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Buckling Sensitivity of Ultra Fine Grained Material AA2618 Connecting Rod

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Abstract: ***The objective of the work is to evaluate the best design parameters of connecting rod using Ultrafine Grained Material AA2618. The critical buckling stress for existing material (C70S6) is high and the primary objective is to optimize connecting rod in terms of reduction of weight and stress. The numerical investigation has been carried out using ANSYS. Modeling of connecting rod is done in Solid works designing software. The analysis is performed on Ansys to calculate the critical buckling stress and Von-mises stress is calculated in the stress analysis by applying the maximum external load. The analysis results are plotted graphically and results are compared to find the useful outcomes which are used to predict the structural behavior of connecting rod under given load.***

Keywords: Ansys, buckling analysis, connecting rod, material, properties.

I. INTRODUCTION

Engine connecting rod converts the cyclic motion of piston into the rotational motion. It plays a significant role in transmitting motion and is one of the important parts in terms of an efficiency and durability of engine [1]. During the power cycle it transmits thrust force which is developed due to the ignition of the fuel. It acts as an intermediary link between piston and crankshaft. It has a both rotary as well as linear motion. Since connecting rod is subjected to the tensile and compressive load both therefore it should have strength to stand at high load in both directions to sustain compressive stresses, buckling and fatigue stresses [2, 3, and 4]. There are different parameter and factor which has a major effect in the performance and life of connecting rod. The factors includes engine type, rotation per minute, area of shank etc., and design parameters such as thickness, radius, etc. The performance and factors of connecting rod can be improved by optimizing these parameters and factors [5, 6].

A limited number of researches have been performed by the researcher on the optimization of connecting rods. Consequently, reduction of weight in connecting rod proportionally effects the criteria such as yield and fatigue [7]. To obtain the better performance of connecting rod in terms of life and cost materials like forged steel, aluminium alloy and titanium etc. are used to produce the connecting rods. After a stretched period of investigation the Ultra Grained Fine Materials are considered as an vital category of material for manufacturing of the connecting rod. Ultrafine-grained (UFG) metallic materials display wonderful properties which make them very interesting for future structural or functional engineering applications. During the last decade there is huge development in severe plastic deformation techniques which is a technique to produce the Ultrafine-grained (UFG) metallic materials. Because of current advancement in stern plastic deformation process ultrafine-grained material are no longer only limited to single-phase materials, but can also be used in complex and hard alloys of technological application. An UFG material has a high-quality hardening effect and a high mechanical property [8].Various other practice also exist to manufacture high standards of plastic deformation, such as Equal Channel Angular Extrusion (ECAE), High pressure torsion (HPT), Accumulative Roll Bonding (ARB). Among others, severe plastic deformation (SPD) being a positive scheme to conform and to manage the mechanical performance of the materials [9]. In the present investigation the buckling analysis is performed for the two different materials namely C70S6 and AA2618 analytically as well as numerically using Rankine's formula.

II. METHODOLOGY

Buckling analysis is performed numerically and the Rankine's formula is used to calculate and predict the critical buckling stress of C70S6.

The geometric modeling is done using model of connecting Solid works. The critical buckling stress analysis is analyzed using ANSYS R 14.5 version. The analytical and numerical analysis has been performed for UFG AA2618 and the obtained result has been compared graphically with the C70S6. In the second phase both the analysis (analytical and FEM).

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III. MODELING OF CONNECTING ROD

A. Design Parameters

The Figure 1 shows the layout of connecting rod design for the analysis. All the portions, parts and dimension are illustrated and depicted in Figure 1.

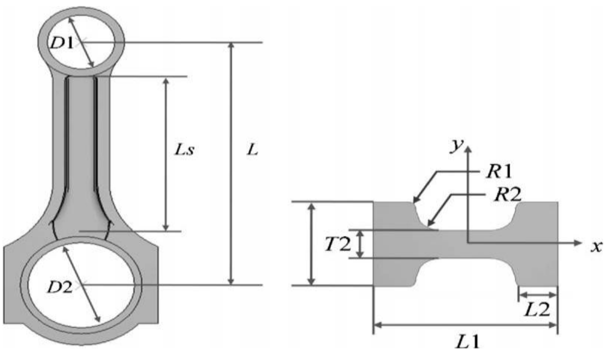

Fig1. Layout and cross-section of a connecting rod

Table- I Design Parameters

Design Module	Dimension (mm)
Frontal Profile	
Bore Diameter small (d1)	24
Bore Diameter big (d2)	48
Effective Length (L)	141
Shank Length (Ls)	98
Shank Section	
Radius 1 (R1))	1
Radius of Fillet (R2)	3.5
Width (L1)	18
Thickness (T1)*	16
Width of Side (L2)	2.5
Middle Thickness (T2)*	1.5

*Design Variables

B. Geometric Modeling

The modeling of connecting rod is done using design software Solid works. The Figure 2 shows the geometry of connecting rod used for numerical analysis. The result will help to estimate and predict the behavior of connecting rod. The calculation of the stress has been performed using the parameter shown in Table 1.

