of the bucket and
W_f = Outer width of bucket.

3. Excess material capacity

$$V_e = \left[\frac{1022 * 1000^2}{4} - \frac{988^3}{12}\right]$$

V_e = 175130810.7 mm³ = **0.175130 m³**

C. Obtained Bucket capacity

$V_B = V_s + V_e$

V_B = 0.452848 + 0.175130 = **0.627978 m³**

Table-2: Modified Bucket forces

Bucket Digging force	Brealout Force	Vol.Capacity of bucket
35.41KN	123.94KN	627Kg

4. Modeling & Analysis of Bucket

4.1 Modeling of Excavator Bucket

3D model of the excavator bucket was developed in Catia V5 from the design calculations done. The model was then converted into a parasolid to import into ANSYS. A Finite Element model was developed with solid elements. The elements that are used for idealizing the bucket were described below

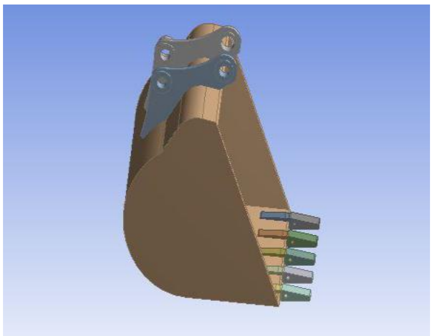

Figure -7: Existing Bucket model

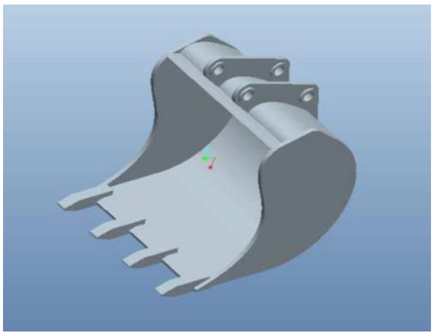

Figure -8: Modified Bucket structure with adapter and hinged plate

4.2 Procedure for structural analysis in ANSYS 14.5

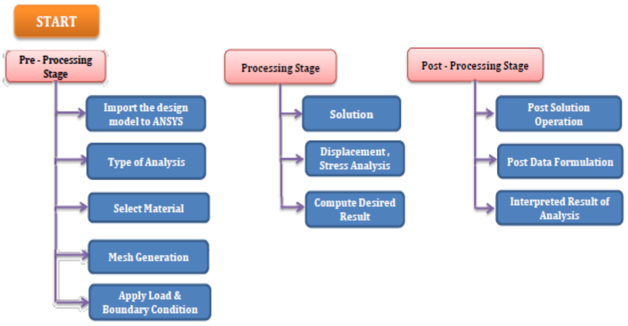

Figure -9: Structural analysis procedure

4.2.1 Structural analysis results of Existing bucket for Dynamic Loading

A. Material: - Medium Carbon Steel

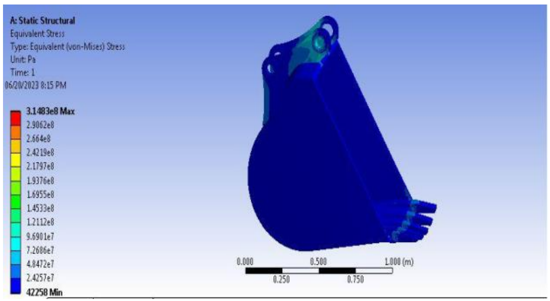

Figure -10: Von Misses stress view of existing Bucket

Fatigue life calculation:

By using Goodman's Fatigue life calculation method prediction of fatigue life as:

Alternating Stress(Y) $= \frac{\sigma_{max} + \sigma_{min}}{2} = \frac{314.83 + 0.04225}{2}$

$= 157.43$Mpa

Now,

Alternating Stress(Y) $= \frac{\sigma_{max} - \sigma_{min}}{2} = \frac{314.83 - 0.04225}{2}$

$= 157.39$Mpa

Slope (m) $= \frac{\sigma_{alternate}}{\sigma_{mean}} \frac{157.39}{157.43} = \mathbf{0.99}$

Coordinate (Y1) = Endurance limit-mX=300-(0.99 * 157.43) = 144.14MPa

Margin of Safety $= \frac{Y_1}{Y} = \frac{144.14}{157.39} = 0.91$

Margin of Safety < 1 so that design is not safe

Fatigue Life = (1-(1/Margin of safety)) = 98901cycles

= 300 hrs

4.2.2 Structural analysis results of Modified bucket for Dynamic Loading

B. Material: - SM50A (Steel Alloy)

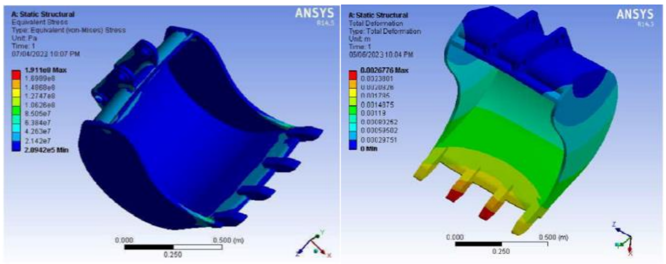

Figure- 11 (a) **(b)**

(a): Von Misses stress view of Modified Bucket **(b)** Total deformation for Modified bucket

Figure 11(a) shows the results of analysis excavator bucket with material SM50 A (Steel Alloy). The Maximum von-Mises stress observed during analysis is 191.1 MPa which is less than yield value.

