Performance Investigation of Gudgeon Pin to Enhance the Competence

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Abstract— High temperature distribution over the internal combustion cylinder leads to the infringement of the contact with the piston to the connecting rod, in this project we have scrutinized the recital of the gudgeon pin to resist from the shear and wear along the bending deformation during the loading of the engine, here we were using diverse materials to improve the performance of the cotter pin hence the materials with high temperature conductivity & low weight ratio to withstanding propensity and structural potency will make a alternate for the commercial pin used now a days, by analysing the gudgeon pin we can see the results of shear stress, bending stress, contact stress, displacement and deformation due to the load distribution over the whole pin. The concept design were going to done in modelling software Solid works and analysis of stress and load will be done in ANSYS, this project mainly deals with stress, shear, load, contact, bending stress and Von Mises Hencky theory of failure analysis of the gudgeon pin by exploiting dissimilar materials.

Key words: Piston Pin, Shear, Bending, Contact Stress, ANSYS

I. Introduction

Automobile components are in great demand these days because of increased use of automobiles. The increased demand is due to improved performance and reduced cost of these components. R&D (Research and Development) and testing engineers should develop critical components in shortest possible time to minimize launch time for new products. This necessitates understanding of new technologies and quick absorption in the development of new products. The Piston pin which connects the piston and connecting rod fig.1 shows the assembly view of the piston with small end of the connecting rod, In an engine the gudgeon pin (which connects the piston to the connecting rod in a conventional internal combustion engine, ICE to pivot upon as the piston moves) is subjected to a combination of shearing and bending loads. As an important part in an engine piston pin endures the cyclic gas pressure and inertia forces at work and this working condition may cause the fatigue damage of the pin.

Failure of pin is due to stress concentration is one of the mainly reason for fatigue failure. Generally the piston pin is hallow cylinder, but according to the different working conditions and requirements, the selection of the piston pin material can be various. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. But more than wear and fatigue, damage of the piston pin is mainly due to stress development – shear stress, bending stress, contact stress & combined stress. Fig. 2 shows the photograph view of the new and damaged piston pin, Replacement of the piston pins is a cumbersome procedure, because the piston has to be checked, disassembled and possible collateral damages in the adjacent structures such as deformation due to bending stress, contact stress and shear stress must be checked.

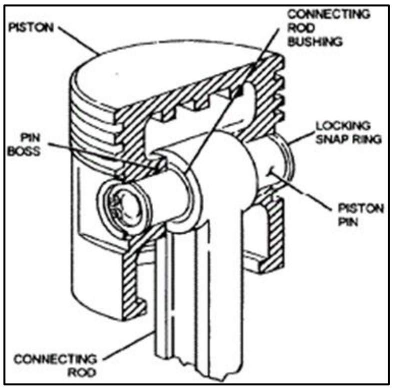

Fig. 1: Assembly View of the Gudgeon/piston pin of the piston with small end of the connecting rod.

Then, every component must be realigned, recalibrated and reinstalled. Thus besides the costs of new piston pins, one should also consider the costs due to maintenance and energy production cut. Hence it is important to analyze for the causes of piston pin's premature failure of the engine at real condition during combustion process. The Finite Element Technique (FEA) technique to predict the higher stress and critical region on the component of the material to enhance the performance of the gudgeon pin.

Fig. 2: Photograph of a New Piston pin and damaged piston pin

II. Problem identification

The piston pin which connects the connecting rod and piston in fig. 3 and it help in piston movement which makes the energy transformation in the proper manner. During the piston movement the piston pin is subjected to both shear and bending loads. Fig. 4 shows the broken piece of the pin due to max. Stress due to loading. The engine runs at a wide range of Rotation / Revolution per Minute (RPM), so fatigue also may also causes damage to the piston pin.

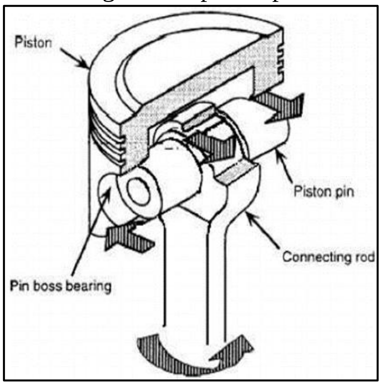

Fig. 3: Pin position

Fig. 4: Pin shear and broken piece

An attempt is made on the paper to enhance the clarity/competence the present problem by suggesting a different material with high temperature withstanding, shear, wear, capacity. The implementation of different metal is an innovative idea to substitute conventional piston pin manufacturing process and to identify the effect of gudgeon pin on fatigue performance of piston pin material. Due to its better physical properties it plays a significant role in automobile application. With the same mind an effort is made to apply materials to piston pin. Thus problem can be ratified by, "Improving pin performance of the piston by applying suitable materials".

