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Weight Optimization Static and Dynamic Analysis of Connecting Rod with Composite Material

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ABSTRACT

Connecting rod is one of the most important part in automotive engine. Connecting rod is the link between piston and crank shaft. Which it converts reciprocating motion of piston into rotary motion of crank shaft. In internal engines connecting rod is mainly made of steel and aluminium alloys (for light weight and absorb high impact loads) or titanium (for higher performance engines and for higher cost) or composite materials , composite materials is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. As a connecting rod is rigid, it may transmit either a push or a pull and so the rod may rotate the crank through both halves of a revolution, i.e. Piston pushing and piston pulling. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required to push. In which it undergoes structural deformations. Thus in this project we are modeling a connecting rod in solid works 2016 design software and doing static structural and modal(dynamic) analysis in ansys work bench 16 software by using advance composite materials. Thus the part which is modelled is converted into igs file to import in ansys work bench and static structural analysis is carried out at 16MPa of pressure load by applying various materials such as one general material 42Cr2Mo4(special alloy steel), and three composite materials such as Aluminium boron carbide (Al+BC4) , Aluminium Silicon magnesium alloy(Al Si Mg), Aluminum metal matrix (KS1275), materials used in this project. By applying these boundary conditions on connecting rod the unknown variables such as stress, deformation, and strain are found using the FEM Analysis based software (ANSYS).

Fig. Connecting Rod

INTRODUCTION

In a reciprocating position engine to the connecting rod or con rod connects the piston to the crank or crankshaft, alongside the crank they form a simple mechanism converts reciprocating motion into rotating motion.

Connecting rod might also converts rotating motion into reciprocatory motion. Traditionally to development of engines they were first using this manner.

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As a connecting rod is rigid, might transmit either push or pull and then the rod might rotate each halves of a revolution i.e. Piston pushing and piston pulling. Earlier mechanisms used like chains, may solely pull in a very few two-stroke engines, the connecting rod is barely needed to push. Now days, connecting rods are best well-known through their use in a internal combustion piston engines like automotive engines. These are clearly different forms earlier types of the connecting rods utilized in stream engines and steam locomotives.

Fig: connecting rod with piston

Importance of Con Rod In Engine

The connecting rod is that the main a part of the engine, additionally backbone of the engine. There is most significant of the connecting rod in an engine.

Fig: connecting rod in engine

Connecting rod rotates the crank shaft that helps the engine to maneuver on or any of the vehicles to rotate its wheels. It is designed to resist stresses from combustion and piston movement.

Connecting rods is toward lighter weight components. It should withstand with greater power loads though it is lower in weight. The main purpose of a connection rod is to provide fluid movement between pistons and a crankshaft and therefore the connecting rod is beneath tremendous stress from the load represented by the piston.

When building a high performance engine, great attention is paid to the connecting rods. The most effective feature of a connecting rod ought to be the uniform shape.

The cross section of rod beam design ought to be spread and minimize stress load over massive uniformly shaped areas. In operation stress are generated and radiate from one or more source on a component because the rod functions.

Top dead centre (TDC) is the point at which the piston is closest to the cylinder head. Bottom dead centre (BDC) is the point at which the piston is farthest from the cylinder head. Displacement is the volume that a piston displaces in an engine when it travels from TDC to BDC during the same piston stroke.

Problem Statement

Connecting rod is one of the most critical components internal combustion. Connecting rod is connected in between the piston and crank shaft. While the crank shaft rotates piston moves from bottom dead centre to top dead centre vice versa. In this process connecting rod undergoes stress and deformation. Hence for the connecting rod when the load is applied, how the stresses and strain are induced in the component and deformation value, due to applied load are analysed.

Decreasing these stresses and increasing stability depends upon the materials applied. Thus in industrial purpose optimization of connecting rod had already started. Optimization is really important for automotive industry especially. Optimization of the component is to make the less time to produce the product that is stronger, lighter and less total cost productions. The design and weight of the connecting rod influence on car performance. Hence, it effects on the car manufacture credibility. Change in the design and material results a significant increment in weight and also performance of the engine. The structural factors considered for weight reduction during the optimization include the buckling load factor, stresses under the loads, bending stiffness, and axial stiffness. Thus, the component can give the higher strength, efficient design and lighter that would create a major success in the automotive and manufacturing industry. Among the main objectives are to improves the engine performance and also to strengthen the product that is ensure the safety of human being.

