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Optimization and Analysis of a Caster Bracket

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Abstract: ***Trolleys and load carriers are provided with caster wheels attached to the bottom of the vehicle which enables the operator to move the heavy components and part assemblies with a greater ease. The Caster wheel is an assembly of wheel and a bracket/fork. The Bracket/Fork is an important part of the caster assembly which has to sustain the loads primarily due to weight of the vehicle and the weight of the goods. The aim of the present work is to study the stresses induced in the bracket and suggest a new suitable bracket design having increased the load carrying capacity and reducing the weight of the bracket with considerable reduction in overall dimensions. The FEA is performed on the Existing bracket and the modified bracket designs and the stresses were analyzed. The work deals with the optimization of caster bracket using the software packages, CATIA V5R20 for modeling and ANSYS Workbench 18.1 for finite element analysis.***

Keywords: Weight Loads, Bracket, Design, Sustainable Cycles

1. Introduction

High capacity, heavy duty casters are used in many industrial applications such as platform trucks, carts and tow lines where it is required to carry heavy components and other assemblies. Casters are available in market in various sizes according to the load requirement and are commonly made of nylon, plastic, rubber, aluminiumor stainless steel. A caster includes the mounting system, bracket/fork that holds the wheel in place as shown in Figure 1. The heavy-duty casters are provided with roller bearings and bushings on either side of the wheel to reduce the friction providing the effective working system. Generally, for heavier weight loads, the larger caster wheels are required. Larger wheels roll more easily and distribute weight over floor obstructions. To determine the capacity for each caster, the combined weight of the equipment or maximum load is divided by the number of casters to be used. Assuming a four-caster trolley which can carry a total weight load of 160 kg while a trolley with six casters can carry weight load of 240 kg.

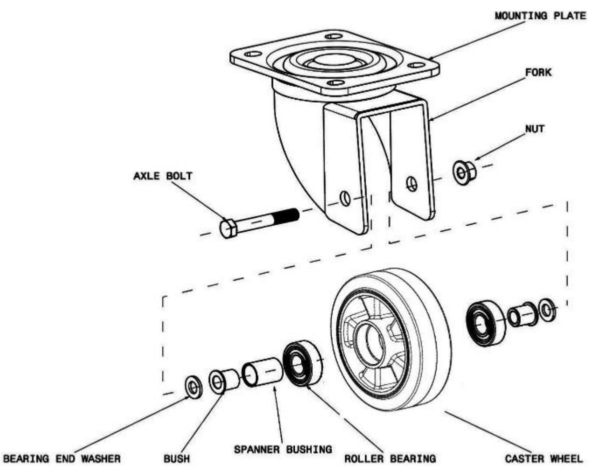


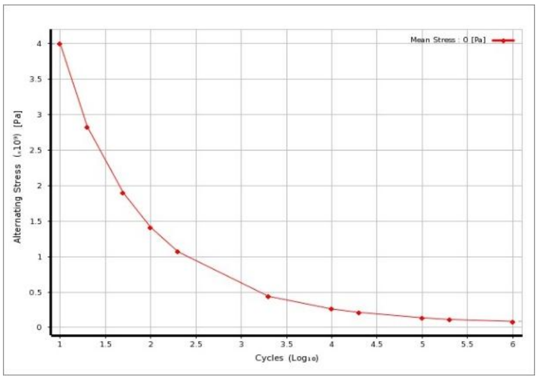
Figure 1: Caster assembly

For higher weight loads, plate mount casters are used because of their ability to carry more weight than stem mount casters. The bracket of the assembly is directly connected to the vehicle or trolley which undergoes high static and dynamic stresses especially in the dynamic conditions while rolling over the floor obstructions. The bracket is subjected to all the induced stresses due to the weight loading. A good bracket or fork is one which can sustain all these stresses over a longer period of time. With increase in the weight load capacity, the size and cost of the caster assembly also increases. Thus, it becomes necessary to increase the capacity of the wheel and bracket.