III. METHODOLOGY

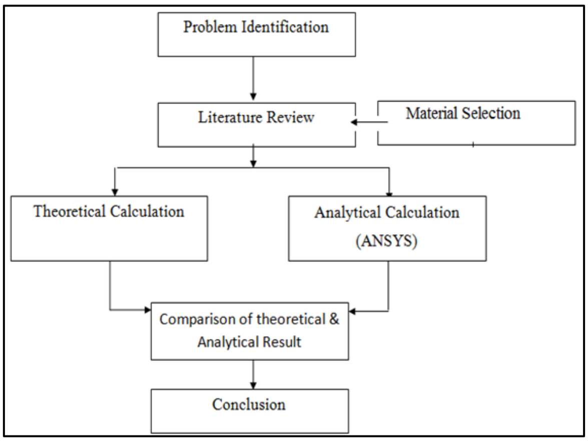

Fig. 5: Flow chart of methodology process of Performance investigation Gudgeon pin.

Investigation of the piston pin is improved by the theoretical and Simulation method with help of SolidWorks (for Designing) and ANSYS (for Analyzing) Investigation consists of material selection by selecting most appropriate materials base on the properties, Selecting the Gudgeon pin specimen for the theoretical calculation and for ANSYS calculation. Assumption is made for the optimization of the theoretical calculation. Then Compare both theoretical and Simulation calculation. Based on the comparison we conclude the material.

IV. MATERIAL SELECTION

Piston pins play a vital, literally essential, role in the internal combustion engine. Internal Combustion engines require higher performance for the longer life. Due to high cylinder pressure, the operating load and temperature of piston pin has become cruel. Therefore, high load capacity and wear and corrosion resistance are required for piston pin. Mechanically they are an extremely simple component and, in their most basic form, could be a simple, short length of solid bar. Indeed, many production piston pins are not far removed from this simplest interpretation, being a very plain steel thick-walled cylinder. Racing pins are generally more complex than production car pins, as we wish to reduce mass to an absolute minimum and are less concerned with cost. Any deviation from a simple cylinder is costly, especially if we have to machine both ends of the component. In chasing minimum mass, look to decrease length and diameter, within the important constraint of having to maintain adequate stiffness. There are other constraints we need to respect, the most important being to ensure sufficient life in the component by keeping stresses within acceptable bounds for the material in question. The most common material for piston pins general is steel; the surface is often hardened to improve wear resistance, and the choice of hardening method will dictate the choice of material in table 4.1 There are two main choices for hardening - carburizing (also known as case hardening) and nitride hardening. Both have a beneficial side-effect of imparting significant compressive residual stresses to the surfaces of the part, which in turn improve fatigue resistance compared to a part without these stresses.

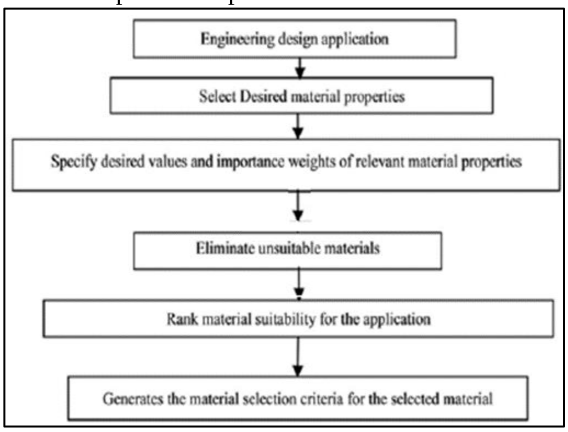

Fig. 6: Flowchart for Selection of Materials

Carburizing steels are characterized by low carbon content and additions of manganese, nickel and chromium; it is the low carbon content that allows diffusion of carbon into the surface. Nitriding steels have additions of elements such as chromium, aluminum and titanium, which are strong nitride formers. These nitriding steels are similar to - and in many cases the same as - steels that we would normally use to make racing crankshafts. There are a number of higher strength steels not necessarily designed for nitride hardening, but which it is certainly possible to nitride and which would make excellent candidates for piston pins. The wear resistance of all kinds of steel pins has been improved by using hard, thin coatings. There are various kinds of DLC that have been shown to be beneficial, and pins with these kinds of coating have been in reasonably widespread use in many categories of motorsport for well over a decade.

Steel is not the only choice for piston pins though Titanium has a much lower density than that of steel, although its elastic modulus (a measure of stiffness) is also low compared with steel. Titanium Ti-6Al-4V is often used, although pins made from Ti-17 (Ti-5Al-2Sn-4Mo-2Zr-4Cr) are also commercially available. We should not, however, expect to replace an optimized steel piston pin with one of the same dimensions made from titanium, and expect to find success. Titanium has particularly poor wear behavior in sliding contacts, so titanium pins has been added with aluminum alloy to increase the wear resistance of material. So, finally titanium and aluminum alloys were selected.