Figure 11(b) shows the results of analysis excavator bucket with material SM50 A (Steel Alloy). The deformation on excavator bucket for iteration I. Deformation comes to be 2.677 mm for maximum digging force condition that was applied on bucket.

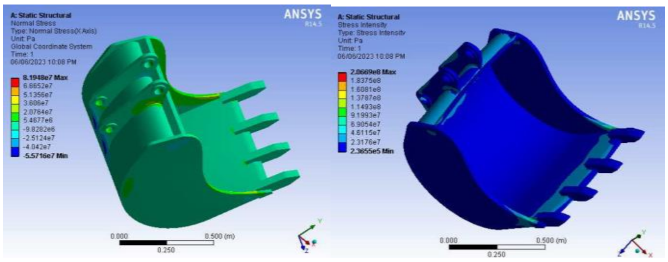

Figure- 12 (a) **(b)**

Figure-12 (a): Normal stress for Modified bucket **(b)** Stress intensity for Modified bucket

Figure 12(a) shows the results of analysis of excavator bucket with material SM50A. The normal principle stress observed during analysis is 81.9 Mpa.

Figure 12(b) shows the results of analysis of excavator bucket with material SM50A. The stress intensity is observed during analysis is 206 Mpa.

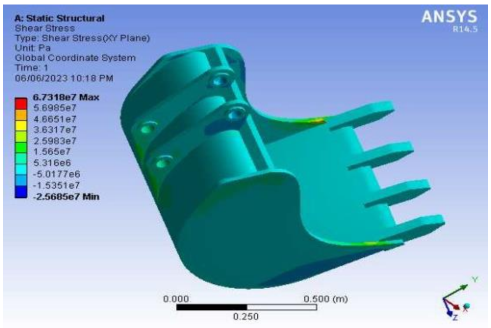

Figure-13: Shear stress for Modofied bucket

Figure 13 shows the results of analysis excavator bucket with material SM50 A (Steel Alloy). The shear stress observed during analysis is 67.31 MPa which is less than yield value.

Fatigue life calculation:

Mean Stress(X) $= \frac{\sigma_{max} + \sigma_{min}}{2} = \frac{191.1 + 0.2094}{2}$

= 95.65 Mpa

Now,

Alternating Stress(Y) = $\frac{\sigma_{max} - \sigma_{min}}{2} = \frac{191.1 - 0.2094}{2}$

= 95.44Mpa

Slope (m) = $\frac{\sigma_{alternate}}{\sigma_{mean}} \frac{95.44}{95.65}$ = **0.99**

Coordinate (Y1) = Endurance limit-mX = 350-(0.99*95.65) = 255.30 MPa

Margin of Safety = $\frac{Y_1}{Y} = \frac{255.30}{95.44}$ = 2.67

Margin of Safety > 1 so that design is safe

Fatigue Life = (1-(1/Margin of safety)) = 625468cycles

= 1100 hrs

5. RESULT AND DISCUSSION

The main objective of this project work is to do the Structural analysis on excavator bucket with different materials at various loads and find out the behavior of the modified excavator bucket by comparing with exsiting bucket model. Here in this analysis of 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 two types of materials SM50A & SCNCrM2B and the action of various stress and strains on the excavator bucket at various loads were investigated.

Table-3: Obtained Result

Material	Existing Model	Optimised Model
	Medium Carbon Steel	SM50A (Steel Alloy)
Equivalent Von-Misses Stresses	314.83 Mpa	191.1 Mpa
Total deformation	3.1182 mm	2.677 mm
Normal stress	92.30 Mpa	81.9 Mpa
Stress intensity	312 Mpa	206 Mpa
Shear stress	98.22 Mpa	67.31 Mpa

Following graph is showing the results of these two different materials

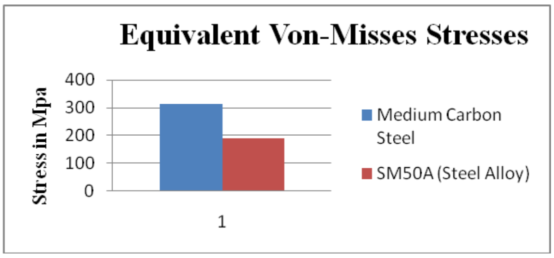

Chart -1: Equivalent Von-Misses Stresses

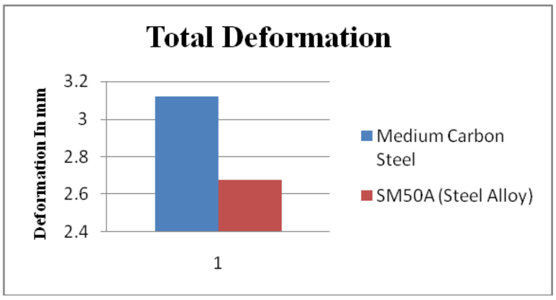

Chart -2: Total Deformation

6. CONCLUSION

The excavator bucket is developed to perform excavation task for heavy construction work. Based on our project work, we have concluded that the capacity of bucket have been increased up to 627 kg from 300 kg. We have modified design and increased capacity also by reducing one tooth to full feel the functional requirements. By using different material properties and based on static force loads, finite element analysis is carried out for excavator bucket By using the results the stress points are carried out and the optimized bucket model is created. By using that model the fatigue life of bucket calculated which is above 1000hrs which is much desirable and required.

We have increase the volumetric capacity as well as reduce the total deformation of modified bucket and also reduce the equivalent von-misses of the modified bucket. Also based on the analysis part, our new design is also safe to carry this much load while in fully operating condition

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