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Weldment to Casting Conversion Using Topology Optimization

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Abstract: The automobile and off highway industries grapple with dilemma of making a required component out of a weldment by welding different plates together or making a single component using a casting manufacturing process. The decision is always based on many parameters viz. volume of manufactured components, tooling cost involved, dimensional stability required, cost of welding, fatigue strength required etc. As the volume of the manufactured components increases, the cost of casting and its tool goes down and hence it makes sense to convert the weldment into a casting. A traditional method to do this is to convert the weldment into a casting based on functionalities and experience. In this paper, a topology optimization based approach is used to understand and decide the most optimal usage of the material based on the different constraints. In this paper, considerations of weldment to casting conversion, usage of topology optimization to arrive at final design and strength and fatigue life calculation are discussed.
Keywords: Weldment, Topology Optimization, casting, Design for Manufacturability

I. INTRODUCTION

The weldment is a term used in Off highway industry for a subassembly which comprises of several components welded together. As number of parameters involved in manufacturing a quality weldment increases, the sources of error also increase. The process control becomes extremely important. To reduce this process control, it is important to minimize the sources of error. The conversion of a weldment to casting is one such step where the process control activity can be reduced.

The cost of weldment is dependent on the following parameters:
Number of weldments being manufactured per year, Number of parts involved in weldment, Length of weld inside the weldment Cost of welding, Cost of material handling etc.

A. Business Challenge

The business challenge for this virtual experimentation work is, to convert the weldment of 9 different parts to single part using casting process and by using topology optimization to ensure the key parameters like stiffness, strength and durability are met.

B. Objective

1) To reduce the cost of weldment by converting the multi parts weldment into single casting component
2) To effectively use the design space and material to get optimum utilization using topology optimization tools
3) To equal or better the performance of a casting compared to weldment in terms of weight, stiffness, strength and fatigue life

C. Methodology

1) Analyze the current weldment for known loading conditions
2) Define design space of a weldment. Define the non design and design space depending on the manufacturing and assembly constraints
3) Use topology optimization to generate different design ideas which meet the stiffness and strength characteristics of the weldment.
4) Apply the DFM (Design for Manufacturability) and DFA (Design for Assembly) considerations to filter out the designs for final casting
5) Develop a casting in CAD environment using CREO.
6) Validate it virtually for stiffness, strength and fatigue life and weight of components
7) Compare the weldment and casting based on the above mentioned parameters

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The weldment under consideration here is the Bell Crank Lever which is used in Off-highway industry. The lever is typically used with two vertical links connected to either end of the lever. The load on the lever is due to the wheel or any other components like hydraulic cylinders

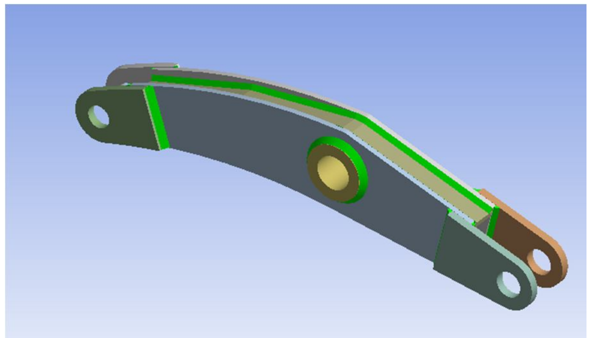

Figure 1 : Bell Crank Lever Used in Off-Highway Industry

As shown in Figure 1, the weldment for Bell Crank Lever consists of 9 different components.

II. LITERATURE REVIEW

Topology optimization: theory, methods and applications, [1], In this book, the basic overview of basic ingredients of material distribution method for finding the optimum layout of a linearly elastic structure is discussed. Here the lay out of the structure refers to the shape, size and topology optimization, all three problems simultaneously.

Allaire G, Jouve F, Maillot H (2004), [2], discuss about minimum stress design in structural optimization. The homogenization method is extended to such a framework and yields an efficient numerical algorithm for topology optimization. The main idea is to use a partial relaxation of the problem obtained by introducing special microstructures which are sequential laminated composites.

D. Spath, W. Neithardt, C. Bangert, [3] in this paper the importance of structural optimization and its integration into the design process from the first drafts to the final product has been described. The paper also describes shape, size and topology optimization techniques. It describes the procedure of the topology and shape optimization.

Engineering report, [4] in this report, analyses and advanced techniques for applying material, architecture and design were used to develop a non-traditional lightweight frame. The results given in this report can be used as a guideline to develop lightweight structures. In this report design methodology has also been described which gives the generic illustration of topology design process.

The objective of the project mentioned in this report is to design a lightweight frame with the ultimate goal of achieving 25% weight reduction from baseline, while maintaining baseline structural performance. Report describes the entire design process consisting of topology and shape optimization of baseline frame structure.

III. CONVERSION OF WELDMENT TO CASTING

A. Factors Considered for Weldment to Casting Conversion

For the current work, bell crank lever of the off highway machine is considered for the weldment to casting conversion. As shown in the figure, the bell crank lever consists of 9 different parts or components. The complete weldment is made up by welding all the components together.

Below are important factors which impact the cost of the weldment

Cost of material handling due to more number of parts and longer BOM, Stringent process control parameters to get the weldment within acceptable tolerance level, Cost of welding Weight – Direct material cost. Considering all these factors, it makes engineering and financial sense to convert this weldment into a casting.