A. Material Description

Based on the factors improving performance of the gudgeon pin the materials have been selected. Not the performance factor it also included availability, cost & way of machining/ manufacturing, operations. The material composition and physical properties are listed below.

1) Ti-6Al-4V

It is an alpha-beta titanium alloy featuring high strength, low weight ratio and good corrosion resistance. It is one of the most commonly used titanium alloys and is applied in an wide range of applications were low density and good corrosion resistance.

a) Composition

Element	Percentage
Carbon C	< 0.08%
Iron Fe	< 0.25%
Nitrogen N_2	< 0.05%
Oxygen O_2	< 0.2%
Aluminium Al	5.5-6.76%
Vanadium V	3.5-4.5%
Titanium	Balance

Table 1: Composition

b) Application

- Aerospace industry
- Biomechanical applications
- Marine applications
- Gas turbine.

2) Titanium Ti-17 (Ti-5Al-2Sn-4Mo-2Zr-4Cr).

It is a beta-rich, alpha-beta alloy approximately used in beta and alpha-beta applications. Often referred to as grade-17, Ti-17 offers to as grade-17, Ti-17 offers improved tensile and creep strengths then Ti-6Al-4V.

a) Composition

Element	Percentage
Aluminium Al	4.6-5.5
Molybdenum Mo	3.5-4.5
Iron Fe	0.3 max
Nitrogen N	0.04 max
Chromium Cr	3.5-4.5
Tin Sn	1.5-2.5
Zirconium Zr	1.5-2.5
Titanium Ti	Balance

Table 2: Composition

b) Application

- Compressor and fan discs
- Other applications requiring high strength.

3) Al Alloy 4032

Aluminium / aluminium alloy are known for strong corrosion resistance. These alloys are sensitive to high temperature ranging between 200º and 250º C (392º and 482º F) and tend to lose some of its strength. However, the strength of aluminium / aluminium alloy can be enhance at subzero temperatures, making them ideal low temperature alloys.

a) Composition

Element	Percentage
Aluminium Al	85
Silicon Si	12.20
Magnesium Mg	1.0
Copper Cu	0.90
Nickel Ni	0.9

Table 3: Composition

b) Applications

Aluminium 4032 alloy is widely used in the manufacture of pistons.

c) Material Properties

The mechanical properties of the material Ti 6Al 4V, Ti 17, Al alloy 4032 are tabled below.

Properties	Ti 6Al 4V	Ti 17	Al alloy 4032
Density	4.43 g/ cc	4.65 g/ cc	2.69 g /cc
Poisson ratio	0.34	0.33	0.33
Modulus of Elasticity	113.8 GPa	109 GPa	80 MPa
Yield tensile strength	880 MPa	1140 MPa	315 MPa
Yield ultimate strength	950 MPa	1180 MPa	380 MPa
Yield strength	970MPa	110MPa	358MPa

Table 4: Mechanical Properties of selected Materials

4) Gudgeon Pin Specimen

For Calculating and Analysing we have taken the Gudgeon / Piston Pin specimen of TATA Manza [2011 – 2015]. The engine Specification of the Manza is tabulated below. The piston pin is made up of steel alloy. Here the engine specification of the Vehicle is specified below it further used in theoretical calculations.

5) Manza [2011-2015] VX Quadrajet

Engine Displacement (cc)	**1248**
Maximum Power	**90 PS@ 4000 rpm**
Maximum Torque	**200 Nm @ 1750-3000 rpm**
Engine Description	**4 Cylinder, Common Rail, Diesel**
Acceleration (0-100 kmph)	**15 Sec**
Turning Radius	**5.1 m**
No. of Cylinders	4
Gear box	**5 Speed**
Steering Gear Type	**Power Assisted Rack & Pinion-Hydraulic**
Fuel Supply System	**CRDI**

Table 5: Manza [2011-2015] VX Quadrajet

V. CALCULATION

The pin arrangement in the piston is like the UDL (Uniformly Distributed Load) acting on the simply supported beam in fig. 7.

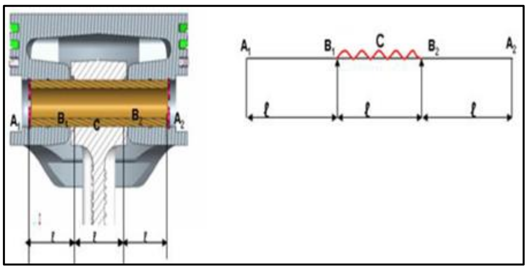

Fig. 7: Pin arrangement in piston

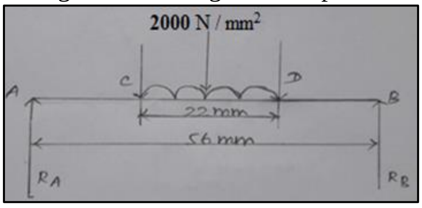

Fig. 8: Force Diagram

A. *Theoretical Calculation*

Shear force and bending moment calculations

Load applied, F	=	2000 N
Length, L	=	56 mm
UDL Length	=	22 mm
Outer diameter, D	=	22 mm
Inner Diameter, d	=	11 mm

Table 6: Theoretical Calculation

Here we assumed simply supported beam for structural analysis for theoretical calculation.