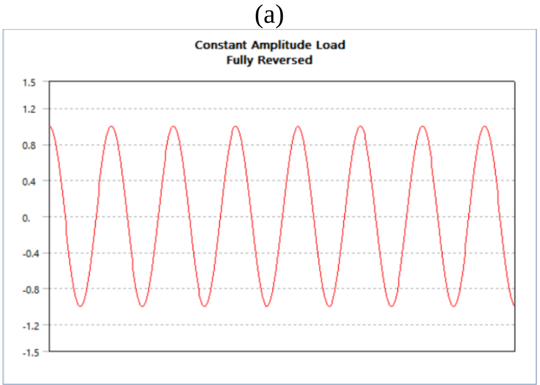
2. Methodology

Components which are subjected the loading which varies with time fails at stresses well above the material's ultimate strength, this is known as fatigue failure. Fatigue failure occurs dur to the formation and propagation of cracks. It is a three-stage process. The first stage is crack formation which usually occurs at free subraces and at stress concentrations. In the second stage, the crack grows in size and in stage three after the crack has grown to a critical size, fracture occurs. To figure out whether a component is likely to fail due to fatigue, one common approach is to run fatigue test by subjecting a component or test piece to a large number of constant amplitudes of stress cycles, and counting the number of cycles until its fracture. If we repeat this test a large number of times with different applied stress ranges, results can be plotted on a graph. With the number of cycles, the file and on the horizontal axis and the applied stress ranges in the vertical axis. Because the number of cycles to fails can be very large, a log scale is usually used for the horizontal axis. By firing a curve to the data points, the curve obtained is known as S-N curve (Figure 2a). The S-N curve allows to calculate the number of cycles until a component is likely to fail for a given stress ranges. For example, for a stress range of a 100 MPa, the S-N curve gives the corresponding number of cycles the component going to survive. S-N curve for many different materials are published in different engineering codes. For some materials (ferrous), it is important to note that the curve at a very large number of cycles becomes a horizonal line. This is known as the endurance limit. Theoretically, the component could be cycled at stress ranges below this level forever and it will never due to fatigue. This makes the endurance an important fatigue design parameter.

Fatigue test are usually run for the constant amplitude fully reversing cycles (Figure 2b). In this case, same address magnitude is applied in tension and in compression. The difference between the maximum and the minimum stresses is the Stress range and the stress amplitude is defined as half of the stress range. The mean stress is the average of the maximum and minimum stresses. In this case, the mean stress is zero but this is only one very specific type of loading. This mean stress will have an effect on the fatigue life of the component. A tensile mean stress will typically result in a shorter fatigue life. One way to account for tensile stress is to use S-N curves derived for specific values of mean stress. But these are often not available. Another approach is to use the Goldman diagram, which adjusts the endurance limit to account for a mean stress. On a Goldman diagram the mean stress is shown on the horizontal axis and the stress amplitude is shown on the vertical axis. A straight line is drawn between the endurance limit at a mean of 0 and the material ultimate tensile strength at a stress amplitude of 0. If cyclic loading conditions are located below the Goodman line, the component will be safe from fatigue failure. There are a few different variations of the Goodman diagram, Gerber and Soderberg. This approach can only be used to determine whether a component will have an infinite life.



(a)



(b)

Figure 2: (a)S-N curve, (b)Constant amplitude load fully reversing cycles.

The main objective of the work is to develop a supporting bracket/fork which is sustainable at all the working conditions and having low weight. For this purpose, both the material and thickness of the existing bracket design are studied and finite element analysis is carried out for different loading conditions to determine the equivalent induced stresses and the corresponding number of sustainable Cycles of the bracket. Similarly, the new designs are modelled in CATIA V5R20, the three-dimensional software package and further analyzed in the ANSYS Workbench for the different static loadings.