B. Material Selection for Casting

The selection of material for casting is based on static strength requirement, fatigue strength requirement, resistance to shock, wear and corrosion, ductility, machinability and capability to get complex shapes

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C. Material Properties for Weldment and Casting

The material properties of the weldment steel and casting are from internet source. [9-8-9]

TABLE I: Material Properties of Steel and Casting

	Young's Modulus (MPa)	Yield Strength (MPa)	Ultimate Strength (MPa)
ASTM A572 Grade 50	201,000	345	448
Nodular Cast Iron – 80-55-06	161,000	379	552
Nodular Cast Iron – 100-70-03	161,000	586	758

There are two material options that are considered for strength and fatigue life calculation of the casting.

IV. WELDMENT TO CASTING CONVERSION USING TOPOLOGY OPTIMIZATION

A. Three Dimensional Topology Optimization of Bell Crank Lever

Design Objective = Minimize Weighted compliance

Constraints
1) Volume fraction = 0.3
2) Upper bound for von Mises strain = 1800 με for four load cases
3) Design variable = Lever volume

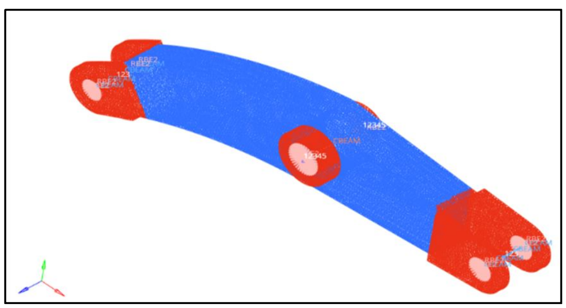

Figure 2 : Topology Optimization Model for Bell Crank Lever

B. Load and Boundary Condition Details

Complete model has been considered for bell crank lever topology optimization. The central pin where the lever is installed on the larger assembly is considered as revolute joint i.e. the rotational DOF is kept free at central pin. Other pin locations are considered for force application and vertical constraints alternatively. The load on the bell crank lever is approximately 200 kN. Additional load of 5% is considered in axial direction of lever to account of any misalignments in the assembly.

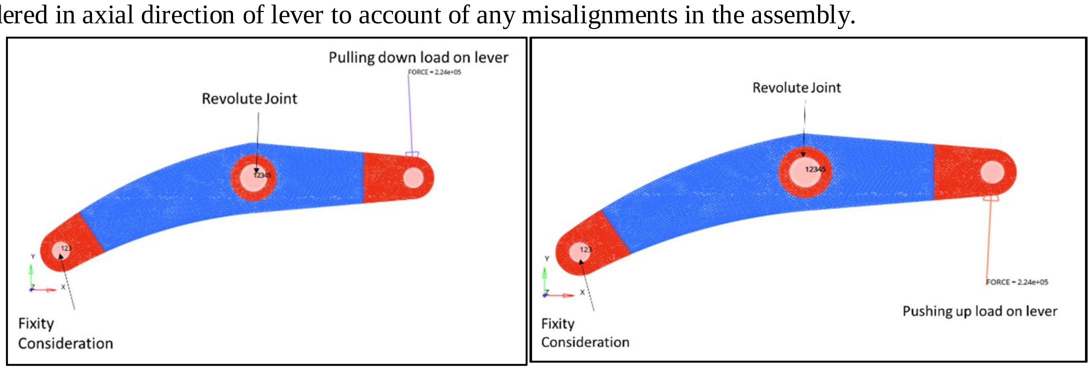

Figure 3 : Loads and Boundary Condition – LC-1 and LC-2

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C. Topology Optimization of Bell Crank Lever using Draw Direction

For manufacturable design using topology optimization, it is important to provide the draw direction. The draw option 'SINGLE' has been used as single die will be used for casting the Bell Crank Lever. This die will be sliding in the given drawing direction. The anchor node and the first node define the drawing direction as shown in Figure 4

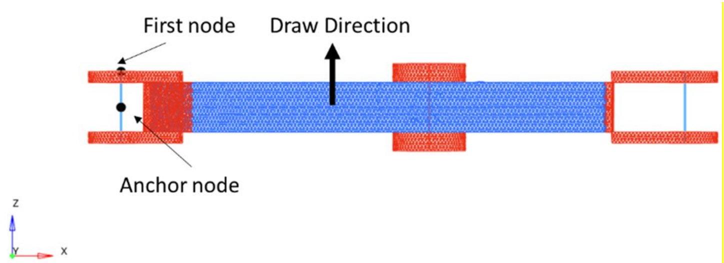

Figure 4 : Draw Direction for Casting Process

D. Definition of Design Space and Constraints

Design Space – Shown in blue color

Non Design Space – Shown in red color

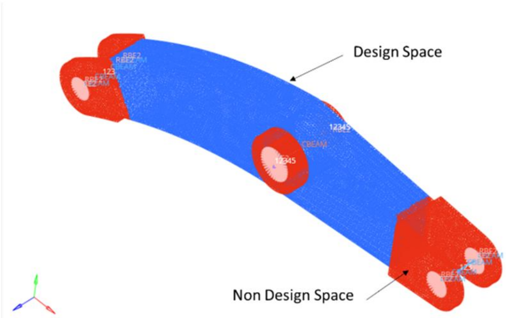

Figure 5: Definition of Design Space and Non Design Space

E. Topology Optimization – Results and Discussion

The density plot of the solution is shown in below Figure 7. The topology optimization shows a hole in the web of the suggested cross section.