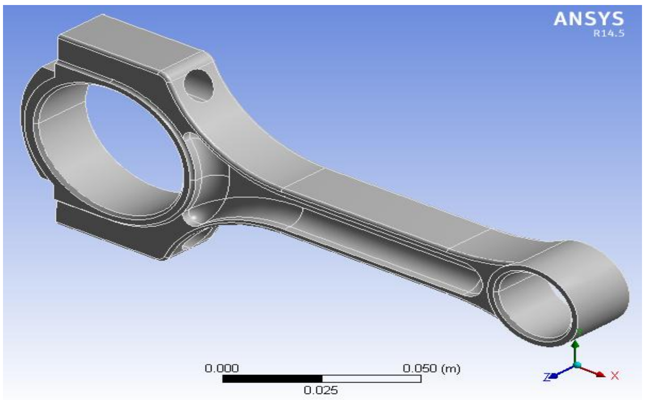

Fig 2. Geomteric Modeling of connecting rod in ANSYS

The finite element mesh of connecting rod is composed of tetrahedral elements. The equivalent stress is verified at four different locations in shank. The convergence is obtained with uniform length of element, additionally the convergence at chamfer is achieved using local size of mesh.

B. Boundary Condition

For static tensile loading connecting rod is assumed to have alternate loading in contact surface area. The pressure at contact surface is given as

$$P=Po\cos\theta \qquad (1)$$

This load is distributed at 180´ of crank angle. Now the total load is given by:

$$Pt = \int_{-\pi/2}^{\pi/2} Po(\cos 2\theta)\, r\, t d\text{£} = P_o\, rt\, \pi/2 \qquad (2)$$

where $Po=Pt/(r\, t\pi/2)$

Pt=tensile load at connecting rod

For compressive load acting on connecting rod the two ends of connecting rod are assumed to load distributed at 120'. Normal pressure at this condition is given as:

$$P=Po$$

Total load is calculated by

$$Pc= \int_{-\pi/3}^{\pi/3} Po\,(\cos\theta)\, r\, t d\text{£} = Po\, r\, t\sqrt{3} \qquad (3)$$

Where $Po=Pc/(r\, t\sqrt{3})$

In this study various models of connecting rod are analyzed. The big end of connecting rod is assumed to be fixed and load is applied at small end. Finite element analysis is conducted for both tension and compression. Two cases were analyzed for each dimension one having tension and other having compression. The load applied considered at connecting rod is 26.7kN. This analysis is linear elastic therefore in static stress analysis displacement strain and stress is proportional to magnitude of load.

IV. BUCKLING STRESS ESTIMATION

A. Critical Buckling Stress

Connecting rod transmits the motion to piston in form of rotary motion. Currently the buckling analysis is getting attention in automobile sector. However, the connecting rod has an irregular structure with small and large ends. Additionally, it suffers load in both direction i.e. tensile as well as compressive in nature. The compressive load may lead to the fracture of a connecting rod if it is higher than the resisting strength. The connecting rod buckles at lower value of compressive load when the slenderness ratio is higher than 40. This load is known as critical buckling load and the stress generated due to this is known as critical buckling stress.

The analysis is executed on "I" section of connecting rod. The "I" section is chosen to satisfy the relation among inertia of x and y axis i.e. $I_{xx}=4I_{yy}$. One major key point is that the connecting rod can buckle along both axes. It has been assumed that both the ends of connecting rod are hinged about x axis and it is unchanging along y axis.

The slenderness ratio plays a major function in choosing the radius of connecting rod for the optimum design. For best performance exclusive of buckling the crippling load should be always smaller than compressive load subjected to connecting rod.

