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Tanya Buddi[1], R S Rana[2*],Dhyanendra S Sikarwar[3], K. V. Durga Rajesh[4] and S K Dhakad[5]

[1]Department of Mechanical Engineering, GRIET, Bachupally, Hyderabad, India.
[2]Department of Mechanical Engineering, MANIT, Bhopal, India.
[3]Department of Mechanical Engineering, MANIT, Bhopal, India.
[4]Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram (A.P.) India.
[5]Department of Mechanical Engineering SATI Vidisha, India
ravindrarana74@gmail.com

Abstract. A connecting rod is an intermediate link between the Piston and the Crankshaft. The primary function of the connecting rod is to transmit the motion from the piston pin to the crank pin, thus converting reciprocating motion of a piston into the rotary motion of crank. Connecting rod plays an important role while designing the Diesel or Petrol Engine. The changes in the material (Al7068 alloy and Si_3N_4) of the connecting rod to increase its strength to weight ratio while maintaining or reducing the maximum stress, maximum strain and the maximum deformation developed during loading. The performance of the component can be analyze by using the ANSYS software and the properties of the material can be find out by performing different tests, after manufacturing the composite material by using an appropriate fabrication process, connecting rod has been modelled in CREO according to specific engine specifications of TVS Apache 150 model. Stress, Strain and the deformation analysis of the connecting rod is carried on the ANSYS WORKBENCH.

Keywords: ANSYS, WORKBENCH, Aluminum Matrix Composite, Al7068, Si_3N_4, Connecting rod.

1 Introduction

The term composite refers to the material which is composed of a discrete constituent distributed in the continuous phase, the discrete constituent is called the reinforcement and a continuous phase is called the matrix and which derives its different characteristics from its original constituents, the architecture of constituents and from the geometry [1].

Department of Mechanical Engineering, GRIET, Bachupally, Hyderabad, India

The physical or the chemical nature of matrix phase is the two bases on which composite materials are generally classified, for example metal-matrix, polymer matrix and the ceramic composites [2]. There are also some reports which indicate the emergence of the carbon-matrix composites and an Inter metallic-matrix. In aluminium matrix composites (AMCs) is one of the constituent of aluminium, which is termed as the matrix phase. The embedded constituent in this alloy matrix is usually the non-metallic and the commonly ceramics as SiC and Al_2O_3 [3]. Properties of the AMCs are varying in nature with its constituents and its volume fraction.
The advantages are:

- Cost reduction can be achieved by changing the microstructure of the connecting rod and strength to weight ratio is high.
- This material exhibits high wear resistance in compare to the conventional connecting rod and can be splitted in to the 2 pieces (the big body and the cap) by fracturing it with an instant impact loads.

There is always a demand for a light-weighting material with improved fuel efficiency in aerospace and automobile industries. This lead to increase the use of materials like aluminum over traditional metals as steel for increasing both range and efficiency. Aluminum has excellent specific strength, thermal properties and stiffness, it is also cost effective for the mass production. However, it suffers from poor wear resistance so its usefulness lowers in moving parts applications. The inclusion of ceramic reinforcements to produce the metal matrix composites (MMCs) which can improve both specific mechanical properties as well as tribological properties of aluminium [4]. The silicon nitride is a ceramic material having high strength, low coefficient of thermal expansion and stiffness. It also have high toughness for a ceramic material hence when combines to give it the extremely high thermal shock resistance [5] Aluminum Alloy 7068 is selected as a matrix material. Al7068 combination has one of the most noteworthy mechanical quality of all aluminum amalgams and significantly more than that of specific prepares [5]. This is the extraordinary combination joining yield quality of up to 700MPa (which is up to over 30% more noteworthy than that of the Al7075 amalgam) and the great malleability with the consumption opposition which is like Al7075 and different highlights is superior part/gear originators[6]. It is created in mid 1990's, Al7068 composite is made as a higher quality option in contrast to the Al7075 for the arms applications [7]. It is the profoundly appealing with a general mix of the mechanical properties (which permits it to hold at the raised temperatures better than Al7075) and the other significant qualities of Al7068 have likewise brought about an across the board determinations of composite to notably lessening the weight/cross segment and fundamentally increment in the quality of the basic segments in the different market segments [8].