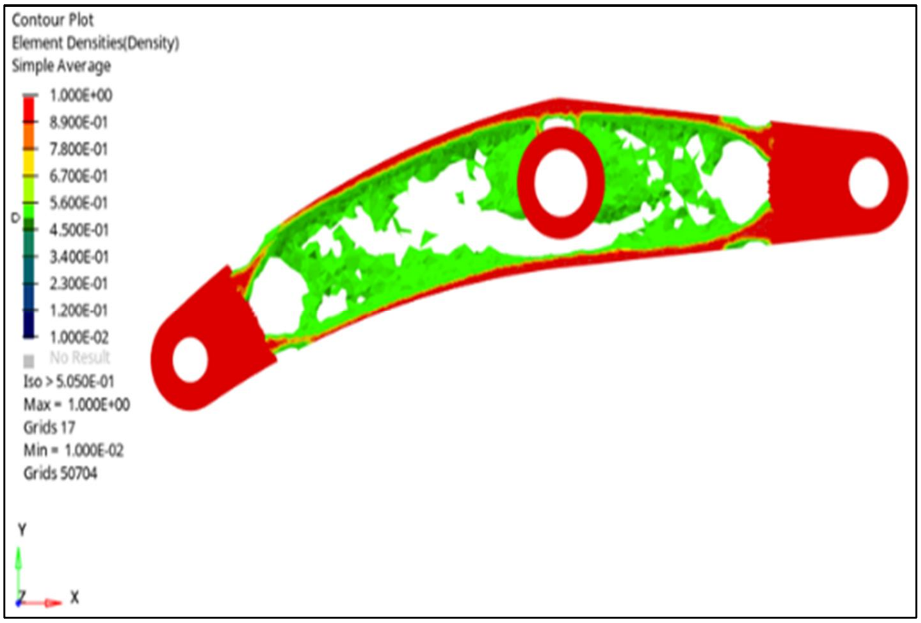

Figure 6 : Results – Topology Optimization – Density Plot @ 0.5

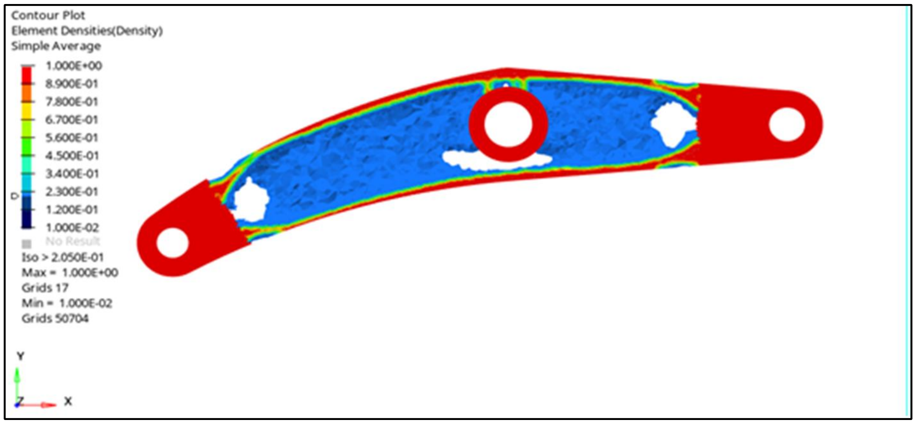

Figure 7 : Results – Topology Optimization – Density Plot @ 0.2

The red colored regions in above figure are with density of 1. That means those locations are required for the component to function normally. No material can be removed from those regions. The material can be removed from the lower density regions.

F. Consideration of Design for Manufacturability (DFM)

1) Continuous material distribution for casting web

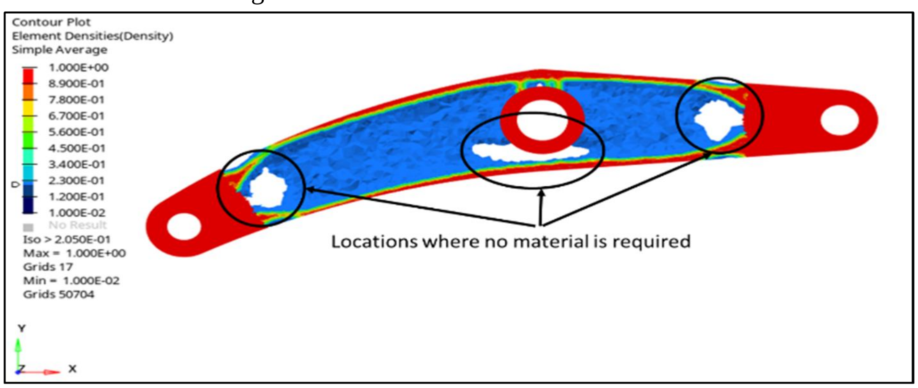

Figure 8 : Results – Topology Optimization – Material distribution

2) Uniform thickness of flange of casting

3) Consideration of draft angle for casting

Considering the design for manufacturability (DFM) considerations and constraints from the casting process, the CAD model of the bell crank lever casting is built in CREO, as shown in Figure 9.