1) *Taking Moment*

R_B * 56	=	2000 * 22 * ((22/2) +17))
		22000 N
$R_A + R_B$	=	2000 * 22
R_A	=	44000 – 22000
	=	22000 N

Table 7: Taking moment

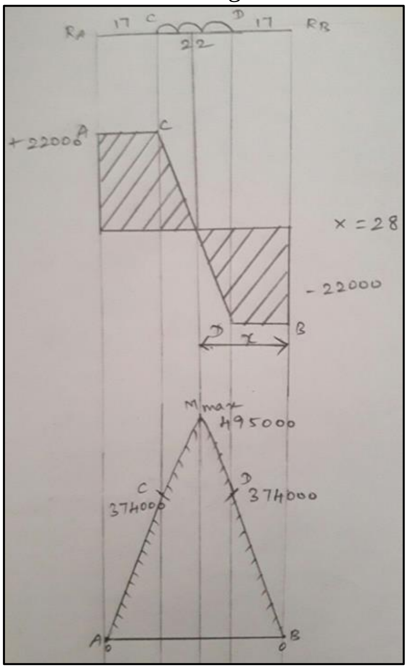

Fig. 9: Shear force and bending moment diagram

SF Calculations		
SF at B	=	- 22000 N
SF at D	=	- 22000 N
SF at C	=	22000 N
SF at A	=	22000 N

Table 8: SF Calculations

BM Calculations		
BM at B	=	0
BM at D	=	R_B* 17
	=	374 *10^3 N-mm
BM at C	=	R_B* 39 – (2000 *22*(22/2))
	=	374 * 10^3 N-mm
BM at A SF has (-) sign	=	0
SF	=	- 22000 N +(2000(X –17))
X	=	28 mm

Table 9: BM Calculations

2) *Model Calculation for Titanium Ti - 6 Al- 4 V*

- Elasticity Modulus E = 1.13 * 10^5
- Yield stress σ_y= 970 N/mm^2

Area	=	$\Pi/4 * (D^4 – d^4)$
	=	$\Pi/4 * (22^4 – 11^4)$
	=	284.955 mm^2
Shear stress τ_{sf}	=	22000 / 284.955
τ_{sf}	=	77.20517 N / mm^2

Table 10: Model Calculation for Titanium Ti - 6 Al- 4 V

Strain energy U	=	M^2 * L / (2EI)
I	=	$(\pi / 32)* ((D^4 – d^4) / D) * D / 2$

Table 11: Model Calculation for Titanium Ti - 6 Al- 4 V

I	=	$(\pi / 32)* ((22^4 – 16^4) / 22) * 22 / 2$
	=	10774.86
U	=	(495 * 103)2 * 56 / (2*113000 * 10774.86)
	=	5634.797 N - mm
Contact Stress $\sigma_{o\ max}$	=	$0.418[P^l E * ((1/R_2)-(1/R_1)]^{1/2}$
P^l	=	P/A
	=	2000/284.955
	=	7.018652
$\sigma_{o\ max}$	=	$0.418[7.018652*1.13*10^{5}*((1/5.5)-(1/11))]^{1/2}$
	=	112.2396 N / mm^2
τ_{max}	=	0.3* $\sigma_{o\ max}$
	=	33.67187 N / mm^2

Table 12: Model Calculation for Titanium Ti - 6 Al- 4 V

Bending Stress $\sigma_{b\ max}$	=	$32*M_b*D / (\pi*(D^4 – d^4))$
	=	32*495000*22/ (π*(224 – 114))
	=	505.3429N / mm^2

Table 13: Model Calculation for Titanium Ti - 6 Al- 4 V

Principal Combined Stress (Von Mises Hencky distortion energy theory) PSG D.D Pg.no7.3	=	$((\sigma_x+\sigma_y)/2) \pm \sqrt{(((\sigma_x-\sigma_y) /2)^2 + (\tau_{xy})^2)}$

Table 14: Model Calculation for Titanium Ti - 6 Al- 4 V

σ_x	=	0
σ	=	$((0+505.3429) / 2) \pm \sqrt{(((0 - 505.3429) /2)^2 + (33.67187)^2)}$
σ_1	=	516.875 N / mm^2
σ_2	=	-11.5321 N / mm^2
σ_y^2	=	$\sigma_1^2 + \sigma_2^2 – (\sigma_1 \sigma_2)$

	=	$516.875^2 + (-11.5321)^2 -$ (516.875-11.5321)
σ_y	=	522.7365 N / mm²

Table 15: Model Calculation for Titanium Ti - 6 Al- 4 V

- σ_y yield strength of the material is 970 N / mm²
- σ_y (material) > σ_y (calculated)
- σ_y (970 N / mm²) > σ_y (522.7365)

Hence design is Safe.