3. Modeling and Analysis

3.1 Existing Bracket (Fork).

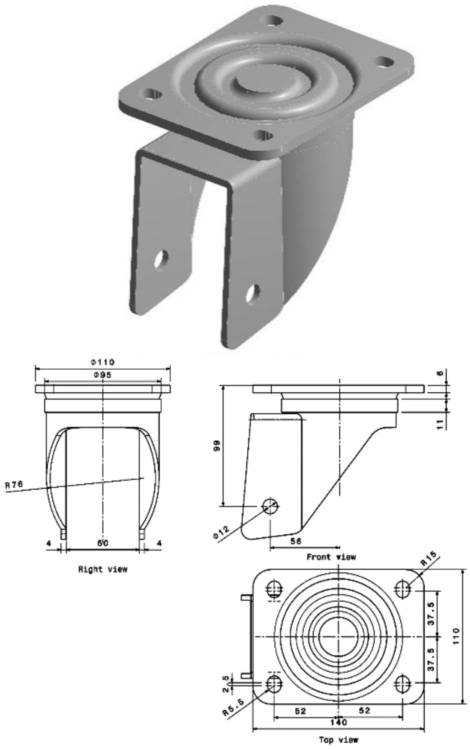


Figure 3: Geometry and dimensions of the existing bracket

The conventinal rigid bracket geometry and dimensions are shown in Figure 3 which is made up of mild/ low carbon steel. The material properties of mild/low carbon steel are as follows.

1. Ultimate Tensile Strength= 440 MPa
2. Yield Tensile Strength= 370 MPa
3. Modulus of Elasticity= 2.05e+11 Pa
4. Poissons Ratio=0.290

The CAD model of the bracket is imported in the Ansys Workbench and for the static condition of the assembly, the static structural analysis is carried. It includes the analysis of deflection, forces, strains and stresses on the component due to applied weight load. Tetrahedral(10 node) elements are used for the meshing and the mesh generated.

Practically, the bracket is bolted to the bottom of the trolley or the chassis and the caster wheel is assembled to the bracket or the fork through the axle bolt. The static structural analsysis is done by clamping the axle holes and applying the weight load on the upper faces of the bracket. Further, the Total Deformation, Elastic Strain, Equivalent (von-Mises) Stress and the minimum successful Number of sustainable Cycles cycles are calculated for different weight loads. The bracket analyzed for weight load from 60 kg (588.4N) upto the fatigue load and results obtained are illustrated in Figure 4.

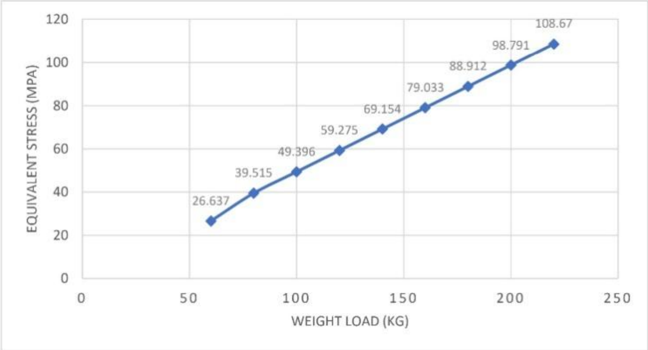
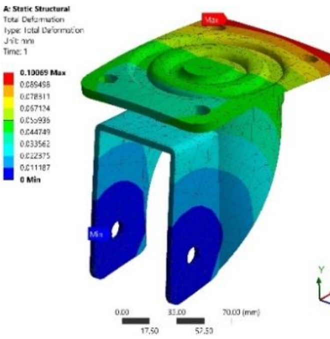


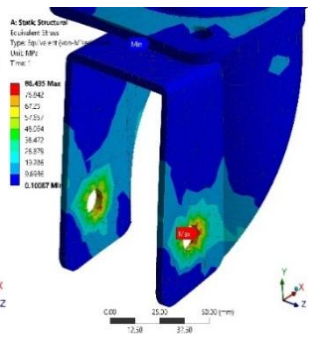
Figure 4: Equivalent stress for Existing Bracket at varying loads