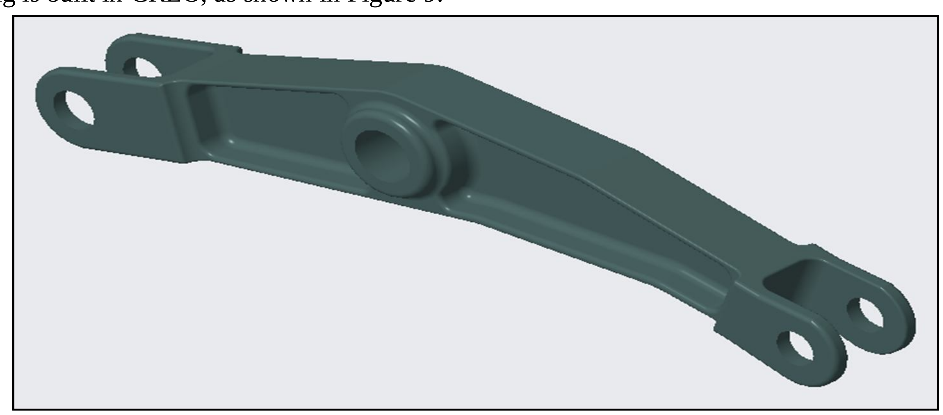

Figure 9 : Final CAD Model of Casting

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V. FINITE ELEMENT ANALYSIS OF WELDMENT AND CASTING

A. Loads and Boundary Conditions

The loads and boundary conditions used for finite element analysis are same as topology optimization.