Fatigue Life		
σ_a	=	$(\sigma_1 - \sigma_2) / 2$
	=	(516.875 - (-11.5321)) / 2
	=	264.2035 N / mm²
σ_m	=	$(\sigma_1 + \sigma_2) / 2$
	=	(516.875 + (-11.5321)) / 2
	=	252.6715 N / mm²

Table 16: Fatigue Life

R	=	(σ_2 / σ_1)
	=	- 11.5321 / 516.875
	=	- 0.02231

Table 17: Calculation

A	=	σ_a / σ_m
	=	264.2035 / 252.6715
	=	1.045641

Table 18: Calculation

$(\sigma_a / \sigma_e^1)+(\sigma_m / \sigma_a)$	=	1
$(264.203/\sigma_e^1) + (252.6715/264.20)$	=	1
σ_e^1	=	6052.991

Table 19: Calculation

$(\sigma_a / \sigma_e^1) + (\sigma_m / \sigma_y)$	=	1 / n
(264.2035/6052.9+ (252.6715/522.73)	=	1 / n
n	=	1.897492

Table 20: Soderberg Equation

$(\sigma_a / \sigma_e^1)+(\sigma_m / \sigma_u)$	=	1 / n
σ_u	=	522.7365 N / mm²

Table 21: Goodman Equation

B. *Theoretical Result*

The theoretical result of the selected material are calculated based on the applied load, shear force and bending moment of the pin assumed as an UDL.

Material	Contact Stress $\sigma_{o\,max}$ N / mm²	Max. Shear Stress τ_{max} N / mm²	Bending Stress $\sigma_{b\,max}$ N / mm²	Yield Stress σ_y N / mm²	Factor of safety n
Ti 6Al 4V	112.2396	33.6718	505.3429	522.736	1.8974
Ti 17	110.2351	33.0705	505.3429	650.736	1.9574
Al alloy 4032	94.43909	28.3317	505.3429	740.736	2.1974

Table 22: The contact stress, max shear stress, bending stress, yield stress & factor safety of the selected material Ti 6Al 4V, Ti 17, Al alloy 4032.

VI. DESIGN AND ANALYSIS

A. *SolidWorks*

SolidWorks is a solid modelling Computer Aided Design (CAD) and Computer-Aided Engineering (CAE) computer program that is published by Dassault Systèms. It is used draw the solid modelling & we can analysis the flow, static and thermal analysis. The piston pins are designed according to piston pin what we have been taken and specifications given in machine design and design data book. Dimensions are calculated and these are used for modelling the piston pin in SOLIDWORKS13.

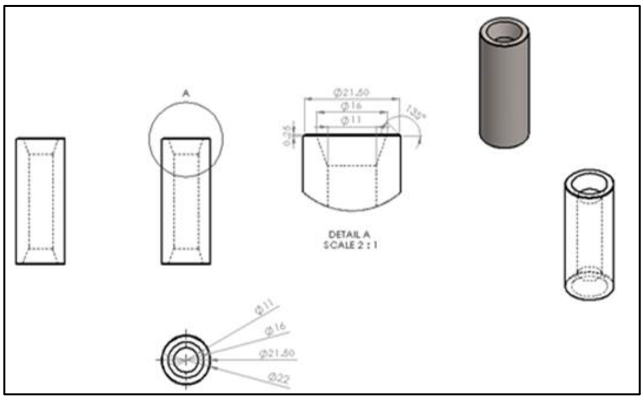

Fig. 10: Dimension of the piston pin

B. *Dimension of the Piston / Gudgeon / Wrist Pin*

- Length of the Pin = 56 mm
- Outer diameter of the Pin = 22 mm
- Inner diameter of the Pin = 11 mm
- Tapper Diameter = 16 mm
- Tapper angle = 45°

C. *Procedure*

- Select the circle; draw the circle for 16mm and 11mm.
- Select the smart dimension for giving the dimension.
- Draw the tapered line for 5.5 mm for angle 45o.
- Piston pin is designed.