Connecting rod failed due to insufficient strength to hold the load. Increasing the strength, automatically it will longer the life cycles of the connecting rod. In this study, the design of the connecting rod will be modeled and at the same time increase the strength. And different materials are applied for gaining more stability. The study will be focus on the finite element modeling and analysis. From the analysis results, the decision whether connecting rod needs to change in material, load, design etc factors which induces stress in the component.

Objectives of project

The objectives of the project are as follows

(i) To develop structural modeling of connecting rod

(ii) To perform fea of connecting rod

(iii) Suitable composite material study

(iv) Study of load factors

(v) Study of stress, strain deformation induced in the connecting rod

(vi)To develop structural optimization model of connecting rod

Parts of connecting rod

Fig: parts of connecting rod

- Crankpin end
- rod shank
- gudgeon pin end

Types of Connecting Rods

- Marine type
- Fixed centre design
- Fork and blade type
- Articular type

COMPOSITE MATERIALS

Composite material can be defined as a combination of two or more materials on macro scale with different properties, or a system composed of two or more physically distinct phases separated by a distinct interface whose combination produces aggregate properties that are superior in many ways, to its individual constituents. The matrix acts as the building block which prevents any sort of external damage to the composite whereas the presence of reinforcement is to improve its mechanical and thermal properties such as strength, ductility, stiffness, toughness, thermal conductivity etc. i.e. the matrix can be thought to be the parent material to which various alterations in physical, whereas mechanical and thermal properties are brought about by addition of fillers. Composite materials consists of two constituents one is matrix and other is reinforcement. The primary phase of a composite material which is having continuous character and present in greater quantity is called matrix. The main function of this matrix is to acts as a binder and to hold the fibers in the desired position thereby transferring the external load to reinforcement. While the other constituent is reinforcement, can be either synthetic or natural fibers. The mechanical property mostly depends upon the shape and dimensions of reinforcement.

The most primary applications of composite materials are found where high strength and low weight are concerned. Few properties of composites accounted for their wider uses are high strength, low density, high tensile strength at high temperatures, high toughness, and high creep resistance. The matrix constitutes more than half of the volume fraction of the composite and fillers contribute less towards the volume but the change in properties is quite considerable. The variation over strength of composites lies with amount, distribution and type of filler material inclusion broadly.

THEORITICAL CALCULATIONS

Pressure calculation:

Consider a 220cc engine,

Engine type air cooled 4-stroke

Bore × Stroke (mm) = 67×62.4

Displacement=220 cm3

Maximum Power = 20.8 Bhp at 8500rpm

Maximum torque= 19.12 Nm at 7000rpm

Mechanical efficiency of the engine (η) = 80 %.

$$\eta = \frac{\text{BrakePower (B.P)}}{\text{IndicatedPower (I.P.)}}$$

$$\text{B.P.}=\frac{2\pi NT}{60} = \frac{2\pi x 19.12 x 7000}{60} = 14.015 \text{ kW}$$

$$\text{I.P} = \frac{Bp}{\eta} = \frac{14.015}{0.8} = 17.518 \text{ kW}$$

$$\text{I.P} = \text{P x A x L x } \frac{N}{2}$$

$$\text{I.P} = \text{P x} \frac{\pi}{4} \text{ x } D^2 \text{ x L x } \frac{N}{2}$$

$$17.518 \text{ x } 1000 =$$

$$\text{P x } \frac{\pi}{4} \text{ x } (0.067)^2 \text{ x } (0.0624) \text{x} \frac{7000}{2x60}$$