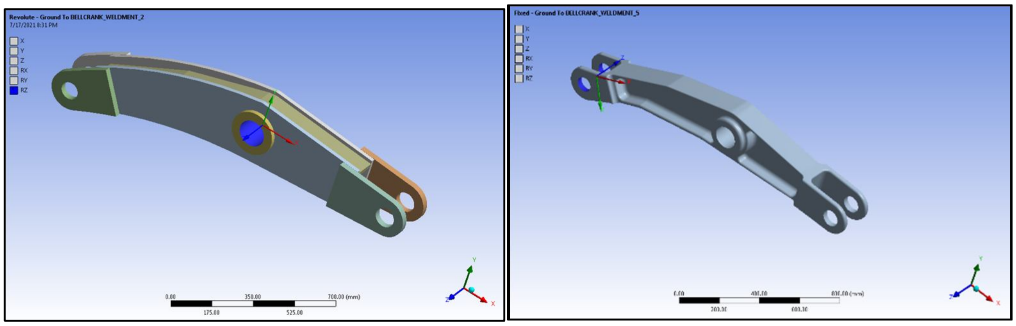

Figure 10 : Boundary Conditions

B. Results Discussion

1) Static Analysis Results – Weldment

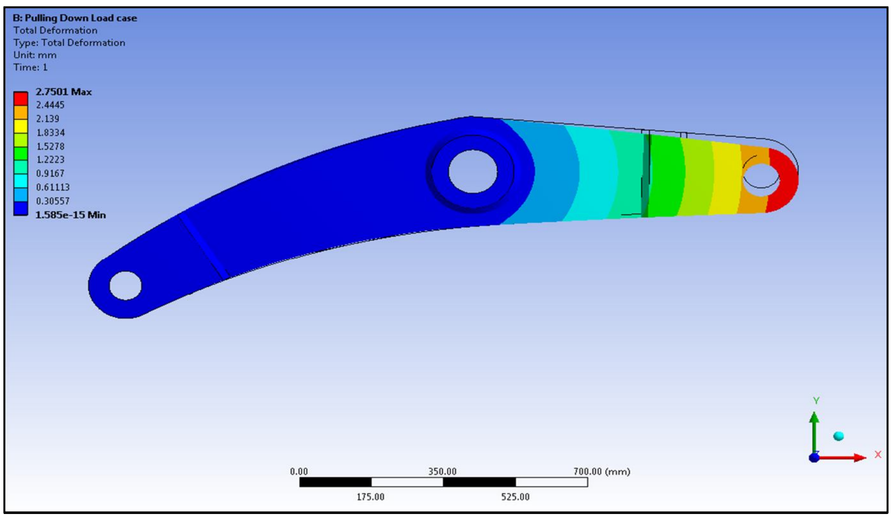

Figure 11 : Total Deflection – Pulling Down LC

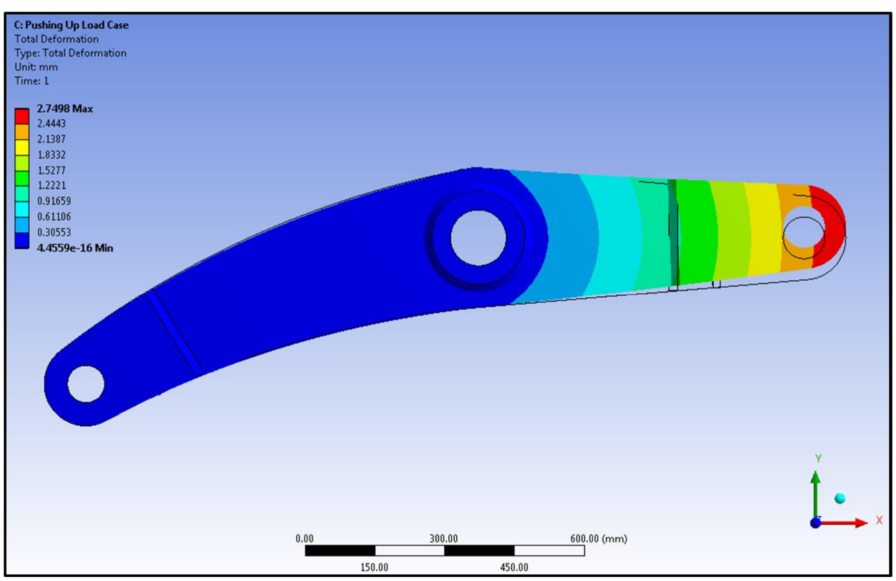

Figure 12 : Total Deflection –Pushing Up LC

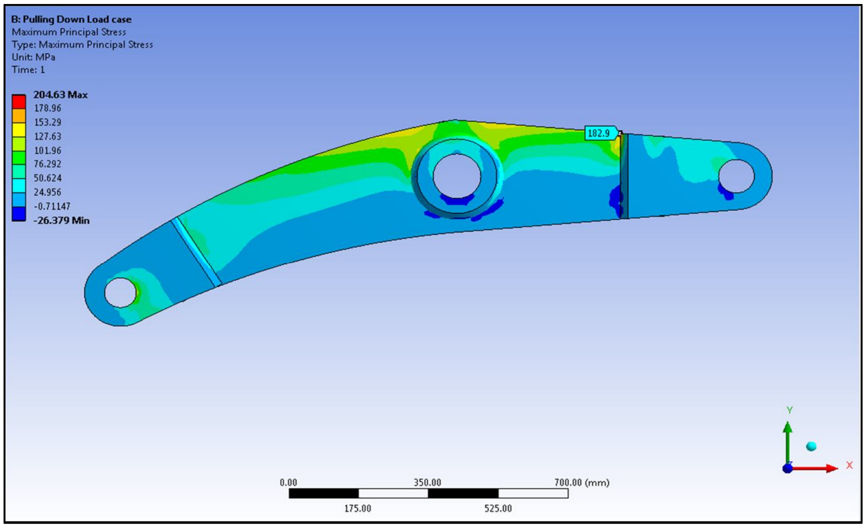