Connecting rods, Bearing caps in high performance engines, Auto sport gearbox actuators, Automobile shock absorbers, Mountain climbing equipment, Fuel pumps chain tensioners, Prosthetic limbs, Auto sport wheel components, Ordnance, Load cells, 25mm Sabot, Hydraulic valve components, Tent, ski and High pressure solenoid, backpack rods Survival rifles, Snowmobile engine shaft, Flexible shaft coupling, Quick disconnects for the fluid conveying devices for the racing engines, Motorcycle gears, Rocker arms for racing engines, Racing motorcycle, etc [9]. Silicon nitride is a favored artistic for the high mechanical operational efficiency applications [10]. This clay can likewise be viewed as incredible possibility for the biomedical applications as a result of similar properties which makes it so significant for the designing application like high wear obstruction, compound strength, low grinding coefficient and it is chiefly because of mechanical conduct under the enunciation which is commonly viewed as superior to that for the alumina pottery [11]. Silicon nitride (Si_3N_4) is solid and the warmth safe material which can fabricated in various structures with explicit advantages of various kinds like careful inserts. Silicon nitride is first produced in year 1955 for thermocouple tubes and molten metal cruicibles and also used in rocket nozzles. Such materials are formed by nitriding silicon powder compacts [12]. Considerable changes in internal arrangement took place to form silicon nitride crystal which grows with the preexisting pores of silicon powder compact as this is heated in nitrogen at 1200°C. After that they observed its original dimensions of component remain same by nitriding then they heated to provide strength [13]. The final material contains 20-30%

microporosity that limits its strength (<200MPa) for certain applications. So, finally sintered to produce the dense and high strength material [14]. Connecting rod is undergoing different dynamics forces due to the gas pressure acting on the piston, inertia of the reciprocating parts (mass of the connecting rod, mass of piston, gudgeon-pin, etc) which can cause a failure of the connecting rod, also it will be very difficult to analyze and monitoring connecting rod experimentally under the actual conditions [15]. Different materials can be used for the manufacturing of connecting rod to make it stiffer and more durable against the structural deformation [16]. Finite element method is used to analyze as well as to optimize the connecting rod with a different topology for reducing the weight of the connecting rod and to increase the natural frequency of connecting rod. Some literatures are focused to optimize connecting rod for minimization of the stresses which are acting on the connecting rods [17].

CREO Elements/Pro 5.0, is an affiliated, include based, and the parametric programming which was created by PTC (Parametric Technology Corporation).The Parametric programming can adjust various boundaries (geometry, measurements) of the item[18]. The relations and measurements used to make scarcely any highlights are put away in a model. This empowers us to catch the structure plan, and assists with making changes effectively to that model through those boundaries. The highlights are characterized to be in parametric shapes which are related with the characteristics, for example, an inherent geometric boundaries (profundity, width, length, and so forth), position and direction, material properties and geometric resilience [19]. Similarly, highlights can be included, like, pockets, openings, cushions, ribs, filets, drafts and chamfers. As these highlights are made, they can be applied legitimately to work piece. The CREO model is completely partner with drawings and gatherings or parts that reference it [20]. The Changes to the model is consequently reflected in a related drawings and gatherings. In CREO component, this affiliated conduct is a bi-directional, implying that the adjustment in one mode will be naturally reflected in every single other mode.

From the literature, the properties of the material have been enhanced by adding ceramic into alloy at various compositions. The Aluminum Metal Matrix composites can be prepared by different ways like powder metallurgy, stir casting, etc. it not only increases its external strength but also increases the molecular strength and surface texture. The mould is prepared from the connecting rod pattern of TVS apache 150. Different weight percentages are considered and manufactured different connecting rods and checked their properties and compared it with the forged steel which is originally used nowadays. CREO is used for modelling and analysis is done by using ANSYS, and for optimizing the different parameters, finite element method has been used.

2 Materials and Methods

2.1 Materials

Al7068 and Si3N4 are the materials used to manufacture the composite. Al7068 alloy consists of mainly other elements as Zn, Mg, Cu, Fe, Si, Cr, Mn and Ni. The elemental composition of Al7068 alloy is shown in Table 1.