$$\text{So, P} = 13.65 \text{ x } 10^5 \text{ N/m}^2 \text{ or}$$

P = 1.365MPa

Maximum Pressure, Pmax=10xP

=10x1.365

=13.65Mpa

So approx 16mpa is taken as pressure applied on connecting rod

Design Calculation of connecting rod

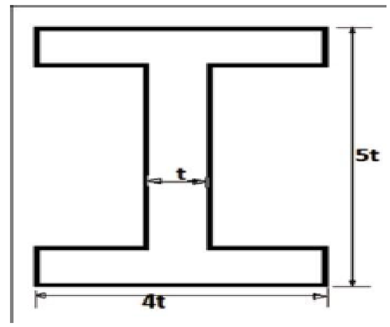


Fig.: I Section for connecting rod

From standards,

- Thickness of flange and web of the sectio = t
- Width of the section B = 4t
- Height of the section H = 5t
- Area of the section A = 11t2
- Moment of inertia about x axis Ixx= 34.91t4
- Moment of inertia about y axis Iyy= 10.91t4
- Therefore Ixx/Iyy= 3.2

So, in the case of this section (assumed section)

Proportions shown above will be satisfactory.

Length of the connecting rod (L) = 2 times the stroke

L = 124.8 mm

Fc= (πd2/4) * gas pressure

Fc= 48125.154 N

WB = FC × F. S.=48125.154 ×1.78 = 85662.77 N

We know that radius of gyration of the section about X-axis,

$$\text{Kxx}=\sqrt{\frac{I_{xx}}{A}} = \sqrt{\frac{34.91t^4}{11t^2}} = 1.78 \text{ t}$$

Radius of crank,

$$r = \frac{\text{stroke length}}{2} = \frac{62.4}{2} = 31.2 \text{ mm}$$

Length of Connecting Rod = 2×stroke

= 2×62.4

=124.8 mm

Equivalent length of the connecting rod for both

Ends hinged, L= l = 124.8 mm

For generaly used aluminium alloy material

Now according to Rankine's formula, we know that

Buckling load (WB),

85662.77 = 7.35 mm (α = 0.002)

Thus, the dime=

$$\frac{170\times 11t^2}{1+\alpha\left(\frac{L}{Kxx}\right)}$$

nsions of I-section of the

Connecting rods are:

Thickness of flange and web of the section

= t =7.35 mm

Width of the section, B = 4 t = 4 × 7.35 =29.4 mm

Height of the section, H= 5 t = 5 × 7.35 = 36.75 mm

Depth near the big end,

H1 = 1.2H = 1.2 × 36.75 = 44 mm and

Depth near the small end,

H2 = 0.85H = 0.85 × 36.75 = 31.23 mm

For Aluminium 6061 SIC-15% composite material

Now according to Rankine's formula, we know that

Buckling load (WB),

85662.77=

$$= \frac{363*11t^2}{1+\alpha\left(\frac{L}{Kxx}\right)}:$$

= 5.254 mm

Width of the section, B = 4 t = 4 × 5.254=21.01 mm

Height of the section, H= 5 t = 5 ×5.254= 26.27 mm

Depth near the big end,

H1 = 1.2H = 1.2 × 26.27 = 31.52 mm

Depth near the small end,

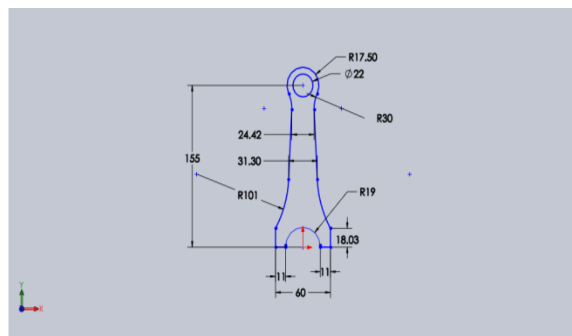
H2 = 0.85H = 0.85 × 26.27 = 22.32 mm

Introduction to Solidworks

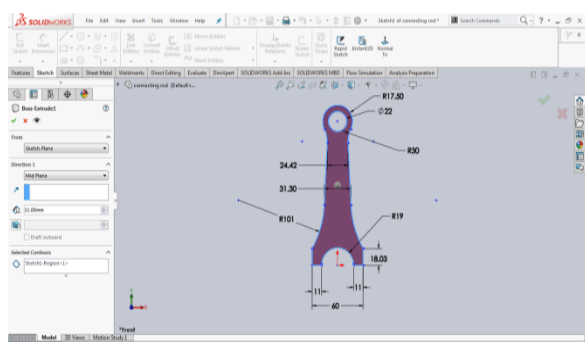
Solid works is mechanical design automation software that takes advantage of the familiar Microsoft windows graphical user interface. It is an easy-to-learn tool which makes it possible for mechanical designers to quickly sketch ideas, experiment with features and dimensions, and produce models and detailed drawings

Design procedure of Connecting Rod

For designing the Connecting Rod the following procedure has to be follow

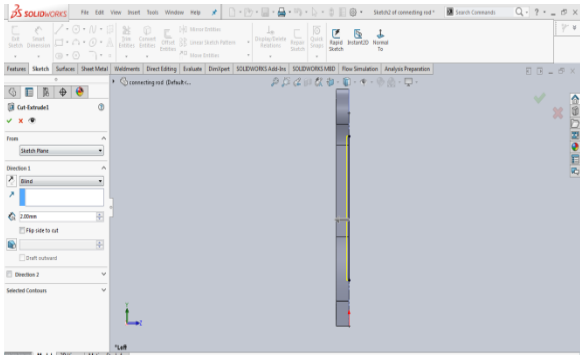


2d sketch of a connecting rod

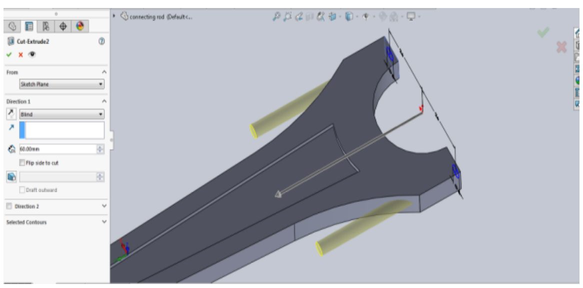


Sketch & extrude

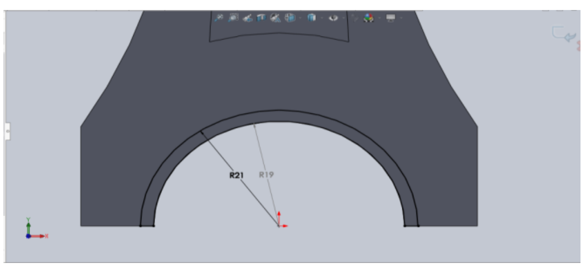
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue-17
December 2017



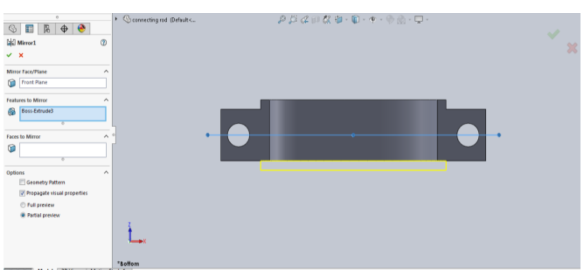
Extrude cut it to 2mm



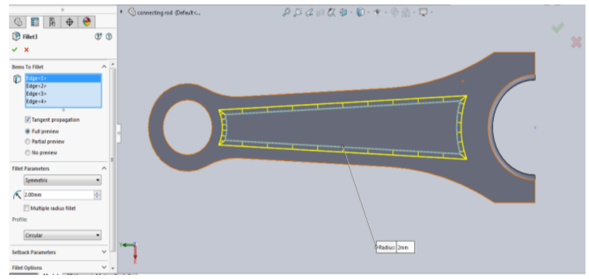
Make Holes



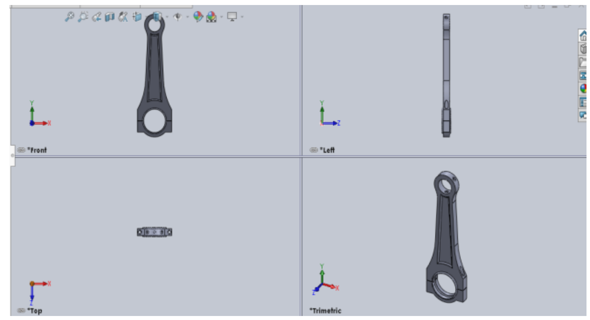
Draw a sketch on front plane for bolting holes