Figure 13 : Maximum Principal Stress – Pulling Down LC

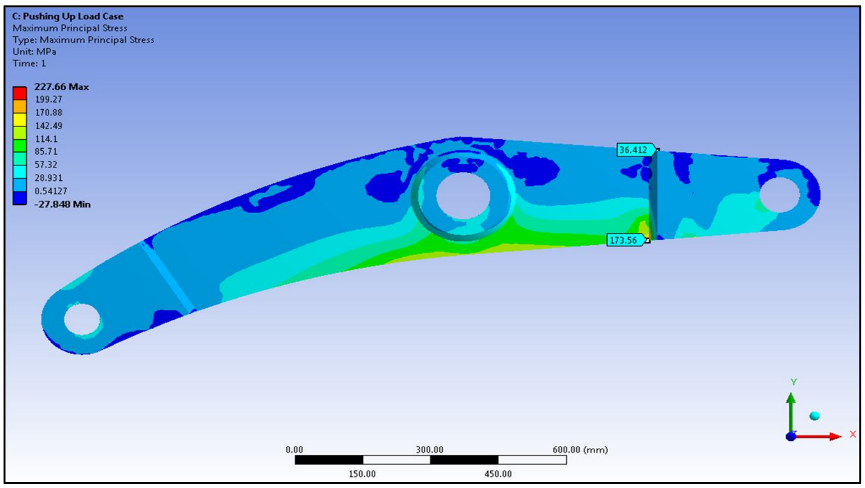

Figure 14 : Maximum Principal Stress – Pushing Up LC

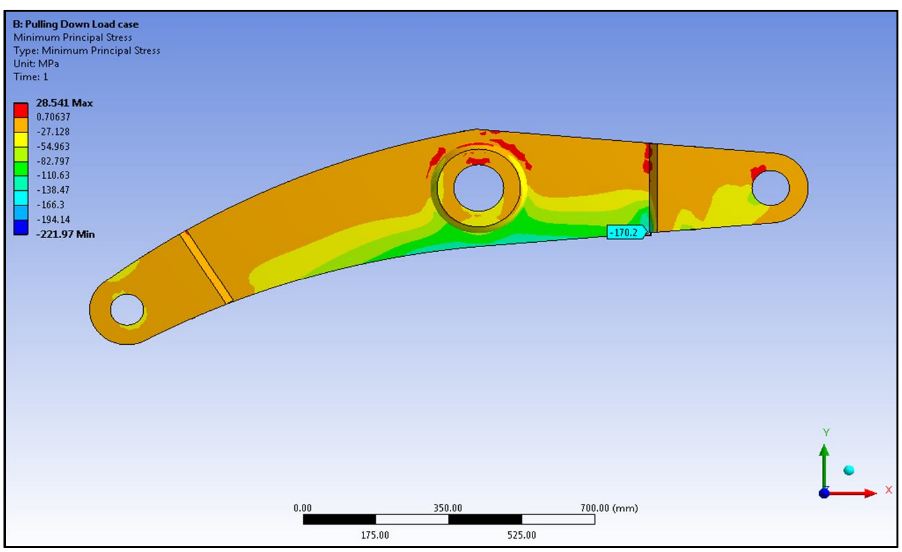

Figure 15 : Minimum Principal Stress – Pulling Down LC

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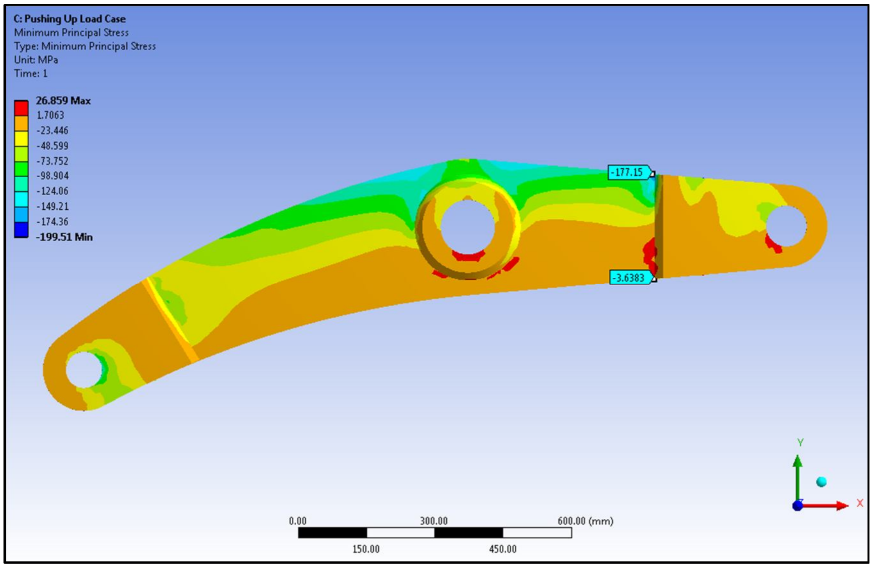