Table 1. Elemental Composition of Al7068

Al	Zn	Mg	Cu	Fe	Mn	Ti	Si	Cr	Ni
85.51	8.30	3.03	2.42	0.192	0.034	0.05	0.142	0.05	0.0075

2.2 Methods

Al7068 is widely used for manufacturing various components because of its good properties as good corrosion resistant property, good castability and machining and the welding characteristics. Three different samples has been prepared by using different combinations weight percentage (wt%) of the two materials as shown in Table 2.

Table 2. Weight % of the composite material

Sample	Al 7068 (wt%)	Si_3N_4 (wt%)
A	100%	0%
B	97%	3%
C	95%	5%

Sample A consists of 100% of Al 7068 and 0% of Si3N4, Sample B consists of 97% of Al7068 and 3% of Si_3N_4, 95% Al 7068 and 5% of Si_3N_4 in Sample C, weight percentages of these materials has been used in the preparation of all the three samples (A,B,C) using Stir casting process.

The stir cast constitute of pre-heater, electric-powered furnace, stirrer, etc. In this process, six heating elements are in use in series. The furnace temperature is maintained at 900°C. Before melting the metal, dies are placed inside heating furnace and pre-heated up to 2500°C. It is to ensure for proper solidification to obtain a desirable grain growth.

Aluminum bars are laid into clay crucible and then it is positioned inside the melting furnace. As the furnace is retained at 900°C, at a period of time, the metal starts converting into the liquid molten form. The stir casting motor starts rotating which is aligned with the crucible, by adjusting a slider rod, rotor is rotated at 700rpm. This setup of the stir casting is set in the Nano composites Lab at MANIT Bhopal as shown in Figure 1.

Fig. 1. Ultra-sonic Stir casting machine

At this stage, Silicon Nitride (Si_3N_4) micro powder particles are dispersed in the molten metal, this process continuous until the entire powder of Si_3N_4 mixes inside the molten metal. The formation of the slag has be removed which is observed to be formed continuously on the surface of the molten metal. After 30min of continuous stirring process, melt which is at ≈ 865^0C is poured into the permanent moulds. After ensuring the proper mixing of Si_3N_4 particles, the molten metal is poured directly into pre-heated die cavities with 116×116×14 mm dimension, at an optimum speed. The required casts are acquired after enduring it through solidification and cooled at room temperature. The casted three different samples of Al MMC have been manufactured by using stir casting process.

2.3 Design of Connecting Rod in CREO:

The methodology of the design calculations for a connecting rod is done by considering that connecting rod to be an equivalent to a standard ‘I’ section and its thickness is assumed to be ‘t’, height ‘5t’ and width ‘4t’. The design calculations for any connecting rod is done on basis of the engine under consideration as the length of the connecting rod depends on crank radius for the crank mechanism, which is equal to twice that of crank radius. The connecting rod model is prepared in CREO software by using the respective geometrical dimensions which are calculated. In this work, the dimensions of the connecting rod are taken from the standard engine of TVS Motor-Apache 150 which is having the specifications of engine as mentioned below:

- 4 stroke, air cooled engine
- Displacement volume, Vs = 147.5 cc
- Maximum Power, P = 9.95 kW @ 8500 rpm
- Maximum Torque, T = 12.3 kW @ 6000 rpm
- Bore and Stroke = 57 × 57.8 mm
- Compression Ratio, r = 9.5:1
- Power to Weight Ratio = 101.6 bhp/ton

The drawing of the connecting rod with the dimensions is shown the Figure 2.

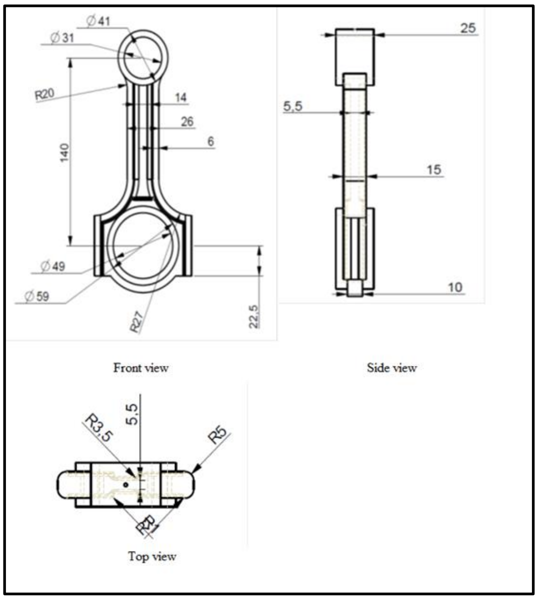
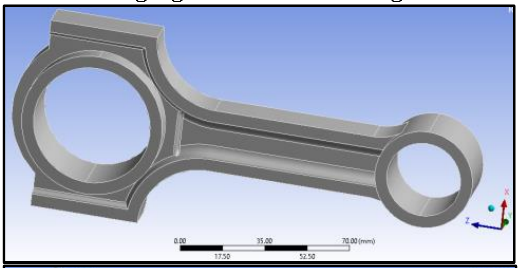


