Failure Analysis and Mass Reduction of Pivot Pin of Clutch Pedal Assembly Using Heat Treatments

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Abstract—In automobiles, clutch pedal assembly is used to engaged or disengaged the gears. In this assembly the pivot pin is used to connect the clutch pedal with the push rod. This pin is getting failed during operation. Due to this sudden failure of clutch pedal pin without giving any alert, the clutch plate may get stucked or jammed within the clutch pedal assembly. This phenomenon may occur during shifting of gear or while applying brakes, which leads to severe accidents. Hence it is necessary to increase the life of pivot pin and to reduce the failure rate of pivot pin with cost effective solution. Investigation of failed part reveals that sudden application of maximum stresses, cyclic stresses, variable loading condition and bearing forces developed in the material of pin leads to failure. Hence to improve properties of material, the different heat treatments like carburizing, nitriding and carbo-nitriding are used. To decide the one process from above all, we go through tensile test, hardness test and wear test, etc. After comparing results of all the heat treated samples of all the heat treatment methods reveals that carbonitriding process is good for pivot pin. Then the case depth obtained from this heat treatment is use for the new design of pivot pin. The newer design is checked with tensile test by applying maximum force conditions of clutch pedal assembly. As well the results obtained from tensile test were comparing with FEA analysis; it shows that design of pivot pin is safe. The combination of best heat treated method and newer design of the pivot pin gives reduction in mass of existing pivot pin. This gives the cost effective solution and better replacement to the existing pivot pin of material SAE1117.

Key words — case depth, FEA, pivot pin, carbonitriding heat treatment, mass reduction

I. INTRODUCTION

In automobiles, clutches are used to engagement or disengagement of rotating shaft of machine. While driving the car we used to press the clutch pedal, which transmit forces to further clutch assembly. This clutch pedal assembly consist of pivot pin which is acting like fulcrum while pressing the clutch pedal. This pin rotates during the clutch operation and carries continues variable load and stresses during the clutch operation. Hence whenever there is the maximum displacement of clutch pedal is done then maximum force acted on the clutch pedal assembly as well as pivot pin. The clutch pedal assembly with the pivot pin is shown in figure 1.

Figure1: clutch pedal assembly.

Figure2: components of clutch pedal assembly.

Figure 3: Pivot Pin of Clutch Pedal Assembly

In automobile sector there is a necessity to achieve the desired output in minimum investment cost. In MacSteel industry, Nashik, the rejection of pivot pin of the clutch pedal assembly is highest, there is need to find out the effective solution for pivot pin. Hence we are going to enhanced material properties of pin using various heat treatments; it will reduce the failure rate of pivot pin. There are following solutions available for obtaining desire effect,

1. Selection of alternate option for the existing material (SAE1117) of pivot pin which eliminates the failure and having longer life with better load carrying capacity as well less coefficient of friction.
2. Obtained the desire properties in existing material by applying various suitable heat treatments on the material of pin.
3. Suggest the new design of pin which gives best results and reduce the failure.

From all the above possible solutions we rejected the alternate material option for the pin. Because, if we introduce the composite material with the better properties of wear and hardness, then the cost of pin will increase. This one is not the cost effective solution.

Hence to overcome those problems we are going to complete this project work by selecting the 2nd and 3rd option simultaneously. The suitable heat treatment and the properties obtained from it were studied. Then, using those properties we will get the new design of pivot pin. Using experimental values and FEA analysis we will decide either design is safe or not.

II. PROBLEM DEFINATION

In automobiles, the clutch pedal assembly is the mechanical part which is continuously under the forces, while driving, changing speed as well as while applying brake. In this clutch pedal assembly the pivot pin is present which connects the clutch pedal to the clutch assembly. The sudden failure without alert occurs in this pivot pin of clutch pedal assembly. This sudden failure leads to jamming of clutch pedal and severe accidents on road while driving. Similarly, the many pivot pins get rejected due to improper surface properties and undesired defects during the assembly.

In a particular industry this failure ratio is very high. So there Is a necessity to eliminate failure of pivot pin and to increase its life is necessary. But the system requires cost effective solution to implement this solution in the industry.