The optimization process of connecting rod improve the performance of rod by suitable weight reduction and help to see variation in buckling stress of connecting rod for different geometries. The major stresses induced in the connecting rod during operation are axial stress and bending. The axial stresses are produced because of gas pressure compressible loading and by the force due to inertia of connecting rod and while bending stresses are induced due to centrifugal effects. Due to this the fillet section of small and big end of connecting rod are subjected to maximum stress. So to reduce the stress in this section various changes are made in the geometry of connecting rod. These changes also lead to weight reduction of connecting rod. Connecting rod should have highest possible rigidity at minimum weight.

The optimization of connecting rod by formulation method is done in true mathematical sense. The optimized solution is the one in which objective function can achieve minimum or maximum possible value under the definite set of constraint. In some cases the dimensions of new connecting rod are reduced in order to decrease the weight of connecting rods. This can be the minimum possible weight under the definite set of constraint. Here the numerical optimization technique has been used for calculation critical buckling stress in new connecting rod. The results are examined quantitative and the modified results. Because this task of optimization is not performed experimentally it cannot be guaranteed that he stress induced in the optimized part is the minimum buckling stress. The following factors has been considered during optimization buckling load stress under load slenderness ratio ultimate strength all are considered and checked to be within allowable limit.

B. Critical Buckling Stress using Rankine's Formula

The equation 4 shows the mathematical representation of buckling stress for connecting rod on shank based on Euler stress, where L is effective length, r is radius of gyration r and k is buckling constant k.

$$\pi_{cr} = \frac{\pi^2 E}{\left(\frac{K_Y L}{r_Y}\right)^2} \qquad (4)$$

where
E= elastic modulus
L/r = slenderness ratio
A= area of connecting rod

Rankine's equation is used to evaluate classical buckling stress is of connecting rod. The harmonic mean of Euler equation can be termed ad Rankine's formula. The yield strength can be mathematically written as:

$$\sigma_{cr} = (1/ \sigma^{e}_{cr} + 1/ \sigma^{p}_{cr})^{-1}$$

The equation above shows the modified Rankine's equation. The Euler formula can only be used on certain conditions (a) when column is slender with uniform cross section and as a defined boundary condition. However, the present analysis does not satisfy the following above condition. The shank is un-uniform along its length. Moreover, it is difficult to represent the effective length therefore modified formula is used for the calculation.

V. RESULT AND DISCUSION

Connecting rod is one of the most critical and important parts of IC engine. It is always subjected to continuous cyclic loading during operation of internal combustion engine. The critical buckling stress analysis of connecting rod is important to know the stress level on connecting rod and it behavior. In this Section numerical analysis for critical buckling stress has been performed on different parameters of connecting rod. The parameters of connecting rod like its width and thickness of I section are increased and decreased with different combination of web and flange dimensions. By changing this parameter we can know how much stress is developed on different geometry of connecting rods. By calculating the stress for various geometry of connecting rod we can know how much stress will develop on particular geometry of connecting rod.

Connecting rod is subjected to various complex motions, reciprocating and rotary motion, which can be characterized by the inertia loads that are induced in connecting rod due to bending stress. In view of numerical analysis of connecting rod for critical buckling stress it is necessary to determining the magnitude of buckling stress caused due to inertia loads. By knowing the value of this critical buckling stress it will be concluded whether the stress is taken into account or it should be neglected in the optimization. After calculating the buckling stress from numerical method it is again calculated by FEM method and both are compared. For validation of the result the stress is first calculated by formulation method then it is calculated by finite element analysis.

In this work the material of connecting rod has been replaced by ultra-fine grained Aluminum Alloy 2618 (AA2618). Ultrafine-grained (UFG) metallic materials display outstanding properties which compose them interesting for future structural or functional engineering applications. Because of current advancement in relentless plastic deformation method ultrafine-grained microstructures are no longer limited to easy to distort single-phase materials, but can also be used in multifarious applications. UFG materials have high-quality hardening effect and higher mechanical properties.

One of the most attractive techniques for producing UFG material is severe plastic deformation (SPD). A variety of other techniques are also exist by which one can manufacture , such as Equal Channel Angular Extrusion (ECAE), High pressure torsion (HPT), Accumulative Roll Bonding (ARB), among others, severe plastic deformation (SPD) being a favorable scheme to conform and to manage the mechanical performance of the materials.