Fig. 2. Drawing for the connecting rod

Thickness of flange,	t =3.075 mm
Width of section,	B = 4t= 12.33 mm
Depth or height of section,	H = 5t= 15.375 mm
Depth near big end,	H_1= 18.066 mm
Depth near small end,	H_2= 12.684 mm

The mesh in the model is generated with element size. The shank portion is given an element size of 1 mm and rest of model is given an element size of 2 mm. So, the total of 0.24 million elements have generated in the mesh of model. The relevance center has given medium in order to have a fine mesh at the small element size sections and the coarse mesh at the large element size sections. The generated mesh has tetrahedron in order to match the connectivity between elements. Using the tetrahedron mesh maximum aspect ratio of the elements is found to be 12:1 which usually consider to be good for the mesh with 0.26 million elements. The mesh is also checked for the independency. The average orthogonality of the element is 0.8 and this shows that the mesh generated has matched the standards and there is no requirement to refine the mesh further. The modeled connecting rod before meshing and after meshing figure are shown in Figure 2. and Figure 3.



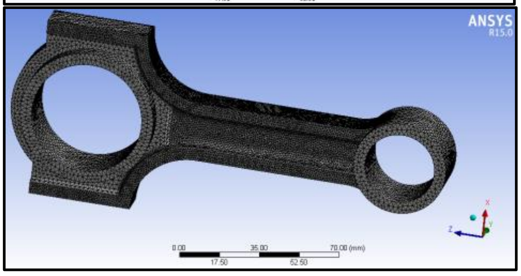


Fig. 2. Modeled element (before meshing) **Fig.3.** Modeled element (after meshing)

The geometry has been imported from PTC CREO to do the modal and stress analysis. All the material properties of the Al MMC have been given as shown in the Figure 4. After the mesh is generated go to the geometry section in the ANSYS. All the required boundary conditions in the Analysis settings like fixed the support forces have applied.

Properties of Outline Row 3: C7S6

	A	B	C
1	Property	Value	Unit
2	Density	7850	kg m^-3
3	Isotropic Elasticity		
4	Derive from	Young's ...	
5	Young's Modulus	2.1E+11	Pa
6	Poisson's Ratio	0.3	
7	Bulk Modulus	1.75E+11	Pa
8	Shear Modulus	8.0769E+10	Pa
9	Tensile Yield Strength	1E+09	Pa
10	Compressive Yield Strength	6E+08	Pa

Fig.4. Material Properties of the Al MMC

3 Results and Discussion

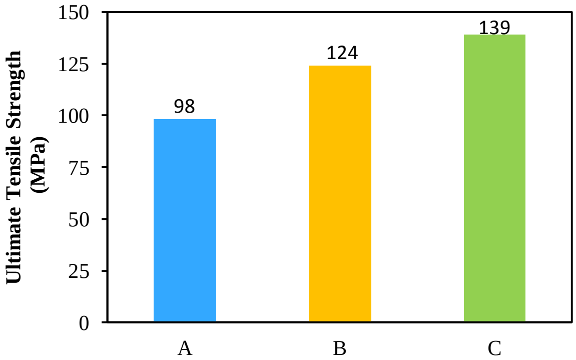
3.1 Mechanical Properties

To investigate the mechanical properties like tensile strength, yield strength, elastic modulus and hardness, tests has been conducted on these casted AL MMC samples.

