Conference Article

Comparison of Backhoe Loader Bucket Teeth Produced by Welded and Casting Methods Using Finite Element Analysis

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Abstract

The teeth in the Backhoe-Loader bucket are exposed to different dynamic loading conditions throughout the machine's usage. According to the manufacturer, the bucket teeth can be produced as dual piece, welded together, or directly cast. Due to the distinctive design of the bucket tooth, reading stress and strain values on the tooth is challenging. Therefore, it is essential to conduct a structural analysis of the design using the finite element method in a computer environment. In this study, the change in stress-strain on the bucket tooth resulting from transitioning from the currently produced dual-piece design to a cast design has been examined. As a result of this change, it is anticipated that the cast tooth will be more robust compared to the welded manufacturing, and the results have been compared accordingly.

Keywords: Backhoe-Loader, Bucket tooth, Loadcell, Structural Analysis, Finite Element Analysis

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1. Introduction

The high-performance construction machinery with intricate mechanism and automated construction activities ensures a rapidly increasing growth rate in the earth-moving machine industry. A backhoe-loader bucket is a heavy equipment attachment specifically crafted for use in site excavation. Attachments like buckets can be connected to backhoe-loaders, excavators, tractors, and similar types of equipment.[1]

Backhoe-loader buckets are constructed from solid steel and typically feature teeth protruding from the cutting edge to break up hard materials and prevent wear and tear on the bucket. The backhoe-loader bucket tooth must endure substantial loads of materials such as wet sol and rock, and it is also exposed to abrasion wear caused by the nature of soil particles when the tooth works to break up material. Typically, alloy steel is employed in crafting a backhoe loader bucket tooth, and hard facing with wear-resistant materials can be applied to enhance its lifespan against abrasive wear.[2]

In the mining sector, there's a significant economic impact due to the need to replace a backhoe-loader tooth roughly every working year, leading to increased costs. [3] This study compares the strength of a double-piece bucket tooth design produced by the forging method with a bucket tooth design produced using the casting production method. Both designs have been modelled using the finite element approach. The forces applied to the teeth were obtained with test data reflecting the machine's field working conditions in accordance with the ISO 6015:2007E standard.

Figure 1. Bucket breakout test position

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The structural analysis of various bucket tooth designs (forged-casting) was conducted using MSC Marc, a finite element package program. A load cell was applied to a model chosen from the designs, and the accuracy of the analysis method was assessed.

2. Materials and Methods

In this section, the methods used to compare alternative designs of backhoe loader work machines in terms of strength will be shared in detail. The bucket teeth, which are currently produced as a dual piece welded design using the finite element method, were compared with those produced as a cast design. Stress distributions on the structure were compared. The force value providing the input for the analysis was measured using a loadcell in accordance with ISO 6015:2006E standard specifications. The analysis results were examined comparatively in a computer environment.

2.1. Geometric Modelling & Description

To explore the stress distribution in the cutting tooth, the author established a finite element model, considering the solid models depicted in Figure 2. The cutting tooth is integrated into the holder as a detachable component. The holder, essentially a steel rectangular structural tube, may be composed of a different type of steel compared to the remaining parts of the structure. The existing model features a bucket tooth composed of two separate pieces, manufactured through a forging process, with the parts joined together by welding. The proposed design aims to produce the bucket tooth as a single-piece casting in contrast to the current model.

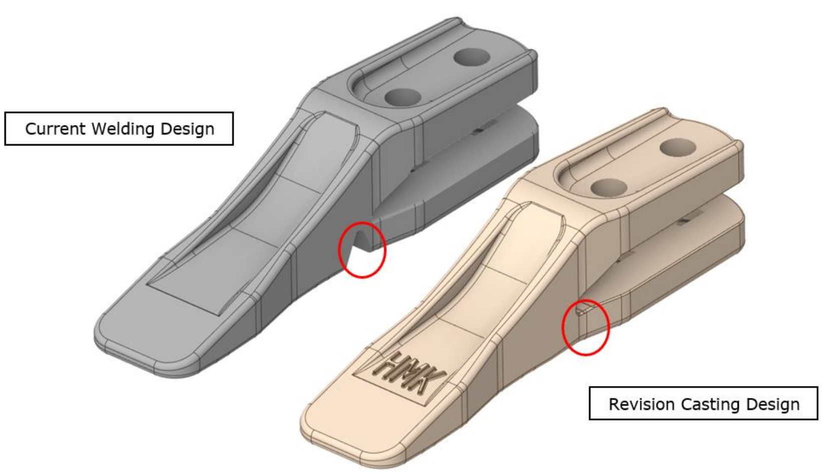

Figure 2. Current and revision solid models view

The raw material for the existing "Forged Design" components in the structure is taken as SAE5135 (DIN 37Cr4). The yield strength of the raw material has been evaluated based