The Endurance limit or Fatigue Limit of the Structural steel is equal to 86.2 MPa which means that if any loading conditions are applied that exceeds above this stress strain curve, above the stress fatigue life, then the part will be unsafe under the condition. Any loading condition underneath the S-N curve is going to be safe material also if the loading condition is kept lower than the endurance limit. In this case, if the loading conditions kept under the endurance limit, the bracket(fork) will never fail due to fatigue and can run infinite number of cycles. If the loading exceeds 86.2 MPa then depending upon where this stress intersects the S-N curve, those many numbers of cycles the part will survive.

From Table 1, based on the Endurance Limit of the material, the maximum load that the bracket can sustain the maximum weight load of 180 with induced equivalent stress equals to 88.912 Mpa. Hence, analysing the bracket for 175 kg (1716.2N).



(a)



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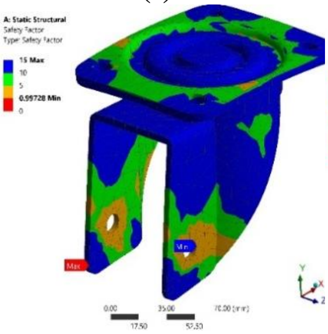
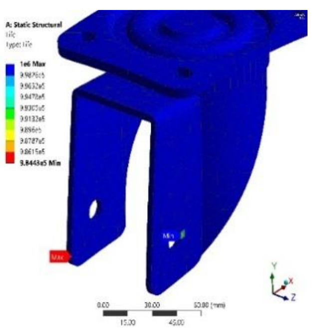


(c)



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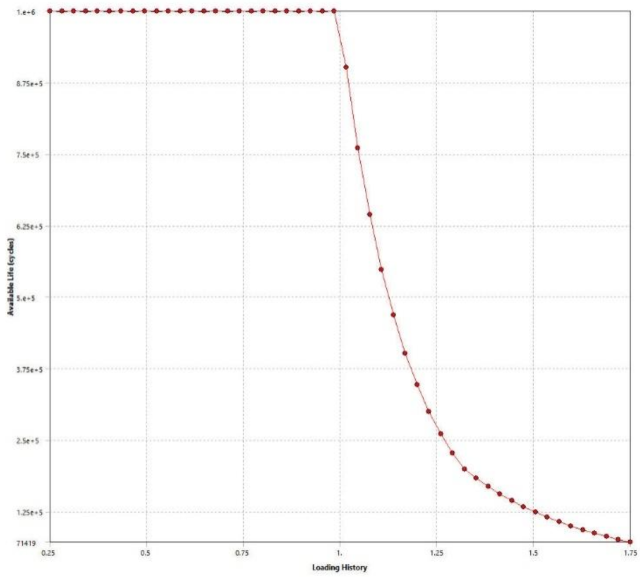


(e)

Figure 5: (a)Total deformation, (b)Equivalent (von Mises) Stress, (c)Safety Factor, (d)Number of sustainable Cycles and (e)Fatigue Sensitivity at 175 kg weight load for Existing Bracket

The maximum Total deformation is 0.10069mm and the Equivalent stress is 86.435 MPa which is slightly larger the endurance limit indicating the bracket can sustain maximum 170-180 kg of weight load. he Safety Factor is equal to 0.99728 at the localized stressed area and maximum is 15 which also can be calculated based on the Goodman theory, which is equal to 1 over FS that is equal to the mean stress divided by the ultimate strength of the material plus the stress amplitude divided by the fatigue strength of the material.Number of sustainable Cycles means minimum numbers of cycles is the successful cycles performed by the part before the fatigue failure that the component can survive is 9.8443e5 which indicates that the localized area is going to fail at the most heavily stressed area and the remaining part will not experience much of the failure and is capable of handling the cycles till 10^6 (Figure 5d).Fatigue sensitivity graph (Figure 5e) explains that currently we have number of cycles equals 9.8443e5. For the loading 175 kg (1716.2 N), 9.8443e5 cycles will be survived by the component. If the load increases to 1.25 times then the Number of sustainable Cycles will further be reduced. Similarly, if the loading is reduced to 0.75 times or less than 175 kg then the Number of sustainable Cycles may reach to 10^6 cycles.