Avg. no. of failed pins within one year - 1300 no. of pins

Cost of single pin (including machine work) - 27 Rs

Total cost of failed pins - 27 × 1300 = 35100 Rs

The main objective of this paper is, to analyze the pivot pin of clutch pedal assembly and to reduce its weight and cost, with the help of various heat treatments and FEA analysis.

III. LITERATURE SURVEY

N.F.Timerbaev (2017) et al, article reveals, the use of CAD/CAE/FEA system allows to reduction in the calculation time in comparison with the known method of design and calculations, specifically in the design of shafts present in engineering world. To avoid the calculation related to shaft design and study of defects in it as well as to improve the results the above systems are preferred. The calculations of strength of machine parts, optimization of the shafts and to choose the best optimize design the CAD/CAE/FEA systems were adapted. [1]

Mahmoud T. El-Sayed(2017) et al, includes the study of shaft misbehaviour and defects caused by misbehaviour. It gives the direct relationship between internal torsional resistances and the deflection of torque. There is increase in deflection of shaft and the change in angular velocity, leads to the increase in torsional resistance of shaft. As well as for the same speed but due to increased time period, the internal resistance torque increases.[2]

R. C. Chen(2017)et al, Study of this article concludes that, the heat treatment is affected by various parameters and according to change in those parameters we can achieved the required results. The article involves the study of austenite grain growth behaviour in the isothermal heat treatment of 300M steel. Which states that, the initial grain size, temperature and time are all have significant effects on the average grain size evaluation and the grain size distribution.[5]

MaziarRamezan(2014)et al, this article gives the result of carbon diffusion in heat treatment of H13 tool steel under different atmospheric condition. Which reveals that the carbon movement during austenization of H13 tool in the surface region is totally dependent on the surrounding atmospheric condition. In the carburization the carbon monoxide is continuously supplied inside the surface from atmosphere which increases hardness of steel[4].

Samuel Koechlin(2017) et al, this article is good example of estimating strength of hollow shaft pinion connection in the case of specific design. In the case of gear motors, input pinion is directly fixed on the electric motor shaft for connection, the small diameter shaft like pinion is used. The above machine shows the complex mechanical behaviour due to variable load condition.[6]

Paresh S.(2016) et al, the study of this article gives the idea about the recovery of shaft failure with the help of various heat treatments. In automobile due to variable load and internal resistance torque the shaft is getting cracked. The carburising, hardening such various heat treatments are used to obtaine the required properties in material of shaft.[10]

Hence from above study, we can conclude that, generally heat treatments are used to reduce the failure of shafts.

IV. METHODOLOGY

1. Selection of best suited alternative option for the pivot pin material
2. Following various heat treatments were decided to achieve desire properties in pivot pin material.
   a) Carburizing
   b) Nitriding
   c) Carbonitriding
3. Select best suited method from above heat treatment methods, by comparing
   a) Case depth results achieved from following tests, achieved during heat treatment.
   b) Hardness of the heat treated sample
   c) Core hardness of heat treated samples
   d) Wear coefficient of heat treated samples
   e) Tensile testing
4. Compare the results obtained in step 3 and select one best suited heat treatment method to achieve desired properties in pin. Now, Determine the UTS and YTS of best selected Heat Treatment Material.
5. Use dimensions of the case depth and material properties achieved in the results of heat treatment obtained from step 4 is selected for new optimized design of pivot pin.
6. Finite Element Analysis with existing design and newer design of pivot pin under Bearing or tensile Load using properties found in step 5.
7. Compare the results of both analysis, If safe then this is the required optimize result if not then go to step 4 and determine new design for the pivot pin.
8. If Safe, then Prepare proposal of cost and mass effectiveness of optimized result, for the industry.