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on σ_y=630 MPa. The IS0 17804 standard is referenced for the selection of casting material, and the yield strength of the raw material is determined at σ_y= 700 MPa.

The Finite Element Method (FEM) is a numerical analysis method commonly used for mathematical modelling, allowing for various analyses of a substance with any physical quantity. This method divides a large system into smaller components called finite elements to discretize the space where the equation is solved.

The finite element mesh of cutting tooth is of free type using tetrahedral elements and so this solid structure is divided into 105.000 finite elements.

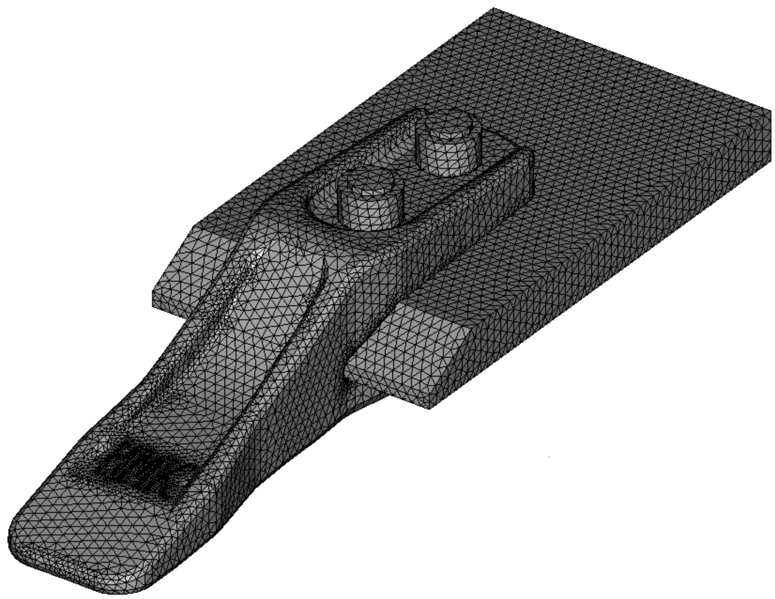

Figure 3. Geometrical model of tooth of meshing in finite element analysis

2.2. Boundary Condition

Comparative strength analyses have been conducted for the Beko-loader bucket teeth with welded and cast designs. The back legs and the bucket of the machine were grounded, and the Beko-loader was secured. The force providing input as a boundary condition was obtained from test data using a load cell. The tests were conducted in accordance with ISO 6015:2006E standards, avoiding any slipping or rolling conditions. All cylinders were positioned to create maximum moment.[4]

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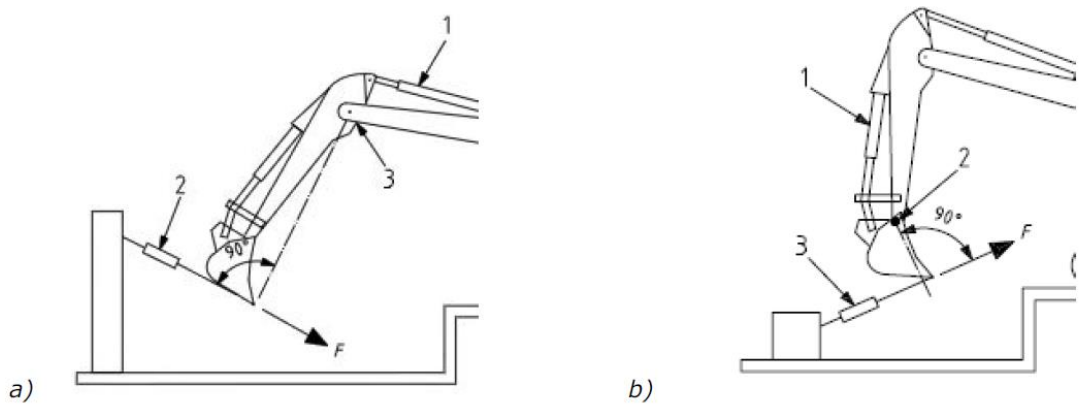

Figure 4. Placement of load cells according to ISO 6015:2007E standard

The test results obtained for the bucket breakout force are shared below. By examining the test results, it is determined that the maximum force that the cylinders can generate is 53 kN.