3.1.1 Tensile Test

Tensile test is performed by operating Universal Testing Machine (UTM) TUE-C-400 of ASTM E-8 standard. The test is led in uprooting control mode and crosshead speed is kept up at 1 mm/min. All the samples have been tested with 400 KN load cell which is having a gauge length of 24 mm and breadth of 6.25 mm. The samples A, B, C have been tested for analyzing Ultimate tensile strength and Yield strength.

The comparison of Ultimate tensile strength and Yield strength are presented in the plots as shown in Figure 5,6, it is observed that the tensile strength of the stir casted component increases as the weight percentage of the Si_3N_4 increases from 0 to 5% in Aluminum alloy. From the plot it is seen that the expansion of Si_3N_4 content prompts increments rigidity of composite. In this elasticity expanded from 98 MPa to 139 MPa from perfect Aluminum to 5 wt% of Al-Si_3N_4 composite. This shows with a bringing Si_3N_4 into Aluminum network improves material properties as a result of the great similarity and the interfacial bond among Si_3N_4 and the Aluminum grid. The mechanical properties of Al composite are enhanced the Si_3N_4 digestion. It is seen that the both hardness of AMCs are expanding straightly with the expansion in weight level of the Si_3N_4 particles. It might be credited as a result of enhancing in the event of hard Si_3N_4 particles in aluminum framework and the high hardness of Si_3N_4 particles. Joining of the support particles in aluminum lattice diminishes the grains size of aluminum grid. Further, event of the hard and the weak Si_3N_4 particles in delicate and flexible Al compound network lessens the flexibility substance of the manufactured AMCs because of the little pliable substance of lattice metal in composite, which significantly upgrades hardness of the created AMCs.



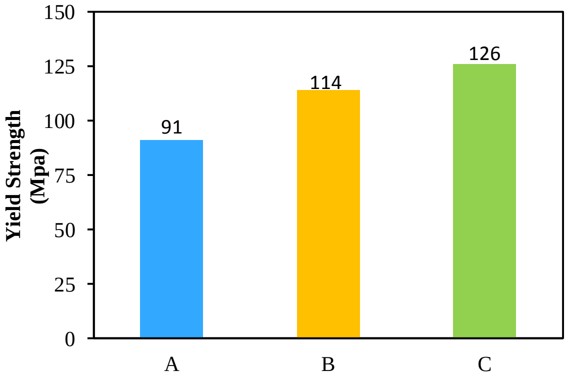


Fig.5. Ultimate Tensile Strength **Fig.6.** Yield Strength

Expanded measure of the fortification in network prompts expanded in disengagement thickness during cementing because of the warm jumble of aluminum lattice and support. The crisscross of the warm development between aluminum framework and the fortification, due to the temperature distinction, brings about the huge inner pressure so aluminum lattice twists plastically to stop a littler volume extension of the support particles. Enlargement in the disengagement thickness at molecule network interface results in the higher protection from the plastic misshapening, prompting the improved hardness. Connection between the elasticity of manufactured AMCs and the weight level of the Si_3N_4 particles. It tends to be presumed that the Si_3N_4 particles are employable in improving elasticity of the manufactured AMCs from 98 MPa to 139 MPa. This ascent in the UTS might be because of the event of the hard Si_3N_4 particles in aluminum network.

These hard Si_3N_4 particles confer their solidarity to aluminum framework by their fortifying system; because of the heap move from the fortification particles to the network, because of which lattice offer more protection from the elastic pressure delivered. It is notable that the warm extension co-productive of Si_3N_4 particulates is $1.4 - 3.7 \times 10^{-6}/°K$and for the aluminum is $24 \times 10^{-6}/°K$. This bungle of the warm extension among framework and support particles results into the higher separation thickness in lattice and the heap bearing limit of the hard fortification particles, which raises quality of the AMCs. At the point when substance of the low coefficient of warm development (CTE) fortification particles ascends in higher coefficient of warm extension network, it results in the miniaturized scale basic attributes of lattice to change with the correspondent commitment in the becoming stronger. Further, increment in the quality might be credited as a result of the heap move of the support particles to the grid, which expands load bearing limit of the created composites which results into an acceleration in the quality.

3.1.2 Percentage elongation

The percentage elongation of the aluminum alloy decreases as increase in Si_3N_4 ceramics (Figure 7) because of decrease in ductility of the component or the increase in brittleness of the component.