Table II Composition of Aluminum AA2618

Element	Content (%)	Properties	Metric
Aluminium	93.7	Tensile strength	440 Mpa
Copper	2.3	Yield strength	370 Mpa
Magnesium	1.6	Shear strength	260 Mpa
Iron	1.1	Elastic modulus	75 Gpa
Nickel	1.0	Poisson's ratio	0.33
Silicon	0.18	Fatigue strength	125 MPa
Titanium	0.07	Elongation	10 %

A. Finite Element Analysis

The buckling stress prediction done be calculating buckling load from load multiplier. In this calculation first the linear buckling analysis of connecting rod is done to calculate the load multiplier after calculating the value of load multiplier load P_{cr} is calculated by multiplying load with static load applied and dividing this with area of connecting rod which is as follows:

$$\sigma_{cr}^{FEM} = P_{cr} / A \quad (5)$$

The elastic buckling stress is obtained by dividing buckling load with area of shank cross section. Finally critical buckling stress is obtained by:

$$\sigma_{cr} = (1/ \sigma^{FEM}{}_{cr} + 1/ \sigma^{p}{}_{cr})^{-1} \quad (6)$$

Analysis is performed with the existing material used to manufacture connecting rod and with the new material. Existing material is C70S6 with elastic modulus 210Gpa and poisons ratio 0.3, and the new material is ultra-fine grained material Aluminum Alloy 2618 (AA2618) with elastic modulus 75Gpa and poisons ratio 0.33.In the analysis overall focused was on shank portion.

Table III Critical Buckling Stress with Varying Width for C70S6 and AA2618

Decrease in width	Slenderness ratio (L/r)	C70S6		AA2618	
		Rankine Formula (MPa)	*FEM (MPa)*	*Rankine Formula (MPa)*	*FEM (MPa)*
18	34	426.6	317.29	234.41	153.62
17	34.82	421.77	314.42	230.29	151.80
16	36.15	414.35	317	223.72	153.40
15	38.63	398.9	306.29	211.83	146.57
14	45.24	360.52	294.55	182.82	139.16