3.2 Design I

To increse the weight load carring capacity of the bracket, the alternate vertical and horizontal circular holes are provided which reduced the weight of the bracket. The holes are provided with 1º draft for the ease during manufacturing. The geometry and the dimensions of Design I are shown in Figure6.

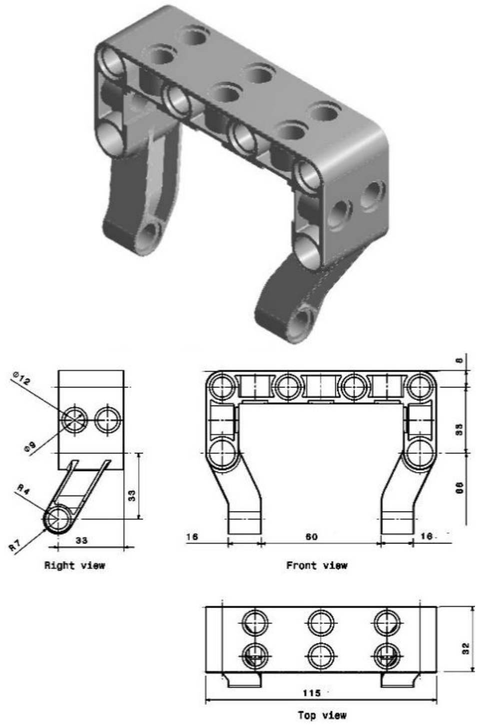


Figure 6: Geometry and dimensions of Design I.

Design I is futher analyzed for weight load from 60 kg (588.4 N) and Stress results obtained are illustrated in Figure 7.

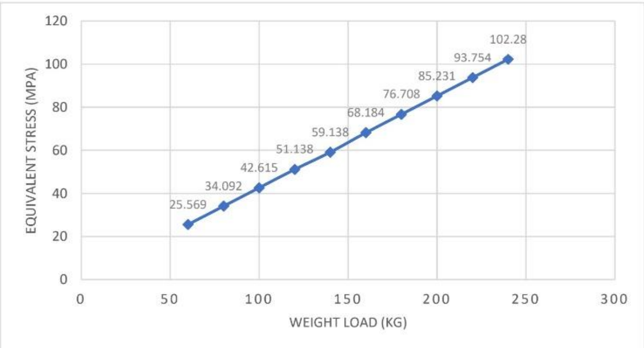
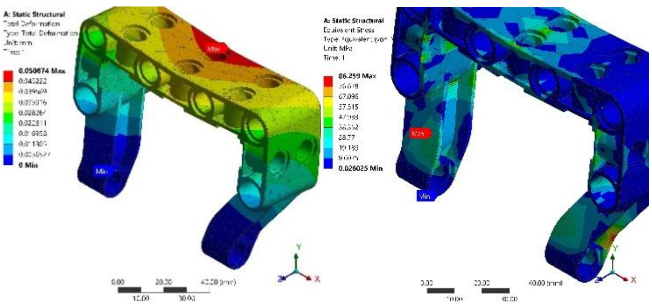
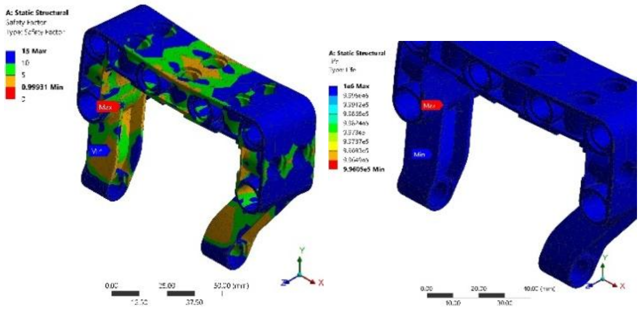