Mirror is used for making for symmetry on both sides



Fillet the edges for smooth surfacing



Different Views of Connecting Rods

INTRODUCTION TO SIMULATION

Simulation is a design analysis system. Simulation provides simulation solutions for linear and nonlinear static, frequency, buckling, thermal, fatigue, pressure vessel, drop test, linear and nonlinear dynamic, and optimization analyses.

Fig: simulation example

FEM (Finite element method)

The software uses the finite element method (fem). Fem is a numerical technique for analyzing engineering designs. Fem is accepted as the standard analysis method due to its generality and suitability for computer implementation. Fem divides the model into many small pieces of simple shapes called elements effectively replacing a complex problem by many simple problems that need to be solved simultaneously.

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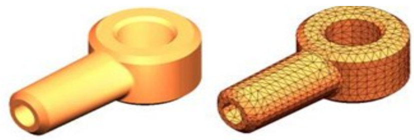


Fig: cad model of a part Fig: model subdivided into small pieces (elements)

Static analyses

Static analysis deals with the conditions of equilibrium of the bodies acted upon by forces. A static analysis can be either linear or non-linear. All types of non-linearities are allowed such as large deformations, plasticity, creep, stress stiffening, contact elements etc.

modal analyses

When an elastic system free from external forces is disturbed from its equilibrium position it vibrates under the influence of inherent forces and is said to be in the state of free vibration. It will vibrate at its natural frequency and its amplitude will gradually become smaller with time due to energy being dissipated by motion. The main parameters of interest in free vibration are natural frequency and the amplitude.

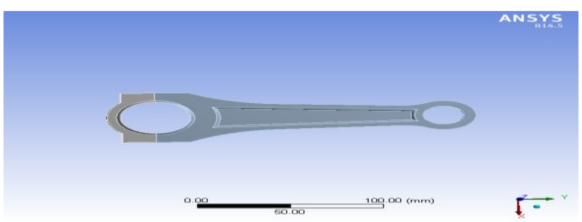
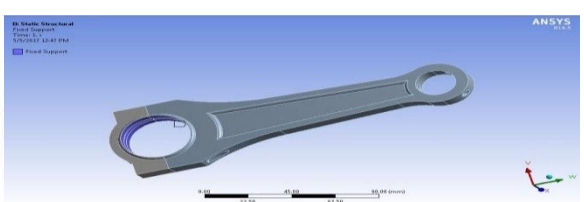


Fig: structural analysis

Materials and their properties

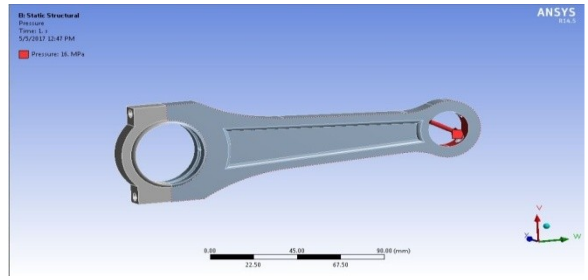
Material	Density (kg/m^3)	Young's modulus (pa)	Poisons ratio	Shear modulus(pa)	Bulk modulus(pa)
42CrMo4	7830	2.1E+11	0.30	8.0769E+10	1.75E+11
Al6061+B4C	2680	1.97E+11	0.32	7.4621E+10	1.8241E+11
Al Si Mg	2700	6.9E+10	0.33	2.594E+10	6.7647E+10
Al Si C	3100	1.3917E+11	0.30	5.3527E+10	1.1598E+11