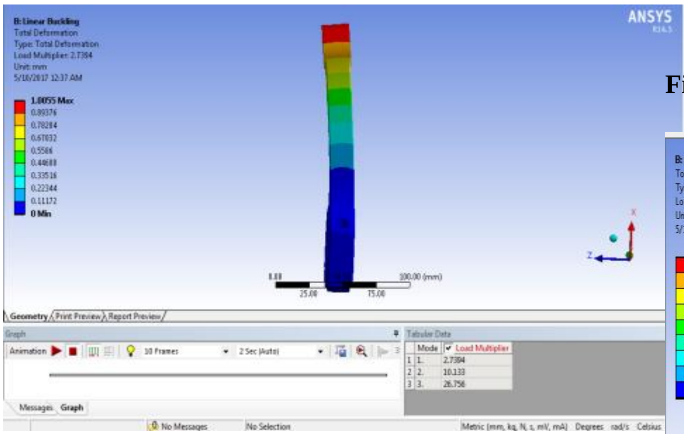

Fig. 3 Value of Load Multiplier for C70S6 at 18 mm width

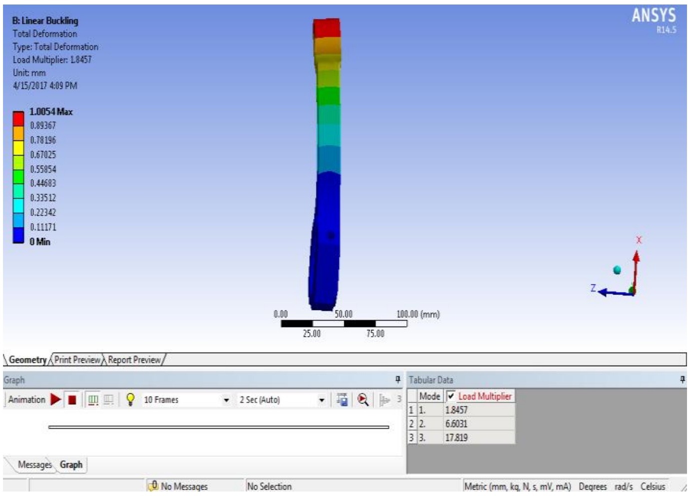

Fig. 4 Value of Load Multiplier for C70S6 at 16 mm width

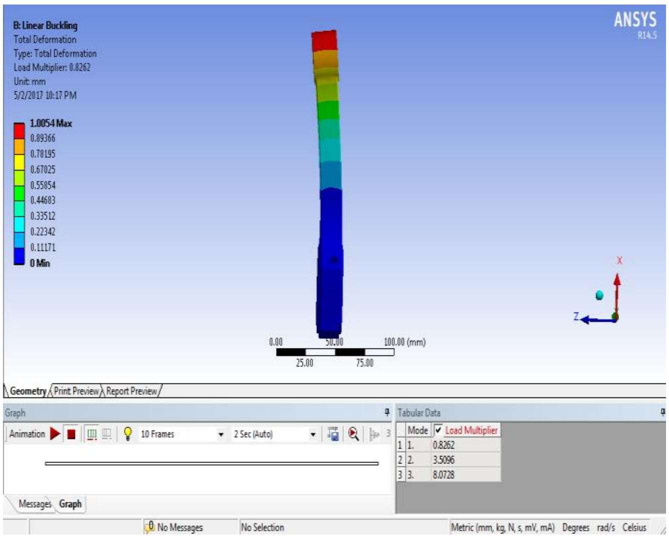

Fig. 5 Value of Load Multiplier for C70S6 at 14 mm width

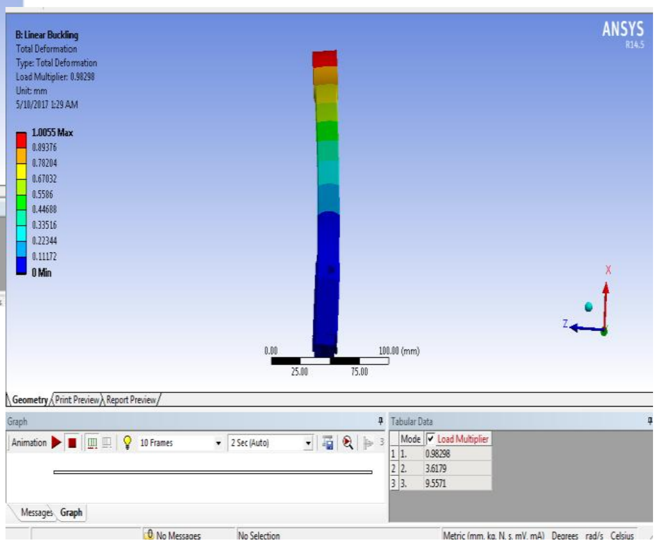

Fig. 6 Value of Load Multiplier for AA2618 at 18 mm width

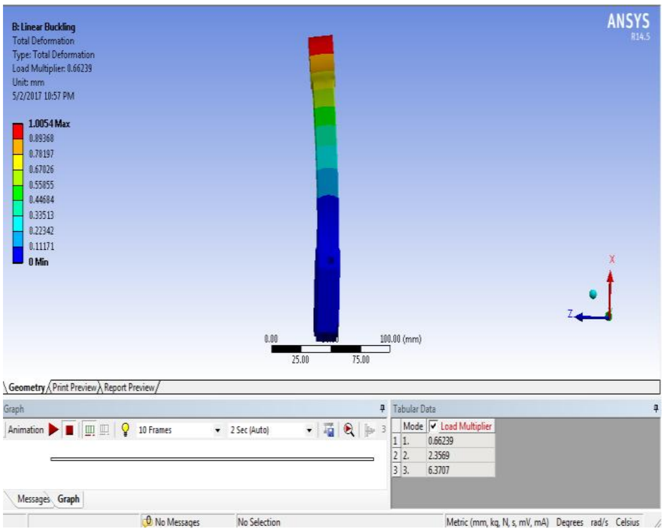

Fig. 7 Value of Load Multiplier for AA2618 at 16 mm width

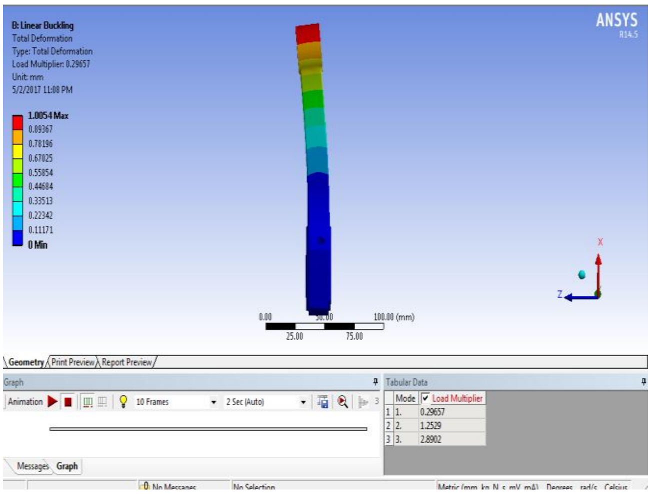

Fig. 8 Value of Load Multiplier for AA2618 at 14 mm width

Table IV Comparison of Critical Buckling Stress for C70S6 and AA2618 with Increasing Middle Thickness