V. MATERIALS AND SAMPLES

The pivot pin of the clutch pedal assembly with dimensions, diameter 16mm, head diameter 20mm with thickness 30 mm, overall length 202 mm, and weight 0.331kg, shown in figure3. The material used for the pin is SAE1117.The chemical composition and mechanical properties of material SAE1117 is shown in table1 and table2 [14]

TABLE1
CHEMICAL COMPOSITION (by weight %) OF SAE1117

C	Si	Mn	P	S	Cr	Ni
o.419	0.160	0.500	0.0448	0.0484	0.038	0.020

TABLE2
MECHANICAL PROPERTIES OF SAE1117

Sr. no.	Property	Value
1	Density	7.82×10^3 kg/m^3
2	Modulus of elasticity	200Gpa
3	Specific heat capacity	4.81 KJ/(Kg×K)
4	Tensile strength	400 MPa
5	Yield strength	220MPa

Heat treatment

Specimens of diameter 16 mm and length 50 mm were cut of SAE 1117 material and subjected to different heat treatment procedures like carburising, carbonitriding and liquid nitriding.

Sample surface treated by carburizing at 920ºC and hardening at 850ºC and tempering at 180ºC in the furnance. Similarly, samples were surface treated by Carbonitriding at 810ºC and hardening at 740ºC Tempering at 180ºC in vertical retort furnace. Nitriding at the temperature 520^{0}C. Macrostructure of all heat treated samples of carburized, carbonitrided and nitride used for the further testings. The results of heat treated sample were used to compare with the results of untreated samples of material SAE1117.

(a) (b)

Figure 4: (a) Macrostructure of untreated sample and (b) Macrostructure of carburized sample

(a) (b)

Figure 5: (a) Macrostructure of carbonitrided samples and (b) Macrostructure of nitride sample.

VI. EXPERIMENTATION

Using the various heat treatment methods like carburizing, carbonitriding and nitriding we achieve the better mechanical properties in material SAE1117. But we have to select one heat treatment method from above methods which will fulfill the required properties for the pin. Hence we use the following testing on samples of all heat treatment methods for comparison purpose only,

1. Case depth Measurement :

This particular portable optical microscope DMM 100X, shown in figure6 is used to perform linear and case depth measurements (Z axis) with centesimal precision. This displays readings directly on the dial.

Sample specification; diameter of 16 mm, length 50mm

Figure6: portable optical microscope

TABLE 3
CASE DEPTH OF HEAT TREATED SAMPLE

Sr.No.	Case Depth (mm)	Average	Heat Treatment
1	0.01	0.00975	Nitrided
2	0.009		
3	0.01		
4	0.01		
5	1.21	1.1975	Carburised
6	1.19		
7	1.17		
8	1.22		
9	0.72	0.7525	Carbonitrided
10	0.76		
11	0.79		
12	0.74		

2. Hardness Testing :

The NewageMT91 System, shown in figure7 is an automatic microhardness testing system. That uses the Rockwell /Vickers /Brinel method for the hardness result. Hardness is measured based on the depth of penetration rather than using an optical system to determine hardness based on the impression diameter.

Test Procedure ; 1.Locate part edge on the machine.
2.Select preprogrammed routine and add part data.
3.select the angular dimensions and set to set the directions. And click start.
3.Results and graphs are directly generated on computer systeme.
Sample specification; diameter 16mm, length 50mm,

Figure7: Microhardness tester

TABLE 4
SURFACE HARDNESS OF HEAT TREATED SAMPLES

Sr.No.	Surface Hardness(HRC)	Average(HRC)	Heat Treatment
1	53.5	53.475	Nitrided
2	52.9		
3	53.6		
4	53.9		
5	64.5	64.525	Carburised
6	65.2		
7	63.8		
8	64.6		
9	57.1	57.35	Carbonitrided
10	57.3		
11	58.1		
12	56.9		

TABLE 5
CORE HARDNESS OF HEAT TREATED SAMPLE

Sr.No.	Core Hardness(HRC)	Average(HRC)	Heat Treatment
1	32.5	32.875	Nitrided
2	32.9		
3	33		
4	33.1		
5	41.9	42.125	Carburised
6	42.1		
7	42.5		
8	42		
9	37.5	37.75	Carbonitrided
10	38		
11	37.9		
12	37.6		