- **Fixed support**

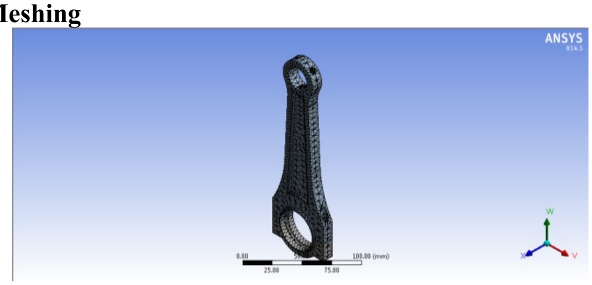


- **Load**

Load at 16 MPA



Meshing



Mesh Type: Tetrahedral

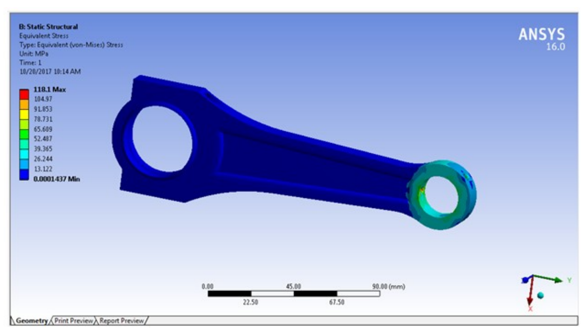
No. of nodes: 16190

No. of elements: 8821

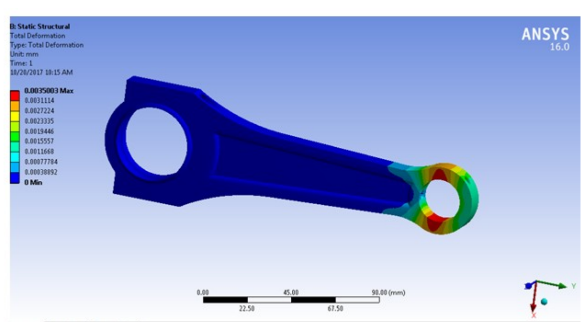
STRUCTRUAL ANALYSIS RESULTS

Material: 42CrMo4 (steel alloy)

Maximum stress

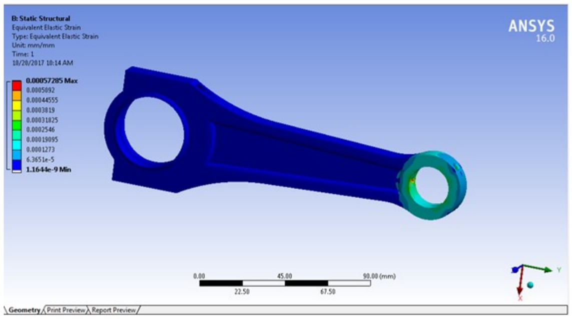


Total deformation



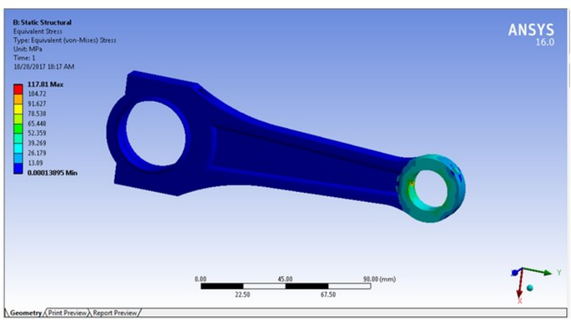
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue-17
December 2017

Maximum strain

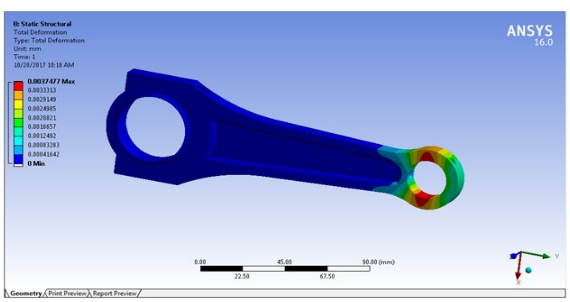


Material: Al6061+B4C (Aluminium alloy+5% boron carbide)