Increase in Thickness	**Slenderness ratio (L/r)**	**C70S6**		**AA2618**	
		Rankine Formula (MPa)	*FEM (MPa)*	*Rankine Formula (MPa)*	*FEM (MPa)*
1.5	34	426.6	317.29	234.41	153.62
1.6	34.82	421.77	314.42	230.29	151.8
1.7	36.15	414.35	317	223.72	153.4
1.8	38.63	398.9	306.29	211.83	146.57
1.9	45.24	360.52	294.55	182.82	139.16

Above process is again performed with the varying middle thickness. It is found that during buckling analysis of C70S6 material Critical Buckling stress by Rankine's formula is slightly decreased with the increasing middle thickness.

While during the FEM method Critical Buckling stress is almost same with increasing middle thickness.

During the analysis of new Material AA2618 it is found that Critical Buckling stress by Rankine's formula is decreased with the increasing middle thickness. While during the FEM method Critical Buckling stress is initially slightly increased then decreased to the previous value with increasing middle thickness. While comparing the values of critical buckling stress for both the material it is found that Critical Buckling stresses (Rankine Formula) for AA2618 is 45%-46% is less compared to C70S6 material and Critical Buckling stress (FEM) for AA2618 is 50%-52% is less compared to C70S6 material. Stress analysis is performed for both the existing material C70S6 as well as new material AA2618 with the variation in the width of connecting rod. The cross sectional area of shank is reduced due to reduction in width in five steps. The stress analysis is preformed for two materials as shown.

Table V Comparison of Von Mises Stress

Decrease in width	**Max von Mises stress for C70S6 (MPa)**	**Max von Mises stress for AA2618 (MPa)**
18	591.03	586.49
17	456.41	455.88
16	518.96	519
15	520.43	520.34
14	505.27	505.18

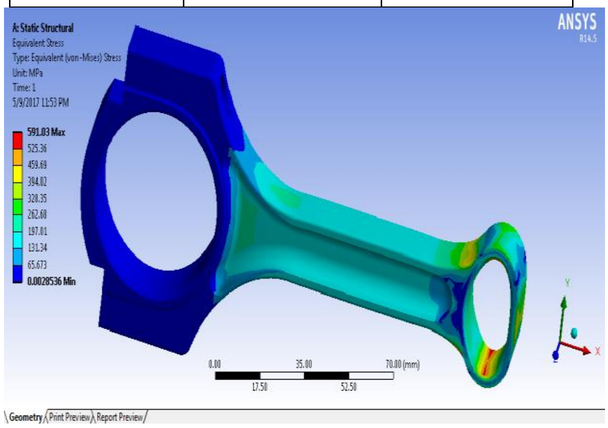

Fig 9. Max Von Mises Stress for C70S6 at width 18 mm

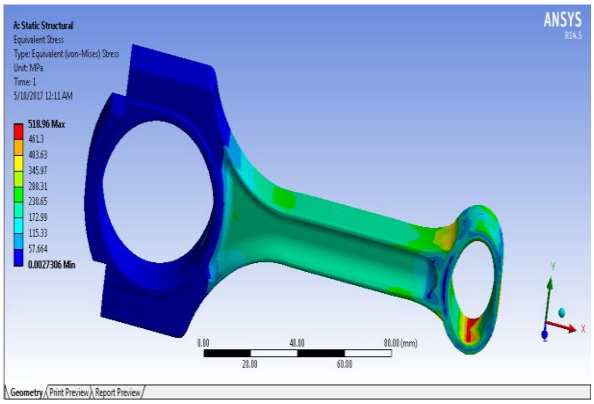

Fig 10. Max Von Mises Stress for C70S6 at width 16 mm

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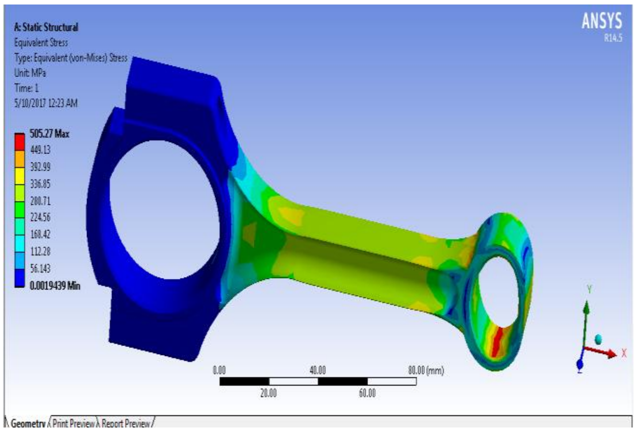