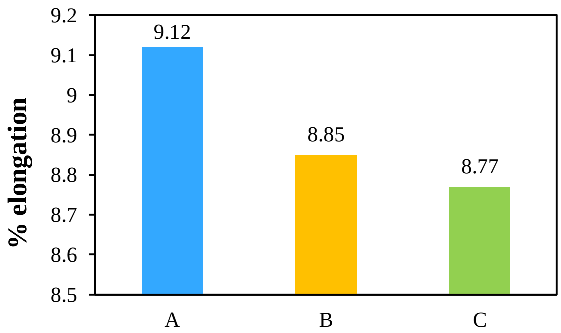


Fig.7. Percentage elongation

3.1.3 Brinell hardness number

Brinell hardness testing machine is used to find out the Brinell hardness number of the different samples. The Brinell hardness test is commonly applied for the hard materials and it quantifies the hardness dependent on space of the point (level tip). The power of the infiltration of indent is utilized to portray hardness of the space in contrast with entrance of an indenter. Qualities are taken at five distinct focuses and the mean qualities are plotted. As the percentage of the Si_3N_4 increases in the sample, the hardness of the sample increases continuously as represented in the bar graph (Figure 8) below.

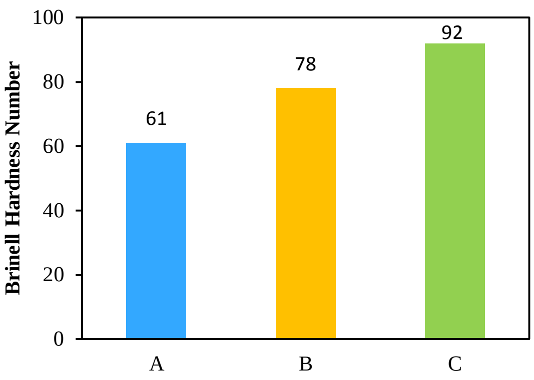


Fig.8. Hardness Number

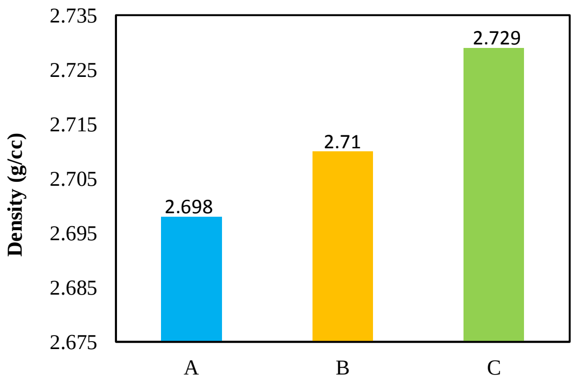


Fig.9. Density (g/cc)

3.1.4 Density

It is also observed that the density of the sample increases as increase in the percentage of silicon nitride ceramics in the aluminum alloy 7068, as shown in Figure 9.

Connection between rate extension of the manufactured AMCs and the weight level of Si_3N_4 particles, the rate stretching decreased with an expansion in rate Si_3N_4 expansion in aluminum framework. The weak conduct of Si_3N_4 particles assumes noteworthy job in diminishing its flexibility; on the grounds that, Si_3N_4 as support is a fragile and they expanded weakness in the created composites, which in-turns decreased malleability substance of the composites. Further, expanding wt. % of the Si_3N_4 particles in composites repulses the stream capacity of aluminum lattice and diminishes malleable network content, which brings about fall of rate lengthening of the composites. Indistinguishable outcomes of the decline in rate extension with the expanding measure of fortification in aluminum network regardless of manufacture procedure of the composites are accomplished.

3.2 Finite Element Analysis

Stress analyzing in the different parts of the connecting rod. Two different conditions has been considered for analyzing stress in the connecting rod,
(a) Pin end Compressive force, (b) Crank end compressive force.
The compressive force applied on the connecting rod has been analyzed. The force is applied on the bigger end by fixing the smaller end and analysis has been done at different points for minimum and maximum stress generated, also for maximum and minimum strain, and total deformation by different failure theories. Figures below display, the maximum stress, strain and deformation transpired on the connecting rod.