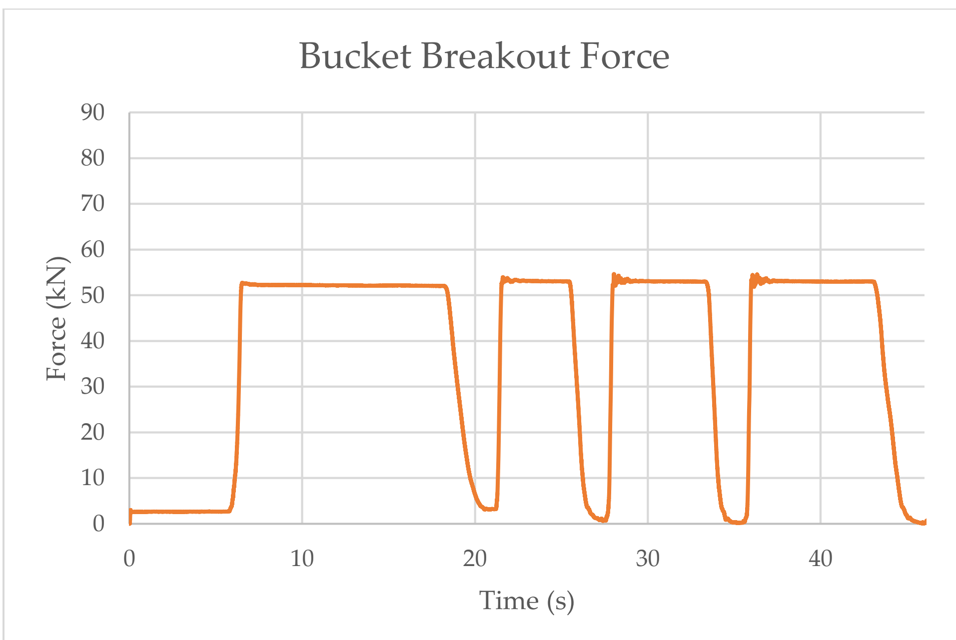

Figure 5. Bucket breakout force test results

2.3. Analytical Calculation

A manual verification will be conducted to validate and compare the analysis results. For this purpose, the bending stress theorem and shear stress theorem will be employed. Simplifications have been made on the part at the tip of the tooth where the force is applied, resulting in the geometry.

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The second moment value for the section is,

$$I_{xx} = \frac{1}{12} \times a^4 \tag{1}$$

Here, a represents the side length of the square. Taking A = 60 mm,

$$I_{xx} = \frac{1}{12} \times (60\ mm)^4$$

$$I_{xx} = \frac{1}{12} \times 1296000^4$$

$$I_{xx} = 1080000\ mm^4$$

Now, we can calculate the bending stress,

$$M = F.d \tag{2}$$

Here, F= 53 kN ve $d = \sqrt{30^2 + 30^2}$ the distance from the center where the force is applied,

$$d \approx \sqrt{1800}\ mm \approx 42{,}43\ mm$$

$$M = 53\ kN \times 42{,}43\ mm \approx 2249{,}79\ kN.mm$$

Bending stress (σ_b),

$$\sigma_b = \frac{M}{I_{xx}} \times y \tag{3}$$

Here, y represents the axial distance of a point on the section $y = \frac{a}{2} = \frac{60}{2} = 30\ mm$

$$\sigma_b = \frac{2249.79\ kN.mm}{I_{xx}} \times 30\ mm \approx 0{,}0658\ kN/mm^2$$

$$\sigma_b = 0{,}0658 \frac{kN}{mm^2} \times 10^3 \frac{N}{kN} \times 10^{-6} \frac{m}{mm^2} \approx 65{,}8\ MPa$$

Shear stress (τ),

$$\tau = \frac{VQ}{Ib} \tag{4}$$

Here:

- V is the shear force at the section,
- Q is the area moment of inertia between the section radius,
- I is the moment of inertia of the section,
- b is the width of the section.