Figure 7: Equivalent stress for Design I at varying loads

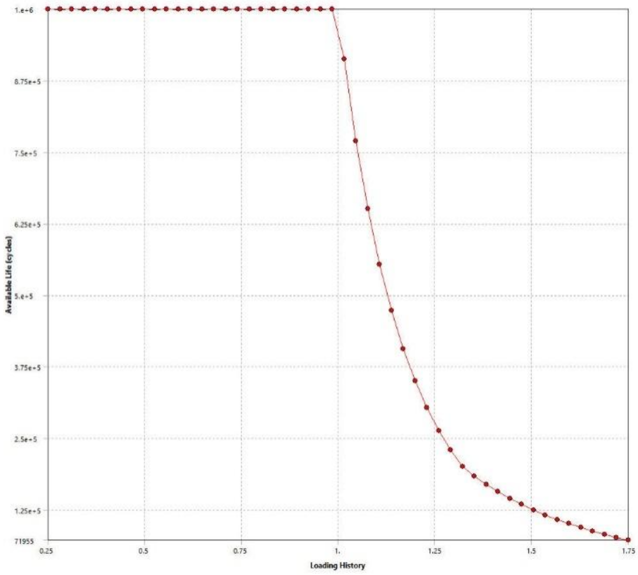
From figure 7, the bracket can sustain the maximum weight load of 200 kg with induced equivalent stress equals to 85.231 Mpa. Analysing the bracket for 205 kg (2010.4 N), analysis results obtained are as follows.



(a) (b)



(c) (d)



(e)

Figure 8:(a)Total deformation, (b)Equivalent (von Mises) Stress, (c)Safety Factor, (d)Number of sustainable Cycles and(e)Fatigue Sensitivity at 205 kg weight load for Design I.

The maximum deformation under the loading is 0.050874mm and corresponding Equivalent stress is maximum at the leg of the bracket, the blue coloured region having intensity equals to 86.259 Mpa which indicates minimum induced stress and it is safe under the loading. The maximum stress is slightly larger the endurance limit indicating Design I can sustain the maximum weight load of 200-210 kg. The Safety Factor at the heavily stressed area is equal to 0.99931 and maximum is 15 for the less stresses (blue) area. Minimum numbers of cycles that the part can sustain under the loading is 0.9605e5 cycles before the fatigue failure. The remaining part will not experience much of the failure and is capable of handling the cycles till 10^6. Fatigue sensitivity graph is an indication that currently the number of cycles is equals to 9.8443e5. For the loading 205 kg, 9.8443e5 cycles will be survived by the component. If the load increases to 1.25 times then the number of sustainable cycles will further be reduced. Similarly, if the loading is reduced to 0.75 times or less than 205 kg (2010.4 N), then the life may reach to 10^6 cycles.

3.3 Design II

In design II, the alternate vertical and horizontal circular cicular holes are replaced with square filleted holes with 1º wall draft for the ease during manufacturing. The geometry and the dimensions are as shown in Figure 9.