3. Wear rate testing :
The Pin on Disc Friction & Wear Test Rig TR-20LE, shown in figure8, is primarily intended for determining the tribological characteristics of wide range of materials under various conditions of normal loads & temperatures under dry & lubricated conditions with different environmental conditions.
Test Procedure; 1. For pin on disc wear test, pin with radiused tip is required specimen.
2.Test machine causes either disc/pin to rotate about center. In either case sliding path is circular path on disc surface.
3.The plane of disc may oriented either horizontaliy or vertically.
4.Pin specimen pressed against disc at specified load usually by mean of an arm or lever and attached weight.
5.Wear results are reported as volume loss in mm^3 for the pin and the disc separately.
6.The amount of wear is determined by measuring appropriatr linear dimensions of both specimens before and after the test.
7.Wear results are obtained by conducting test for selected siding test distnce , load and veloacity.
8.The wear results are displayed dierectly and the graphs are also can be generated if required.
Sample specification; pins of dimeter 12mm and length 25 mm, and parameters selected for the experimental analysis are shown in table.

Figure8: Pin on disc machine

TABLE 6
PARAMETERS SELECTED FOR EXAPERIMENTATION

Sr. no.	Sliding velocity (m/s)	Load kg	Test duration (min)
1.	2.5	10	30
2.	2.5	12	30
3.	2.5	15	30
4.	4.08	10	30
5.	4.08	12	30
6.	4.08	15	30

TABLE7
WEAR RATE OF HEAT TREATED SAMPLE

Sr.No.	Load (kg)	Heat treatment
1.	290	Carburizing
2.	898	Carbonitriding
3.	1028	Nitriding

4.Tensile Load Testing :

Tensile test machine, SERVO600KN, shown in figure9 use to test the tensile stresses and compressive srength of materials.

Test Procedure ;

1. Specimen Placed Between the grips of the machine.
2. During the test Extensometer record the change in length of specimen if Extensometer is not fitted, specimen itself can record between its cross heads on which specimen held.
3. Apply gradually increasing load on specimen.
4. Through the test the control system and associated software record the load and extension of specimen.
5. Readings are automatically displayed on the window.

Sample specification; Gauge length 50 mm, diameter12.5 mm, radius of fillet 10mm, overall length14.5, diameter of end sections 20mm.

Figure9: Universal Tesing Machine

TABLE 8
TENSILE TESTING OF HEAT TREATED SAMPLE

Sr.No.	Load(Kg)	Wear Rate V_1=2.51 m/s (mm^3/m)	Wear Rate V_2=4.08 m/s (mm^3/m)	Heat Treatment
1	10	$7.9X10^{-4}$	$4.5x10^{-4}$	untreated
2	12	$4.5x10^{-4}$	$2.8x10^{-4}$	
3	15	$3.1x10^{-4}$	$1.0x10^{-}$	
4	10	$2.3x10^{-5}$	$1.9x10^{-5}$	Nitrided
5	12	$3.9x10^{-5}$	$2.4x10^{-5}$	
6	15	$2.7x10^{-5}$	$2.1x10^{-5}$	
7	10	$10x10^{-5}$	$3.4x10^{-5}$	Carburised
8	12	$2.5x10^{-5}$	$4.3x10^{-5}$	
9	15	$8.9x10^{-6}$	$8.1x10^{-6}$	
10	10	$6.1x10^{-5}$	$2.8x10^{-5}$	Carbonitrided
11	12	$6.5x10^{-5}$	$2.1x10^{-5}$	
12	15	$5.4x10^{-5}$	$3.3x10^{-5}$	