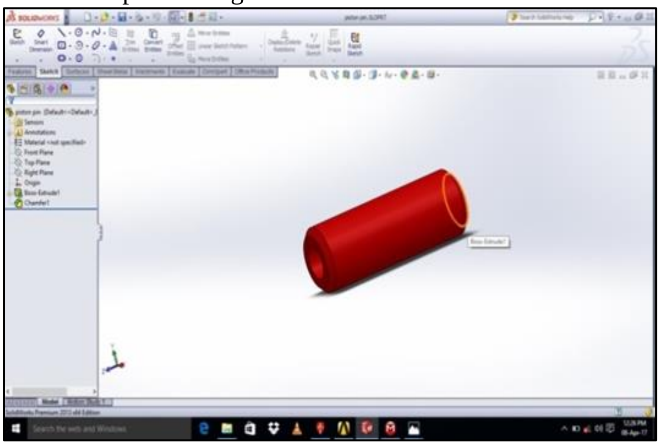

Fig. 11: Design of piston pin in Solid works

VII. INTRODUCTION TO ANSYS R 15.0

ANSYS is the general purpose finite element modelling package of numerical solving a wide variety of mechanical problems. This problem includes static, dynamic structure analysis, heat transfer and fluid problems.

A. Analysis of Titanium alloy (Ti6Al 4V)

Titanium alloy Ti 6Al 4V is undergone the load of 2000 N on the mid span of length 22mm and which undergone deformation due to bending moment.

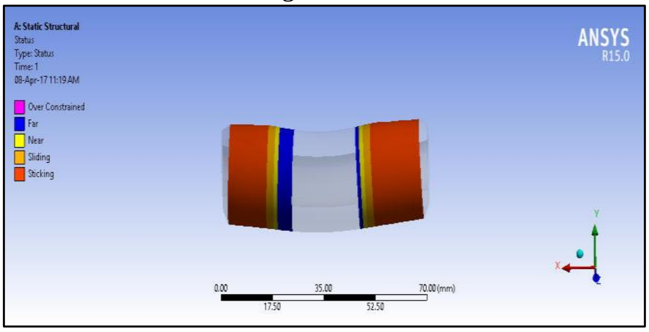

Fig. 12: Contact stress on Ti 6Al 4V material

Figure 12 and 13 show the contact stress and deformation due to bending moment respectively load. The maximum shear stress obtained was (33.34 N/mm^2) and von mises stress was (512.15 N/mm^2) for 5% bending combined with shear load of the shear pin. In this case the maximum shear strength is 970 MPa. It was observed that for the 5% of bending and crushing loads combined with the shear, the stress is lower than the maximum shear stress limit