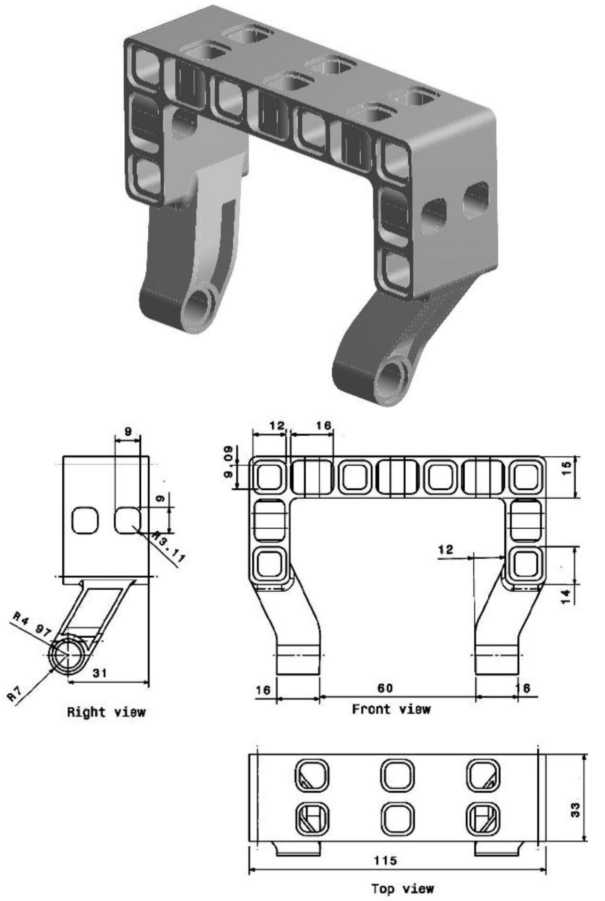


Figure 9: Geometry and dimensions of Design II

Design II analysed for the loading from 60 kg to 400 kg and the induced equivalent stresses obtained are;

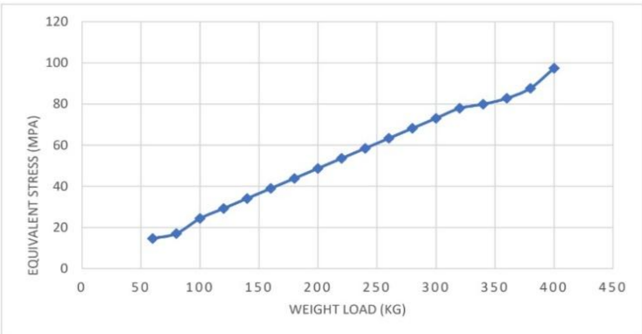
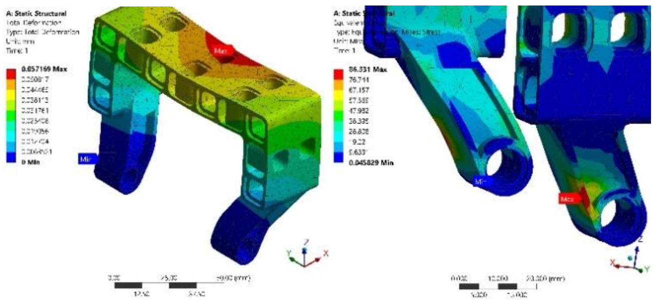
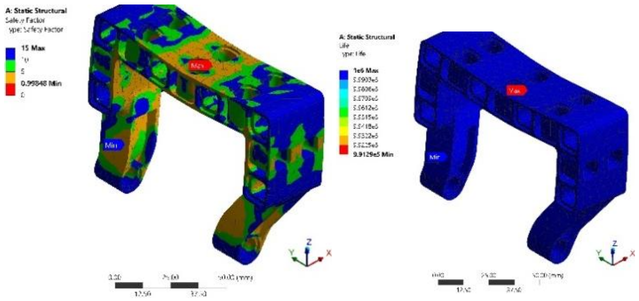