Figure 16 : Minimum Principal Stress – Pushing Up LC

2) *Static Analysis Results – Casting*

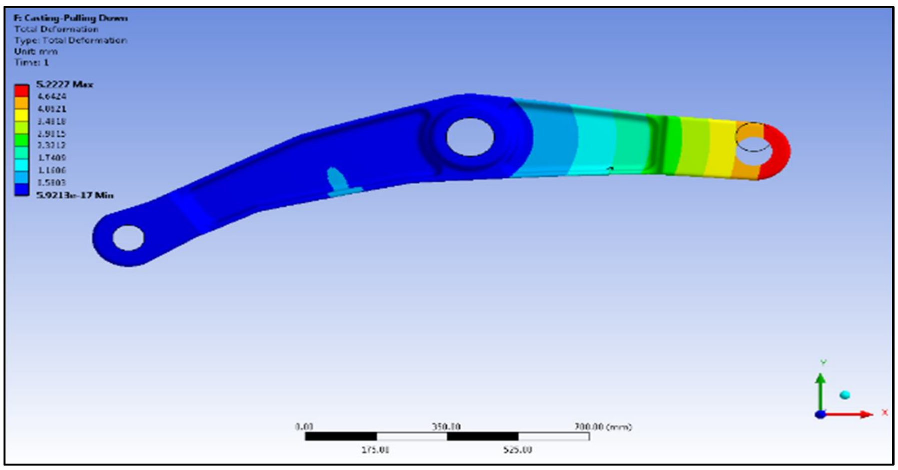

Figure 17 : Total Deflection – Pulling Down LC

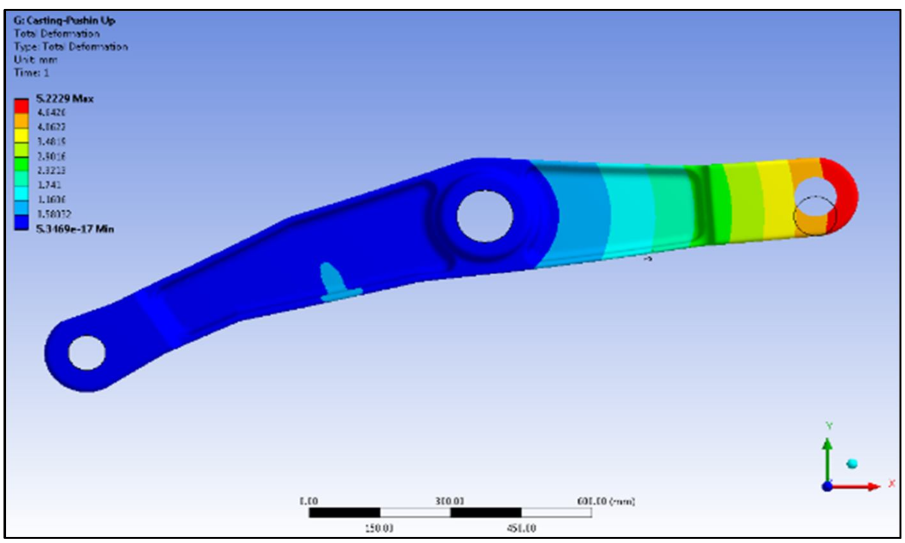

Figure 18 : Total Deflection –Pushing Up LC

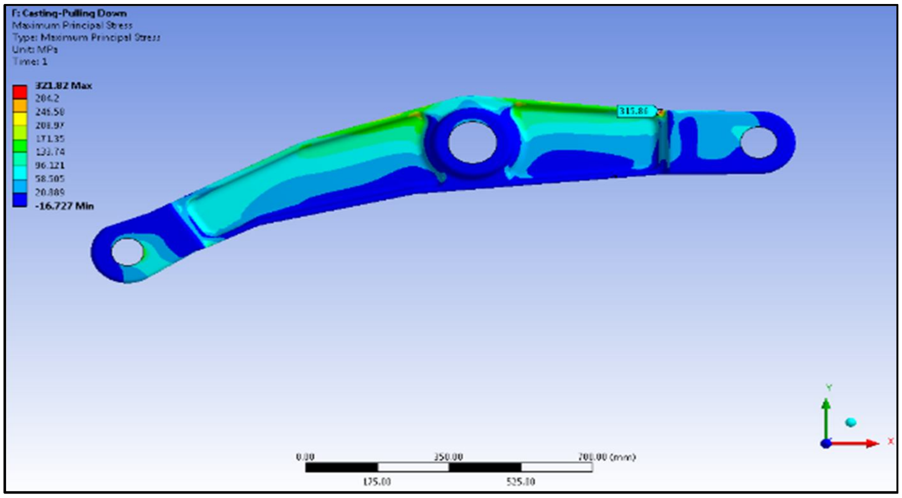

Figure 19 : Maximum Principal Stress – Pulling Down LC

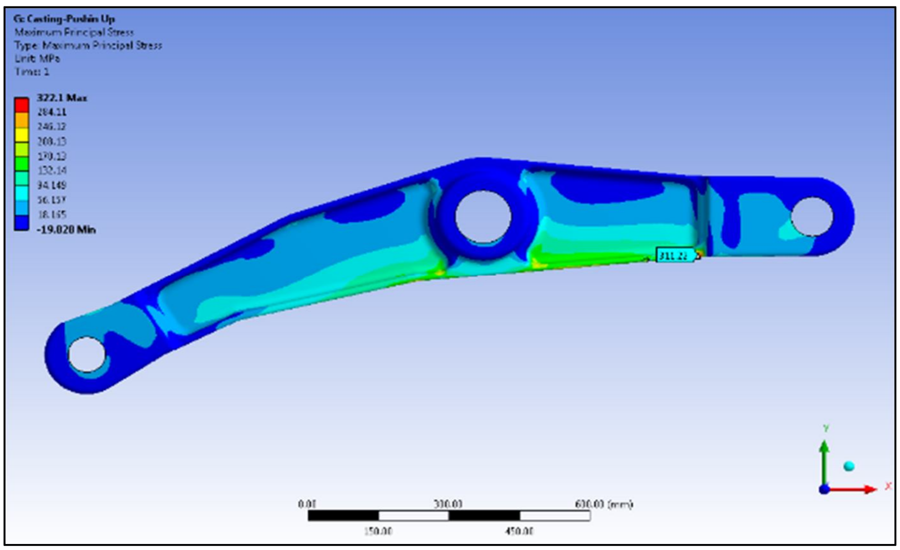

Figure 20 : Maximum Principal Stress – Pushing Up LC

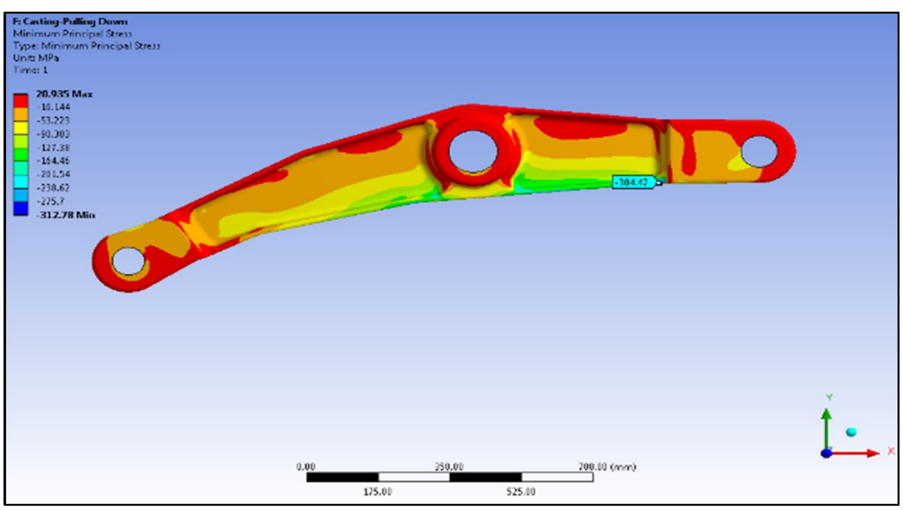

Figure 21 : Minimum Principal Stress – Pulling Down LC

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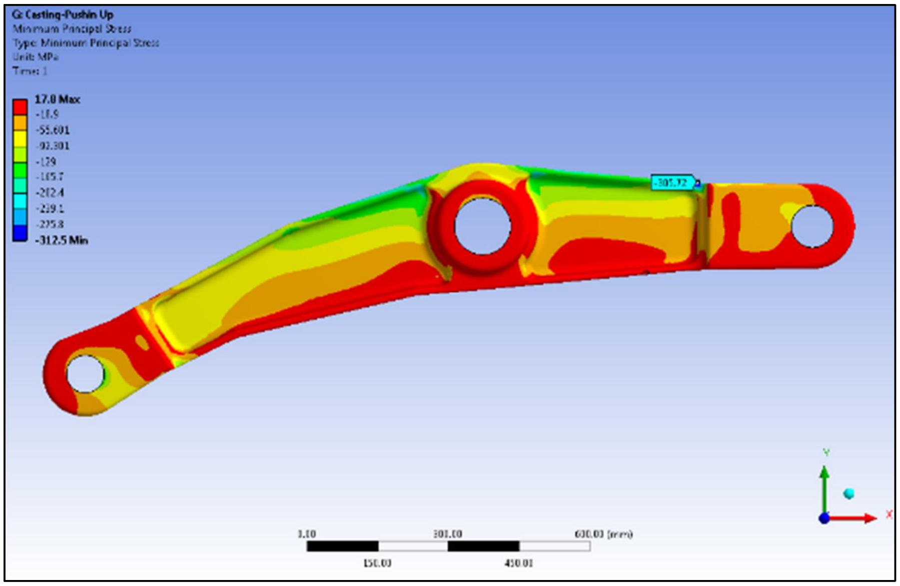

Figure 22 : Minimum Principal Stress – Pushing Up LC

C. Results Discussion

The bell crank level is observed to have more deflection than the weldment. However, the factor of safety with 100-70-03 nodular cast iron is almost similar to weldment.