The cross-sectional area is $60 \times 60 = 3600\ mm^2$ the force $V = F = 53\ kN$.
We need to find the area moment (Q) between the section radius and the centroid. For a square, the distance from the center of the section to a corner is the section radius. Therefore $Q = 30\ mm$. The width (b) is the length of the section, which is 60 mm .

$$\tau = \frac{(53\ kN) \times (30\ mm)}{(108000\ mm^4) \times (60\ mm)}$$

$$\tau = \frac{1590\ kN.mm}{64800000\ mm^5}$$

$$\tau \approx 0{,}0245\ kN/mm^2$$

$$\tau \approx 0{,}0245\ kN/mm^2 \times 10^3 N/kN \times 10^{-6} m/mm^2$$

$$\tau \approx 24{,}5\ MPa$$

In finite element analysis programs, stress values that we observe are calculated according to the Von Mises stress theorem. This theorem combines the effects of bending and shear stresses in the structure, but it is not a simple addition of these stresses; rather, they are combined.

$$\sigma_{VM} = \sqrt{{\sigma_b}^2 + 3\tau^2} \tag{5}$$

$$\sigma_{VM} = \sqrt{(0{,}0658\frac{kN}{mm^2})^2 + 3 \times (0{,}0245\frac{kN}{mm^2})^2} \approx 0{,}1437\ kN/mm^2 \approx 143{,}7\ MPa$$

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3. Result

The application of finite element analysis has been identified as a means to improve the design of the bucket tooth. This approach facilitates the direct comparison of welded and cast fabricated designs, allowing for the evaluation of how key parameters affect the performance of the tooth. In the analysis results, regions with high stress values were examined in both designs. The solution element node located in this region was selected, and the stress values were compared in the results. As a result of this comparison, an approximately 15% reduction in stress was observed in the part to be produced as casting compared to the part to be produced by welded manufacturing. The information obtained from the analysis can be useful in practical applications.