Figure 10: Equivalent stress for Design II at varying loads

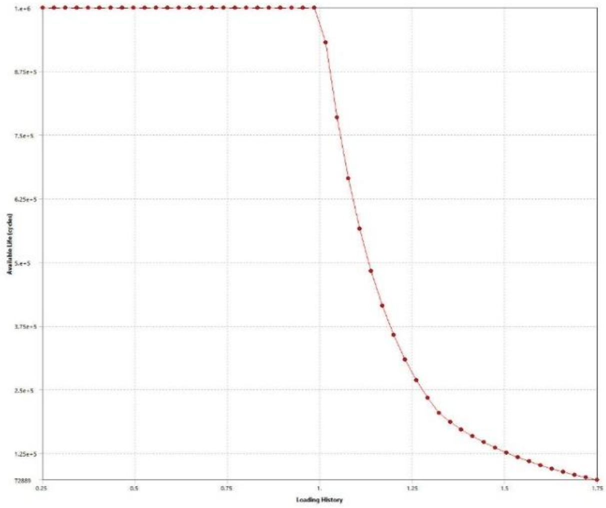
From Figure 10, the maximum load that the bracket can sustain the maximum weight load of 380 kg with induced equivalent stress equals to 87.643 Mpa. Analysing the bracket for 375 kg (3677.5 N) and the analysis results obtained are as follows.



(a) (b)



(c) (d)

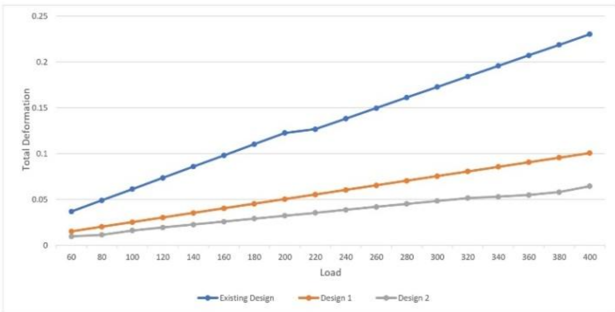


(e)

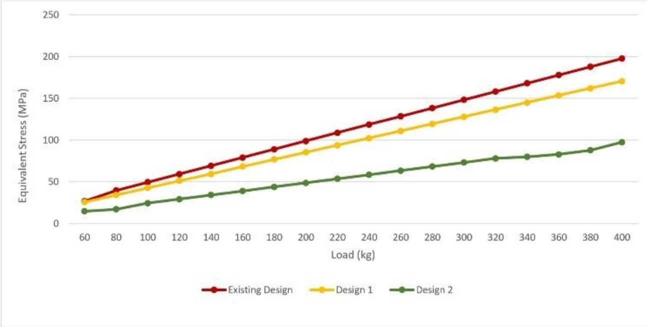
Figure 11:(a)Total deformation, (b)Equivalent (von Mises) Stress, (c)Safety Factor, (d)Number of sustainable Cycles and (e)Fatigue Sensitivity 375kg weight load for Design II.

At weight load 375kg, the maximum deformation obtained is 0.057169 mm and the Equivalent stress 86.331 Mpa, which is larger the endurance limit indicating Design II can sustain the maximum weight load of 360-380 kg. The Safety Factor at the stressed area is equal to 0.99848 and maximum is 15 for the unstressed area. Minimum numbers of cycles that the design can sustain under the loading is 0.9129e5 cycles before the fatigue. The remaining part of the bracket will not experience much of the failure stress and is capable of handling the cycles till 10^6. Fatigue sensitivity graph indicates that currently for 375 kg (3677.5 N), the number of Number of sustainable Cycles is equals to 0.9129e5 which further reduces with increase in the loading.

4. Discussion and Conclusion



(a)



(b)

Figure 12: Comparison Graph plotted for (a)Total Deformation, (b)Equivalent (von Mises) stress for Existing Design, Design I and Design II

Figure 12. gives the comparative view of Total deformation and Equivalent stresses induced in the existing and two modified designs for the varying weight loads. The Total deformation and Equivalent stresses induced in Design I and Design II are much less as compared to the existing Bracket Design. The minimum Number of sustainable Cycles of Design II is much larger than the existing component. Also, the total bracket weight of the Existing design is 2.323 kg and that of Design I and Design II is 0.528 kg and 0.512 kg respectively which is 22.04% of the existing Bracket weight. Though the manufacturing cost of Design I and Design II is more but it can withstand higher weight loads with lower bracket weight and hence can be used for light weight applications.

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