As shown in Figure 10, a compression load of 86.4kN is placed at the bigger end of the connecting rod and it is fixed at another end. The direction of the load represent whether it is compressive or tensile in nature.

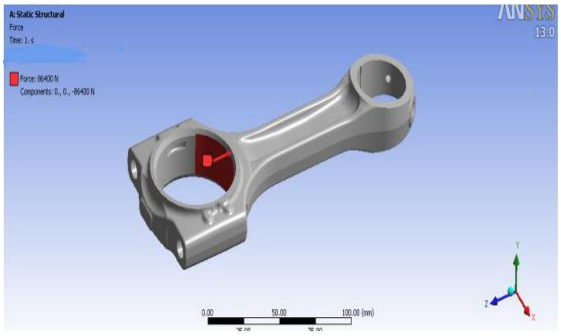
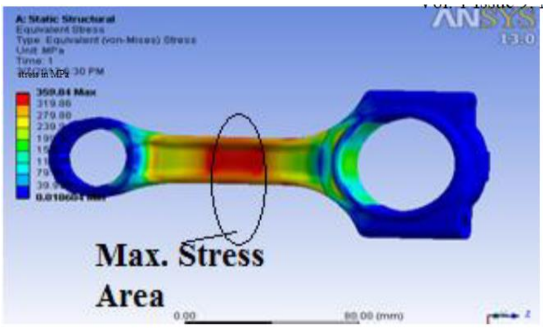


Fig.10. Compression load applied at bigger end

From Figure 11, it is observed that, the maximum stress of 359.54MPa (red colour) is developed at the middle portion of the connecting rod and the minimum stress (blue colour) is at the ends of the connecting rod. In Figure 12, it is observed that the maximum strain of 1.7 (red colour) is developed and the minimum strain (blue colour) developed during the compressive load applied at the bigger end of the connecting rod.



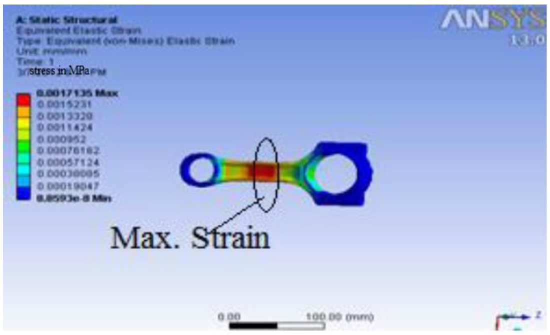
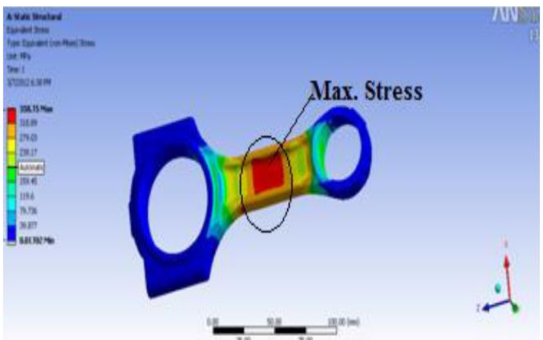


Fig.11. Maximum stress during compression (load at bigger end)

Fig.12.. Maximum strain during compression (load at bigger end)

Figures 13 14, shows that by applying the compressive force on connecting rod at the smaller end, the maximum stress of 357.66 MPa and maximum strain of 1.68 (red colour) is developed at the middle portion of the connecting rod and the minimum stress and minimum strain (blue color) is generated at both the ends of the connecting rod.



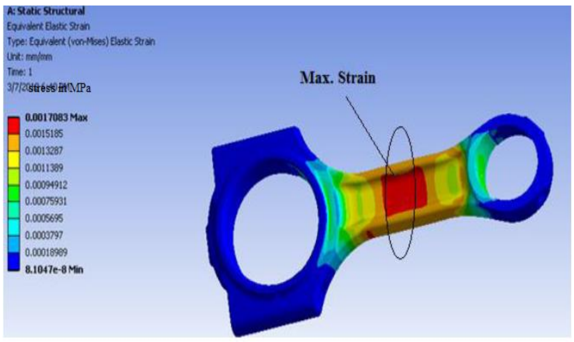
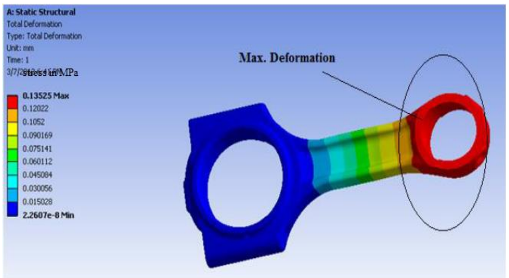