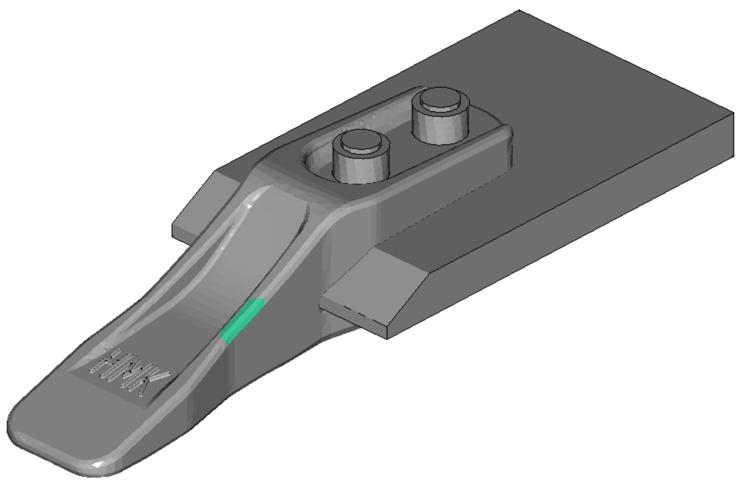

Figure 6. Stress measurement area

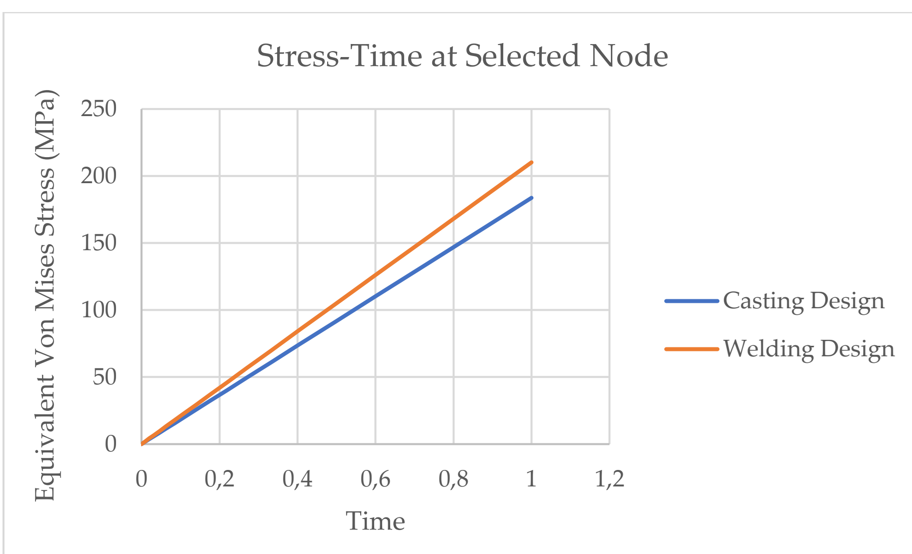

Figure 7. Stress-time graph at selected node

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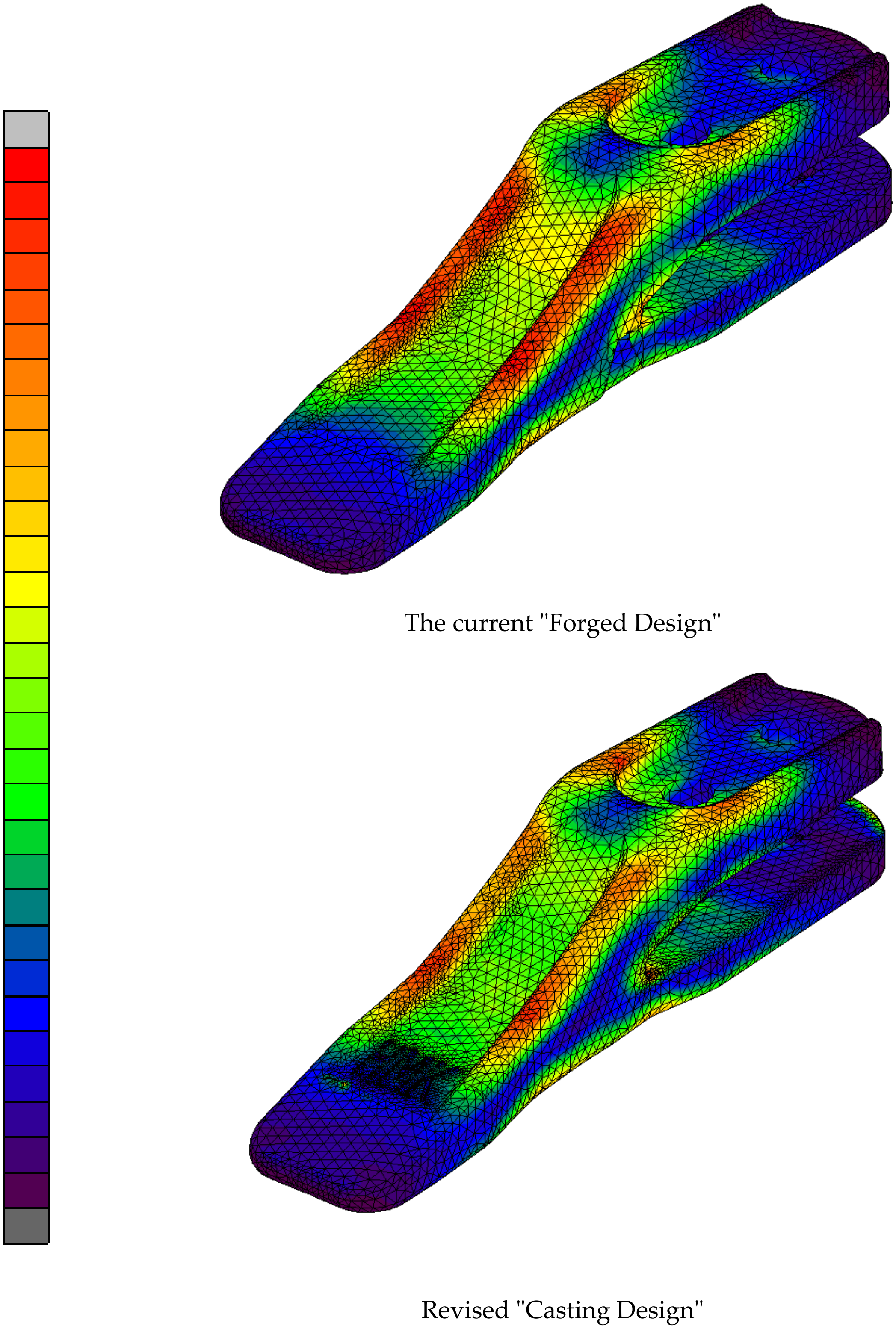