Fig 11. Max Von Mises Stress for C70S6 at width 14 mm

FEM analysis is performed for both the materials. During the analysis of C70S6 material while decreasing the width from 18mm to 17mm max von mises stress is decreased 22.77% but when we decreased the width from 17mm to 16mm stress increased around 13.7%.then slightly very with decreasing width. During the analysis of new material AA2618 while decreasing the width from 18mm to 17mm max von mises stress is decreased 22.26% but when we decreased the width from 17mm to 16mm stress increased around 13.84%.then slightly very with decreasing width. While comparing the Max von mises stress for C70S6 and AA2618 it is found that in the new material stress is slightly less than the existing material.

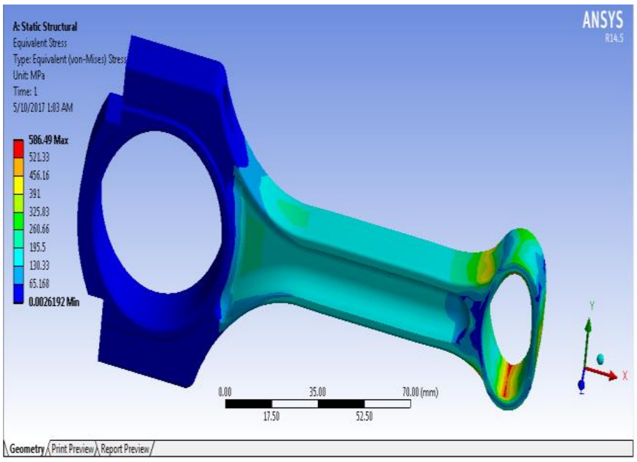

Fig 12. Max Von Mises Stress for AA2618 at width 18 mm

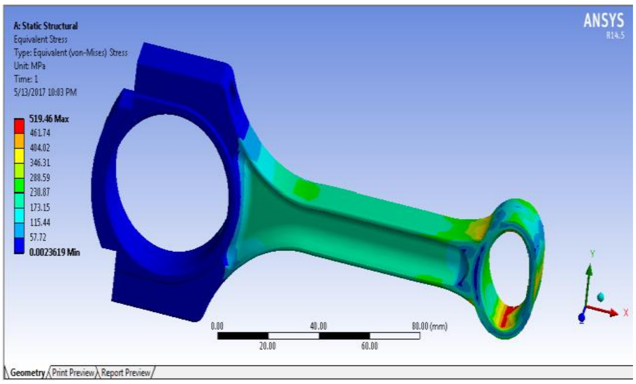

Fig 12. Max Von Mises Stress for AA2618 at width 16 mm

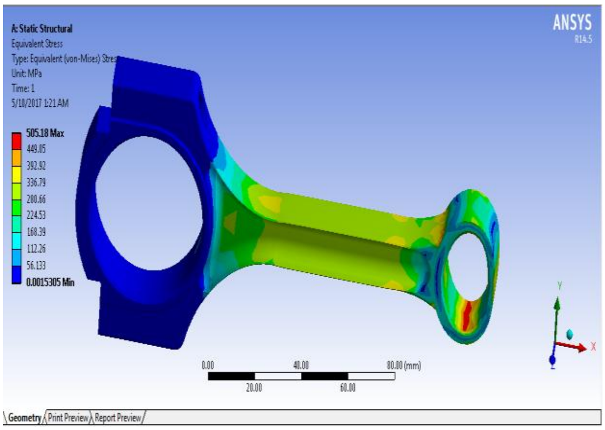

Fig 13. Max Von Mises Stress for AA2618 at width 14 mm

VI. CONCLUSION

In the present work buckling & stress analysis is performed by two methods. First buckling analysis is performed by changing the design parameter and second by changing the material of connecting rod. The connecting rod used for this analysis is taken from a reference paper. After performing the buckling analysis, stress analysis is performed by changing the material with the changing the parameters. All models of connecting rod are designed in Solid works designing software. After that numerical and FEM analysis are performed to calculate the critical buckling stress in buckling analysis and Von mises stress is calculated in the stress analysis applying the external force having the value 26.7 kN of load. After performing both the analysis results are obtained from analysis are use to predict the structural behavior of connecting rod under given load. The following conclusions are drawn from this study:

In numerical analysis various design variables (width & Middle Thickness) of connecting rod are changed. Width is reduced from 18mm to 14mm and middle thickness is varied from 1.5mm to 2mm. The slenderness ratio is calculated for each case. After that Rankine's formula is used to calculate critical buckling stress for each new design of connecting rod. Then for all the design FEM analyses are performed using ANSYS software, later both the results are compared. it is found that Critical Buckling stress (By Rankine's Formula) for AA2618 is 45.05% is less compared to C70S6 material and Critical Buckling stress (By FEM) for AA2618 is 51.58% is less compared to C70S6 material. It has been also concluded that some design variable are directly affect the critical stress so these variable can be accepted for modification and can be use to redesign connecting rod.

Additionally stress analysis is performed for both the materials. In this case the width of connecting rod has been reduced by 1mm. Each design has been analyzed to calculate the max von misses stresses of connecting rod. It is analyzed for compressive as well as tensile loading. The stress at various location of connecting rod is calculated and then results of all two materials are compared with each other.

After performing this analysis it has been found that in the existing design the max von-mises stress for the C70S6 material is found at small end is 591.03 MPa while in case of AA2618 max von mises stress found is 586.49 MPa which is slightly less compare to existing material C70S6.Which shows that the existing material can be replaced by the new material Density of AA2618 (2770 kg/m^3) is very less compare to C70S6 (7850 kg/m^3) because of that fatigue stresses will also be lesser in new material compare to existing material. As far as cost is concerned aluminum alloy is less expensive than carbon steel alloy.

REFERENCES

1. D.Gopinatha, Ch.V.Sushmab 2015. "Design and Optimization of Four Wheeler Connecting Rod Using Finite Element Analysis." Science direct, Materials Today: Proceedings 2 (2015) 2291 – 2299.
2. J.P.Fuertes, C.J.Luis, R.Luri, D.Salcedo, J.León and I.Puertas 2016. "Design, simulation and manufacturing of a connecting rod from ultra-fine grained material and isothermal forging, Journal of Manufacturing Processes 21 (2016) 56–68.
3. M.N. Ilman, R.A. Barizy 2015. "Failure analysis and fatigue performance evaluation of a failed connecting rod of reciprocating air compressor." Engineering Failure Analysis 56 (2015) 142–149.
4. A. Strozzi, A. Baldini, M. Giacopini, E. Bertocchi, S. Mantovani 2016. "A repertoire of failures in connecting rods for internal combustion engines, and indications on traditional and advanced design methods." Engineering Failure Analysis 60 (2016) 20–39.
5. Mohammed Mohsin Ali H, Mohamed Haneef 2015. "Analysis of Fatigue Stresses on Connecting Rod Subjected to Concentrated Loads at the Big End." Science direct, Materials Today: Proceedings 2 (2015) 2094 – 2103.
6. Carmelo J. Luis, Javier Leon, Rodrigo Luri, Ignacio Puertas, Ivan Perez, Daniel Salcedo 2011. "Development of Nano-Structured AA1050 by ECAE and Thermal Treatments." Scientific research, Soft Nanoscience Letters, 2011, 1, 120-129.
7. Moon Kyu Lee, Hyungyil Lee, Tae Soo Lee, Hoon Jang 2010. "Buckling sensitivity of a connecting rod to the shank sectional area reduction", Materials and Design 31 (2010) 2796–2803.
8. Roy, B.K. 2012. "Design Analysis and Optimization of Various Parameters of Connecting Rod using CAE Software's." International Journal of New Innovations in Engineering and Technology 1(1):52-63.
9. Dantale, A.D., and A. J. Keche.2014. "Fatigue Life Validation and Analysis of Connecting Rod." International Journal of Hybrid Information Technology 7(10):423-432.
10. Takemasu, T., V. Vazquez, B. painter, and T Altan.1996. "Investigation in metal flow and perform optimization in flash less forging of a connecting rod." Journal of materials processing technology 59: 95-105.

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Rashmi Dwivedi completed her M.Tech. and Ph.D. from Maulana Azad National Institute of Technology, Bhopal. Presently she is working as an Associate Professor in Sagar Institute of Science and Technology, Gandhi Nagar Bhopal. She has an experience of more than 9 years and has published more than 20 research paper in international journal of repute. She has also guided more than 5 M.Tech. student.

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