After reviewing all results we can say that

1. Case depth as 0.00975 mm in Nitrided samples, 1.1975 mm in carburized samples and 0.7525 mm in Carbonitrided samples. So it is maximum in carburizing and minimum in nitrided sample and intermediate in carbonitrided sample.
2. The surface hardness is 53.475 HRC for Nitrided, 64.525HRC for carburized and for carbonitrided it is 57.35. As well as core hardness of nitride material is 32.875 HRC, 42.125 HRC for carburized and 37.75 HRC for carbonitrided sample. Here we can say that Maximum case and core hardness is for Carburising.
3. For Nitrided samples maximum wear rate is $3.9x10^{-5}$ mm^3/Nm,for carburized it is $10.1x10^{-5}mm^3$/Nm and for carbonitrided it is $6.5x10^{-5}mm^3$/Nm it is maximum for carburized and minimum for nitride.
4. The pull out force is 290 N for carburized, 898 N for carburized and 1028 N for nitride sample.
5. From above study of results we can say that Maximum case hardness 64.525 HRC is for carburizing, Harden case depth is also maximum but pullout force is very less 290 N so this combination will not be suitable for the pin.
6. Nitrides sample shows Maximum Pullout force, good wear resistance but minimum case depth so we can say that this heat treatment is not suitable for the pin.
7. Now, carbonitrided samples shown good wear resistance and also good case depth of 0.7525 mm, good case hardness 57.35HRC, and providing very good pullout force of 898 N.
8. Overall carbonitrided sample gave good results and is suitable for the pin.

VII. CALCULATIONS

1. Calculation of new design for the pin,(From the results obtained from heat treatment, case depth of carbonitrided heat treated sample was selected for the new design of pin and further analysis)

Case depth is 0.75 mm,

Factor of safety 3,

Thickness of new pivot pin = 0.75

= 2.25 mm

(Standard available sizes of pin 3.0mm, 2.5mm, 2.0mm, 1.5mm)

we selected dimensions; thickness for new pivot pin is 2.5 mm

So, Internal radius of new design of pin = outer radius of previous design of pin– thickness

= 8mm - 2.5mm

= 5.5 mm

2. Calculation of the maximum force applied on the clutch pedal

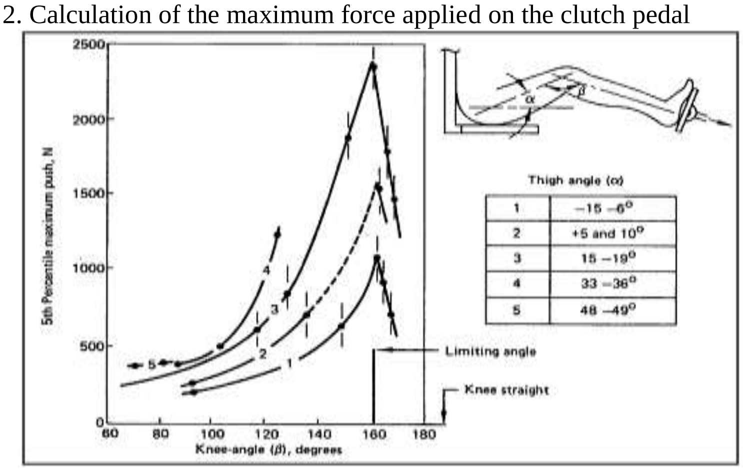

Figure 6: Graph Maximum Push vs Knee angle

Figure6 shows the graph maximum push force applied on the clutch plate vs knee angle varying as p er sitting position of driver. From the figure, we are getting maximum value for push 2400N at the angle 150^0-160^0

Hence, maximum force taken as 2400N (from the data of company resource)

For further analysis in FEA maximum force is considered as 2400N.

VIII. FEA ANALYSIS

We have determined the heat treatment for the material, now we have to do the mass optimization work. For this we will analyze the pivot pin at different input conditions. The various levels are as follows,

1. Solid Pin with bush for 50 N Bearing Load,
2. New design of Pin with bush for 50 N Bearing Load,
3. Solid Pin with moment of 50 Nm,
4. New design of pin with moment of 50 Nm.
5. New design of pin for maximum force (2400 N)