Figure 8. Von Mises stress distribution

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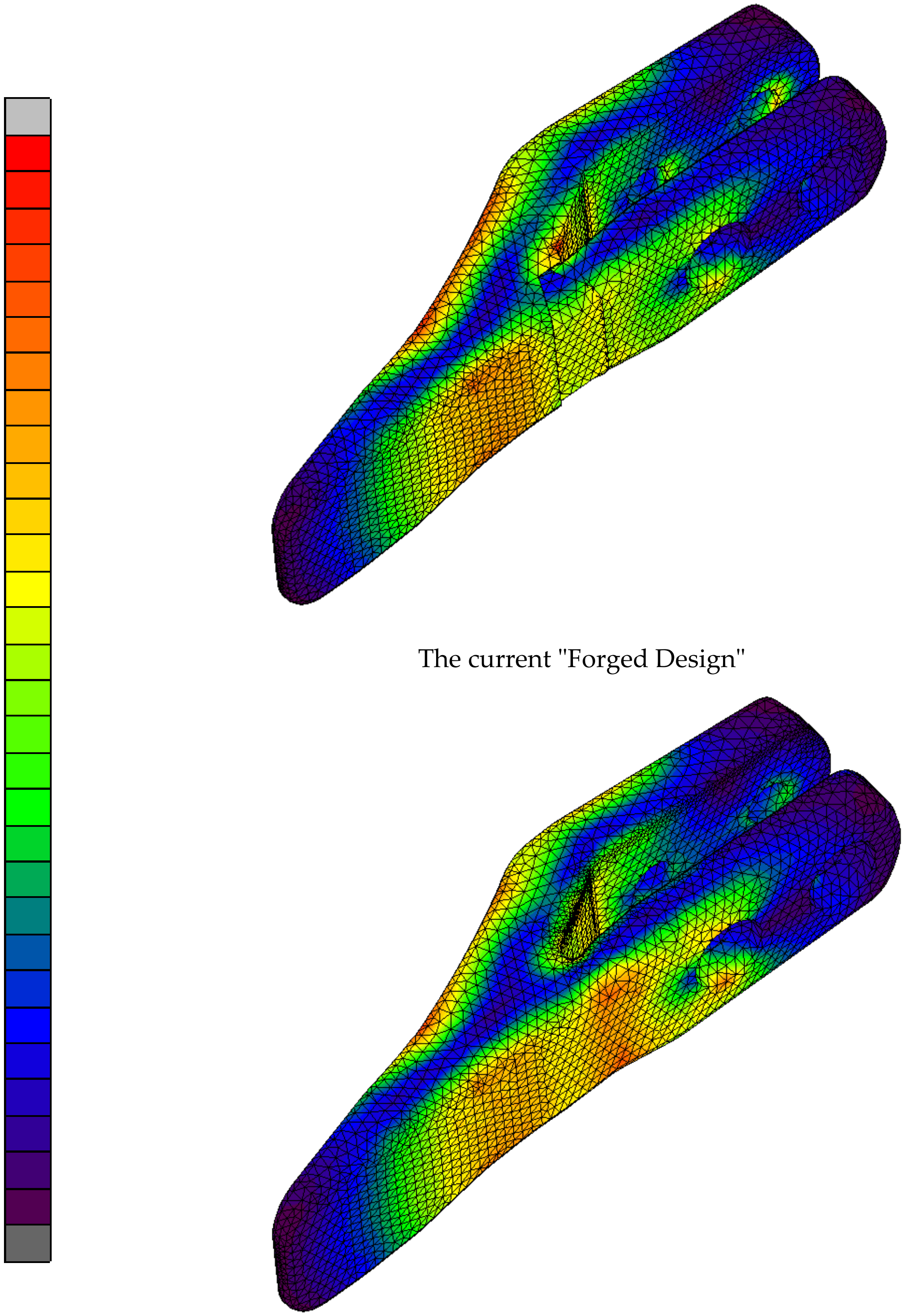

The current "Forged Design"

Revised "Casting Design"

Figure 9. Von Mises stress distribution

In order to have a detailed view of compressive and tensile stresses in the structure, Maximum Principal stresses in the raw materials have also been examined.