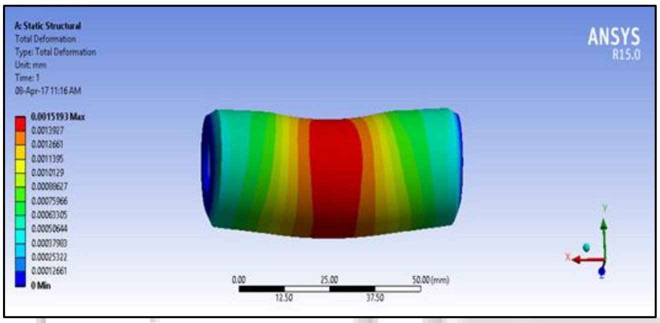

Fig. 13: Deformation for Ti6Al4V material

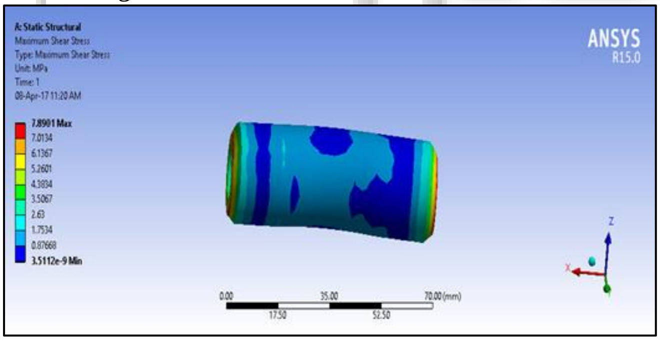

Fig. 14: Maximum Shear for Ti6Al4V material

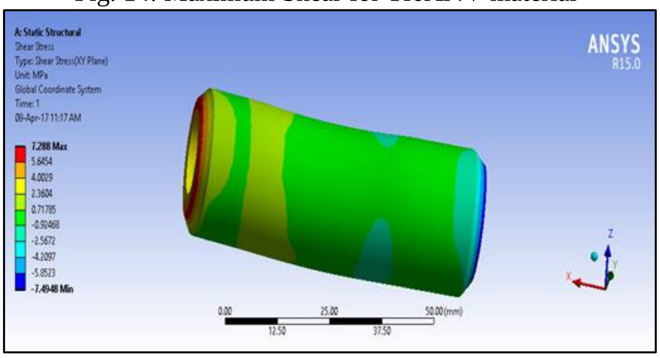

Fig. 15: Shear stress for Ti6Al4V material

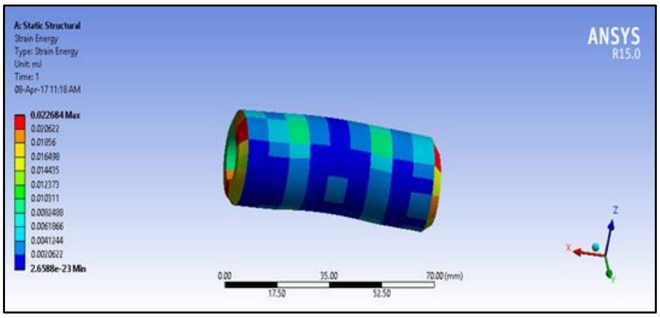

Fig. 16: Strain Energy for Ti6Al4V material

The combined effects of shear load with the bending and crushing loads were done for different percentage of load levels with the shear load. The maximum bending moment is derived from the bending moment diagram, which states that the material shear strength is 0.5 times the yield strength shown in fig. 15& 16.

B. Analysis of Titanium alloy (Ti 17)

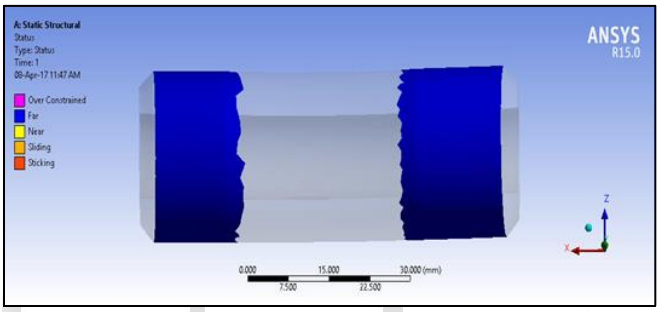

Fig. 17: Contact stress for Ti-17 material

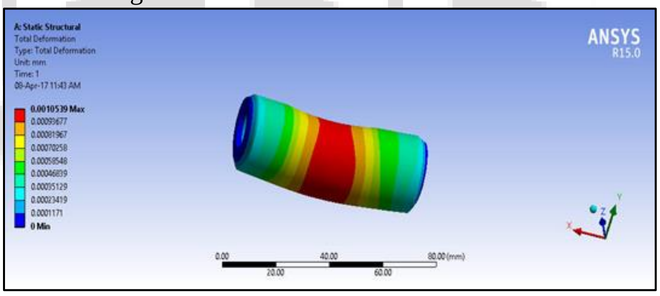

Fig. 18: Deformation for Ti-17 material

Figure 17 and 18 shows the contact stress and deformation due to bending moment respectively load. The maximum shear stress obtained was (34.94 N/mm2) and von mises stress was (630.15 N/mm2) for 5% bending combined with shear load of the shear pin. In this case the maximum shear strength is 1140MPa. It was observed that for the 5% of bending and crushing loads combined with the shear, the stress is lower than the maximum shear stress limit.

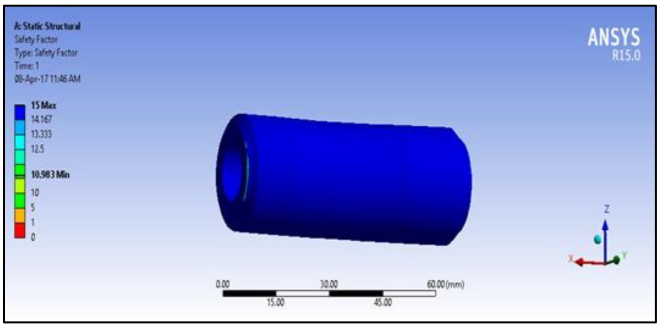

Fig. 19: Safety for Ti-17 material

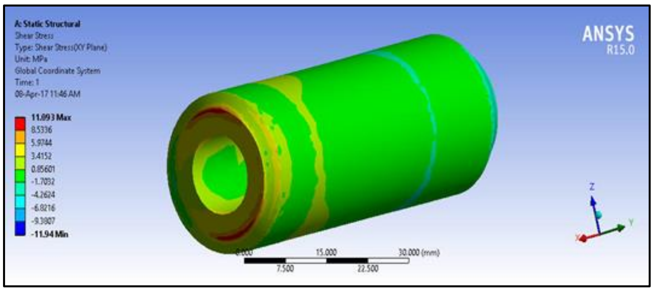

Fig. 20: Shear force Ti-17 material

The combined effects of shear load with the bending and crushing loads were done for different percentage of load levels with the shear load. The maximum bending moment is derived from the bending moment diagram, which states that the material shear strength is 0.5 times the yield strength shown in fig. 19 & 20. The deformation effect the pin boss and cause the pin to damage at the centre. Titanium 17 undergoes more deformation than Ti 6Al 4V.