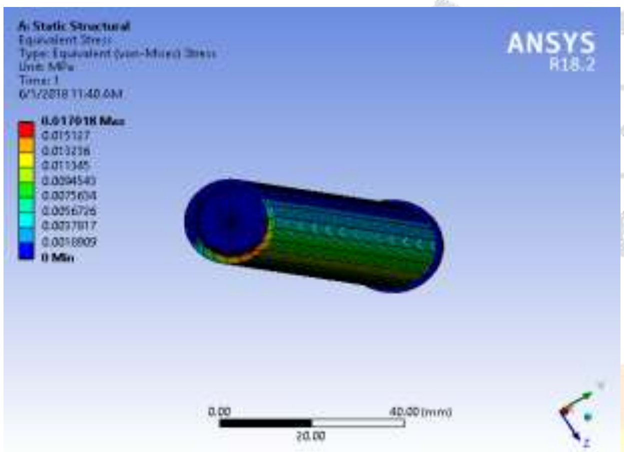

Figure 10: Equivqlent stress of solid pin with bush for 50N bearing load.

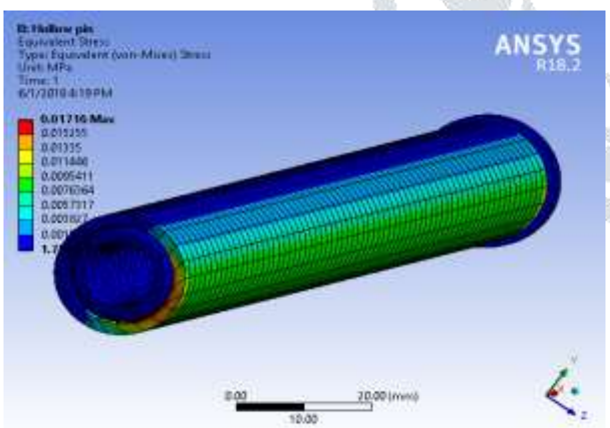

Figure 11: Equivalent stress of hollow pin with bush for 50N bearing load

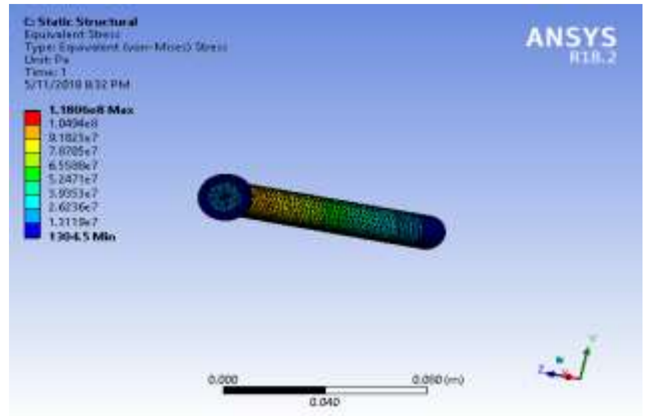

Figure 12: Equivalent stress of Solid pin with moment of 50 Nm.