Summary of results

Table II: Result Summary – Weldment Vs Casting

Parameter	Weldment	Casting (80-55-06)	Casting(100-70-03)
Total Deflection	2.7 mm	5.2 mm	5.2 mm
Weight	215 kg	176 kg	176 kg
Factor of Safety on Yield Strength	1.98	1.27	1.91

VI. CONCLUSION

A. The total deflection of the bell crank lever in weldment form is 2.75 mm and in casting form is 5.2 mm. The increase in deflection can be accepted as there is no assembly constraint.

B. The factor of safety for weldment is 1.98 near weld. At similar location on casting the factor of safety is 1.23 using 80-55-06 grade and 1.91 using 100-70-03 grade of nodular cast iron.

C. Final weight saving from the weldment to casting conversion is almost 40 kg which is 25% of total weight of weldment.

VII. ACKNOWLEDGEMENT

I consider it a privilege to express through the pages of this report, a few words of gratitude in depth and respect to all those, who guided and inspired for the completion of this report.

It is indeed a great pleasure and moment of immense satisfaction for me to express my sincere thanks to the guide Prof. Mrs Pradnya Kosbe. She has given me valuable guidance and advice from time to time which has helped me a lot while completing my task.

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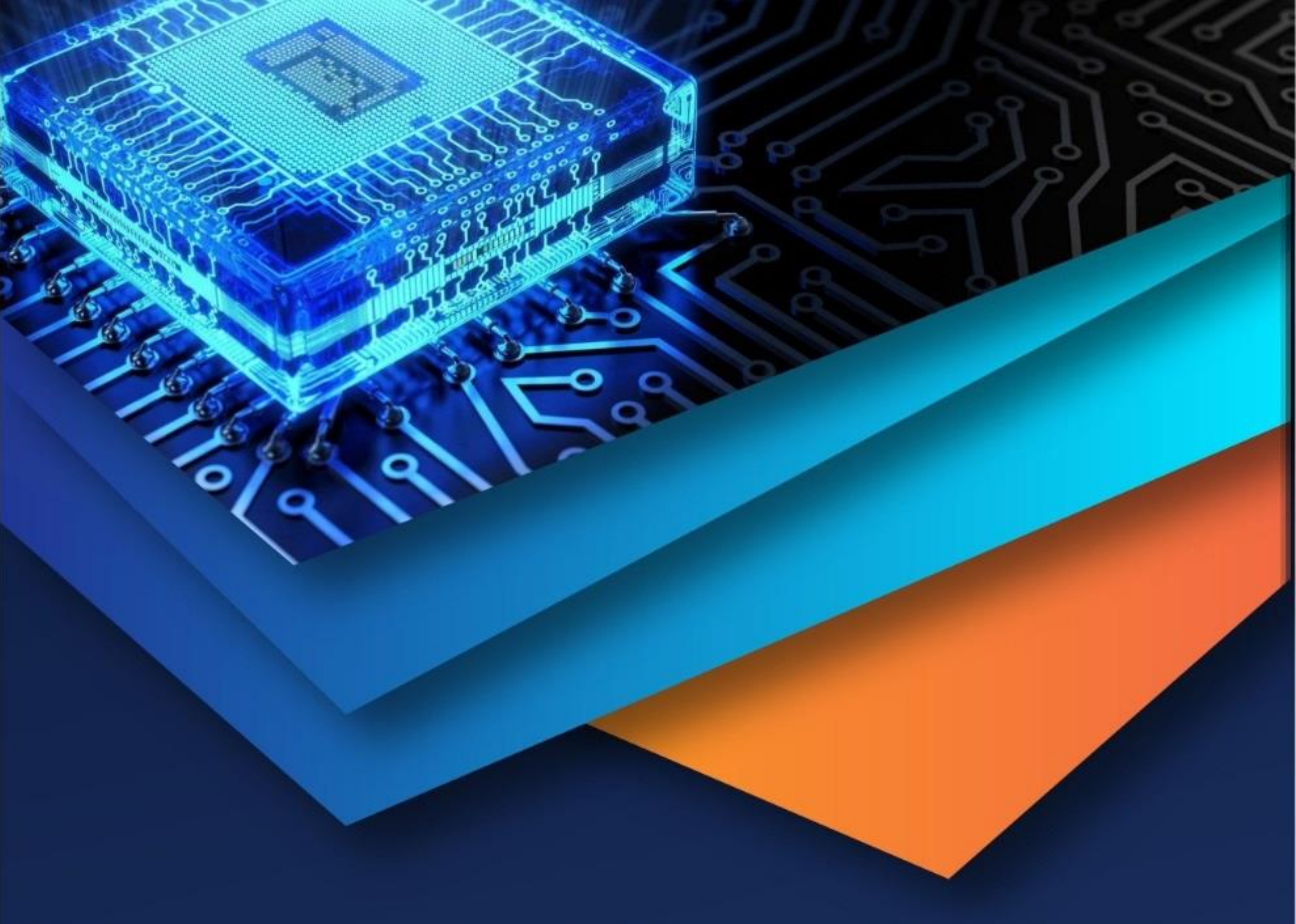

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