C. Analysis of Aluminium 4032

It shows the contact stress analysis on Aluminium 4032 in which both end of piston /gudgeon pin in engaged with the piston.

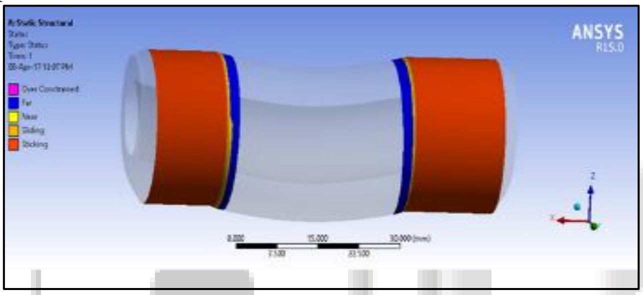

Fig. 21: Contact stress for Aluminium 4032

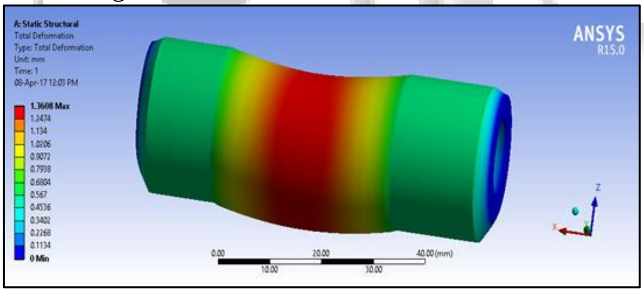

Fig. 22: Deformation for Aluminium 4032

Figure 21 and 22 show the contact stress and deformation due to bending moment respectively load. The maximum shear stress obtained was (28.34 N/mm2) and von mises stress was (739.15 N/mm2) for 5% bending combined with shear load of the shear pin. In this case the maximum shear strength is 380MPa. It was observed that for the 5% of bending and crushing loads combined with the shear, the stress is lower than the maximum shear stress limit.

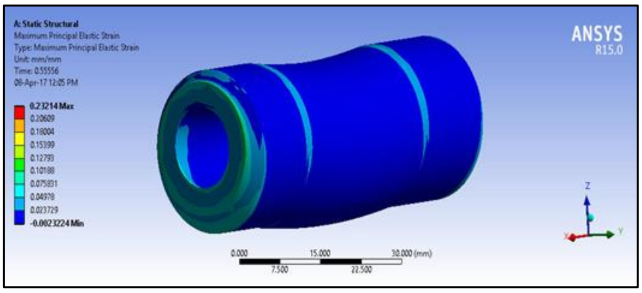

Fig. 23: Elastic strain for Aluminium 4032

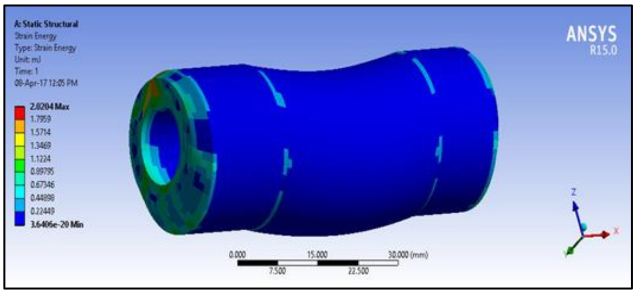

Fig. 24: Strain energy for Aluminium 4032

The combined effects of shear load with the bending and crushing loads were done for different percentage of load levels with the shear load. The maximum bending moment is derived from the bending moment diagram, which states that the material shear strength is 0.5 times the yield strength shown in fig. 23 & 24. The strain energy on Al 4032 absorbs more energy due to deformation

D. Comparison of Analytical and Theoretical Result

By above theoretical calculation and analytical calculation by ANSYS R15.0 it shows the material with low weight density, shear, wear, corrosion resistance is suitable for piston pin which can only enhance the competence. We concluded that that material Ti 6Al 4V which undergone a less deformation while applying various load. It also having high yield strength to withstand the shear and wear. Not only has the performance factored it also haves less availability, cost & way of machining / manufacturing, operations. So Ti6Al4V is better than other two materials Ti-17 & Al4032v which satisfies all the factors.

VIII. CONCLUSION

In our project we have designed am piston pin used for I.C engine by using two titanium alloys (Ti 6Al 4V & Ti-17) and aluminium 4032 alloy material which has found that aluminium alloy has undergone less deformation when compared to other titanium alloys. By absorbing the Theoretical, Analytical results and Von-Mises Stress Theory deformation is less for material Ti6Al4V. Finally from above result we concluded that titanium alloy (Ti6Al4V) is suitable for manufacturing piston pin.

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