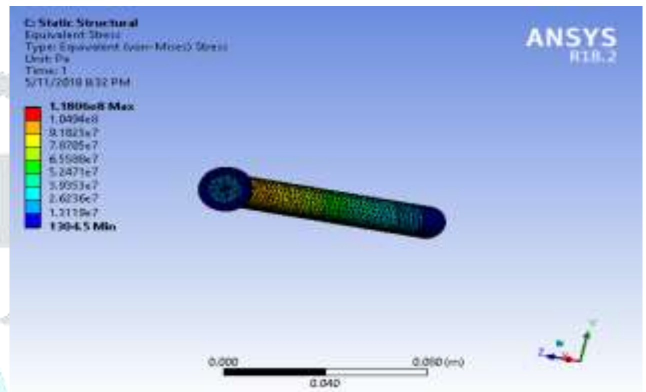

Figure 13: Equivalent stress of hollow pin with moment 50 Nm

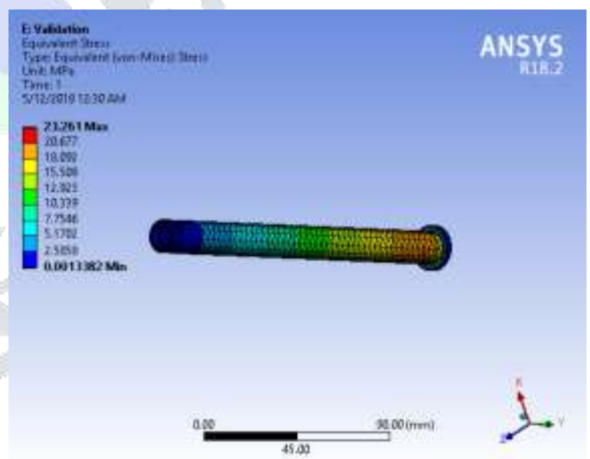

Figure 14: Equivalent stress hollow pin for maximum force 2400 N

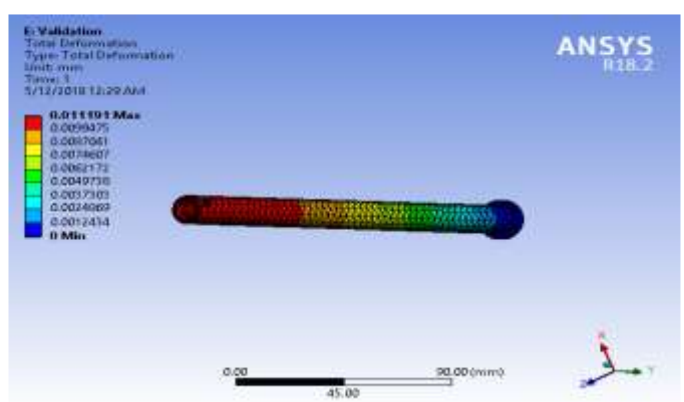

Figure 15: Total deformation of hollow pin for maximum force 2400N

IX. RESULTS AND DISCUSSION

For validation of new design of pin, we have done testing of the samples on UTM under tensile load of 2400 N (maximum force). Experimental Values are as follows,

TABLE 9
COMPARISON OF EXPERIMENTAL SRESS VALUE AND FEA STRESS VALUE FOR THE HOLLOW PIN (NEW DESIGN)

Sr.No	Experimental Stress Value (MPa)	Average Experimental Stress Value (MPa)	FEA Stress MPa	Percentage Difference
1	20.15	21.292	23.261	8.46481
2	24.03			
3	19.06			
4	21.12			

From the study we came to know that FEA and Experimental Values difference only up to 8.5 % so we can say that our work of optimization is validated.

As well as the mass of existing pivot pin sample differs by 0.15502 kg from the mass of new design of pivot pin. Therefore there is 46.825% of mass reduction due to newer design of pivot pin.

X. CONCLUSIONS

In this dissertation, we worked on multiple objectives and obtained the desired results. We studied effect of various Heat Treatment process on the material SAE1117. For various Heat Treatment processes we found Wear Rate, Core and Case Hardness and Tensile strength. We found that by using the carbonitriding heat treatment process we get the desired result for hardness of pivot pin. For optimization purpose we used Finite Element Analysis method using ANSYS software, using the results obtained from carbonitrided process. Using the results obtained from carbonitrided process we introduce the new design of the pivot pin, which gives 46.82% of mass reduction which saves the material cost and rework cost of the pivot pin.

Tensile test was used for validation purpose of new design of pivot pin. Experimental results and FEA results shows difference only upto 8.5%, which is acceptable. By introducing new design of pivot pin cost 3,55,908.1 Rs. Per year will saved.

ACKNOWLEDGMENT

The report is outcome of guidance, moral support and devotion bestowed on me throughout my work. For this I acknowledge and express my profound sense of gratitude and thanks to everybody who have been a source of inspiration during the experimentation. First and foremost I offer my sincere phrases of thanks with innate humility to **Dr. S. P. Mogal,** (H.O.D) Mechanical Engineering Department, NDMVP'S KBT COE, Nashik for providing help whenever needed. The consistent guidance and support provided by **Prof. M. S. Patil** is very thankfully acknowledged and appreciated for the key role played by him in providing me with his precious ideas, suggestions, help and moral support that enabled me in shaping the experimental work.

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