Fig.13. Maximum stress during compression **Fig.14.** Maximum strain during compression

(load at smaller end) (load at smaller end)

Figure 15, shows the deformation developed in the connecting rod, while applying compressive stress on it. The red colour shows the maximum deformation developed in the connecting rod while the yellow and green shows the intermediate deformation and the blue colour represents the minimum deformation developed in the connecting rod.



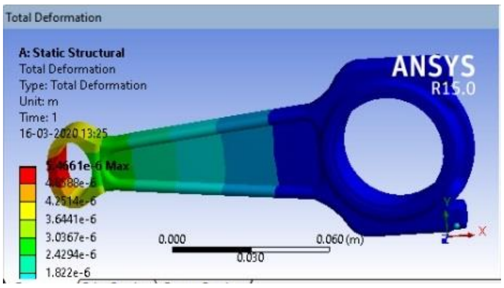


Fig.15. Maximum deformation during compression **Fig.16.** Total deformation during compression (load at smaller end) (load at smaller end)

Similarly, Figures 16, 17represent the equivalent elastic strain and total deformation produced of the connecting rod while applying the compressive load at the smaller end.

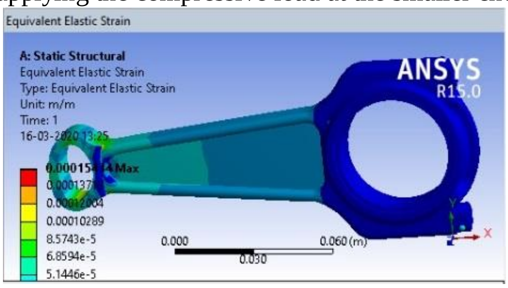


Fig.17. Equivalent Elastic Strain during compression (load at smaller end)

4 Conclusion

The model of the connecting rod is developed by adding ceramics Si3N4 in the Al7068 alloy,

- As the weight percentage of the Si3N4 particles increases from 0 wt% to 5 wt% in the Al-Si3N4 composites, the hardness of the segment is found to increase from 61.2 to 92.4 (BHN). It infers that there is an escalation of 49.8% in the hardness if 5 wt% of Si3N4 added in Al alloy.
- The elasticity expanded from 98 MPa to 140.5 MPa from slick Aluminum to the 5wt% of the Al-Si3N4 composites. It shows that with a bringing Si3N4 into Aluminum composite improves material properties in view of good similarity and the interfacial grip between the Si3N4 and the Aluminum framework.
- It is seen that even the hard and the fragile Si3N4 particles in delicate and pliable Al amalgam lattice diminishes the pliability substance of the created AMCs because of the little malleable substance of framework metal in composite, which significantly upgrades hardness of the manufactured AMCs.
- The weak conduct of Si3N4 particles assumes noteworthy job in diminishing its flexibility; on the grounds that, Si3N4 as fortification is a fragile and they expanded weakness in the created composites, which in-turns decreased pliability substance of the composites. Further, expanding wt. % of the Si3N4 particles in composites

repulses the stream capacity of aluminum framework and diminishes flexible lattice content, which brings about fall of rate lengthening of the composites. Indistinguishable results of the lessening in rate extension with the expanding measure of fortification in aluminum grid regardless of manufacture procedure of the composites were accomplished.

- The maximum stress has observed between the pin-end and the rod-linkage, and between the bearing-cup and the connecting rod linkage. Maximum tensile stress is obtained in the lower half of pin end and between the pin end and the rod linkage.
- Value of Factor of Safety of the connecting rod is between 1.6 to 1.7, which indicates the Safe Design of the Connecting Rod.
- Based on above research this may be extended to Experimental evaluation of connecting rod for the different material which may enable us to the further weight reduction of the connecting rod which is main consideration while designing connecting rod and the dynamic stress and the fatigue stress analysis can also be performed for making it for longer life for heavy and the small engine as well.

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