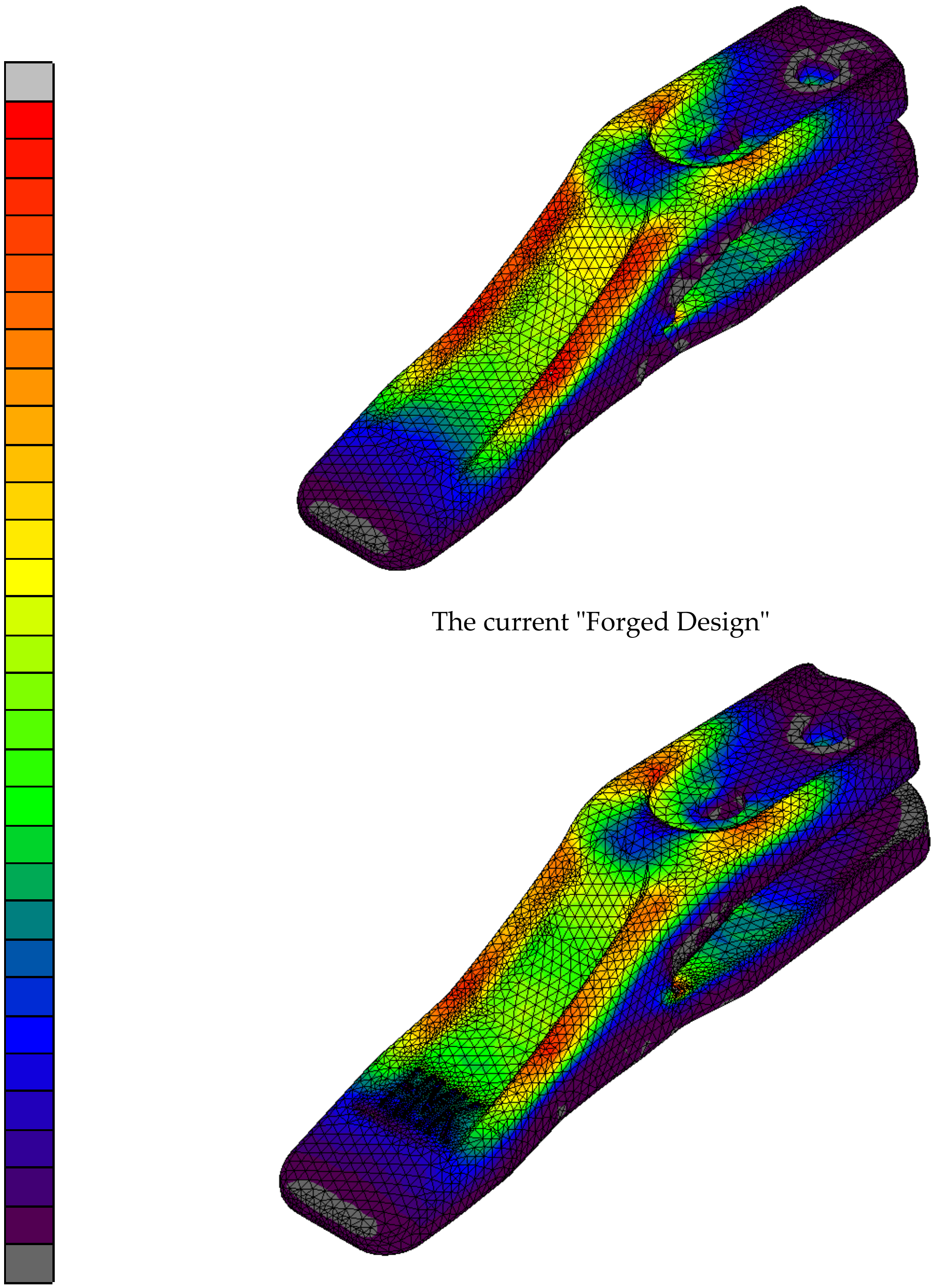

Figure 10. Maximum Principal Stress distribution

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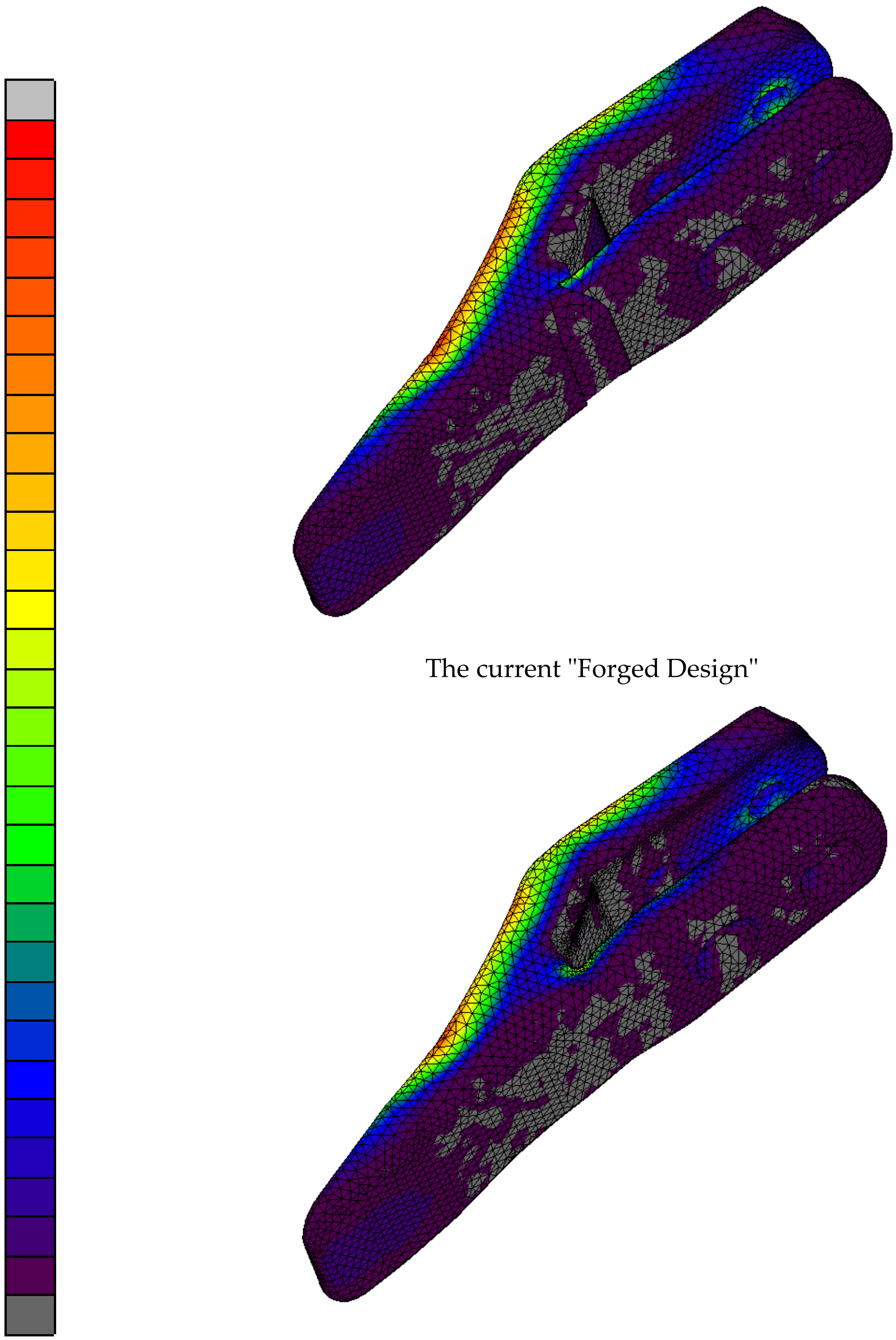

The current "Forged Design"

Revised "Casting Design"

Figure 11. Maximum Principal Stress distribution

4. Discussion and Conclusion

In this study, the strength of bucket teeth produced using the dual-piece manufacturing method was compared to those produced as a single piece through the casting production method. The force input used in the analysis was calculated using a loadcell, and a finite element method was employed to create the analysis model. Due to the unique and oval shape of the bucket tooth, measuring strain using strain gauges is quite challenging. Therefore, the analysis of new designs specific to the bucket tooth using the finite element method is crucial. In light of the analysis results, it has been observed that the design produced as a casting (weld-free) exhibits higher strength compared to the design produced through welded manufacturing. During the analysis of the cast part, it was assumed that the structure was produced in accordance with casting standards and that no production errors were made.

5. Acknowledge

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