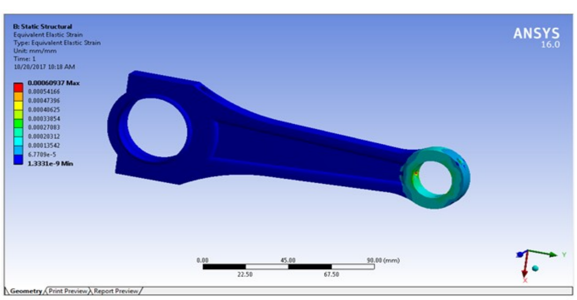
Maximum stress



Total deformation

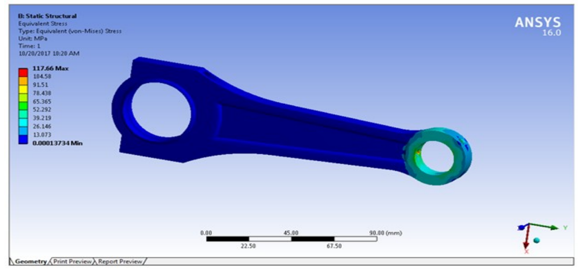


Maximum strain

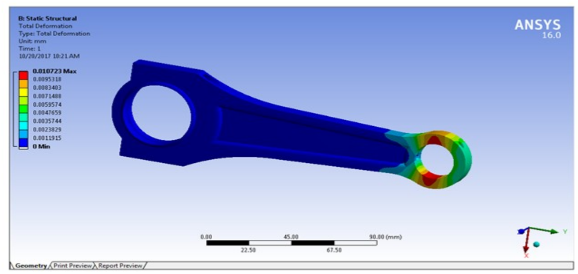


Material: Aluminium Silicon Magnesium Alloy

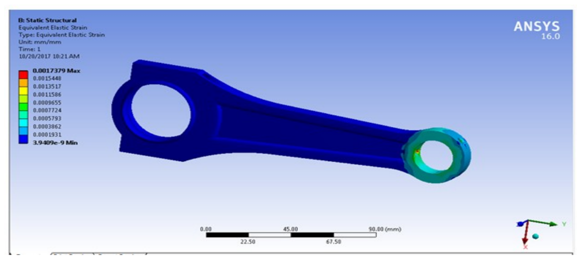
Maximum stress



Total deformation

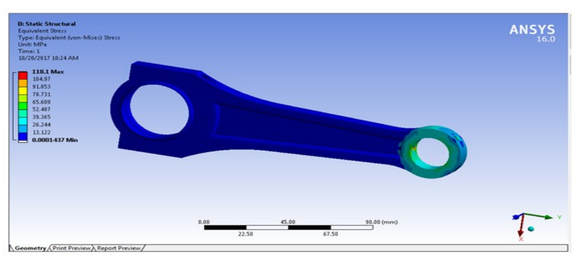


Maximum strain

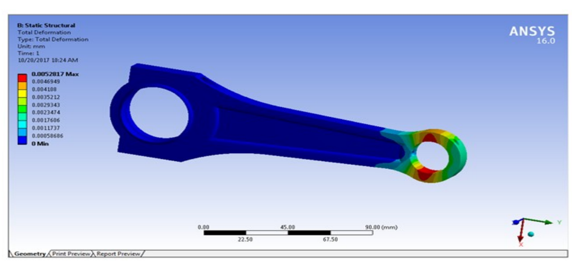


Material: Aluminium Silicon Carbide

Maximum stress



Total deformation



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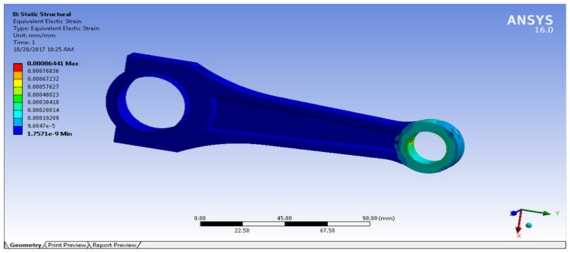
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue-17
December 2017

Maximum strain

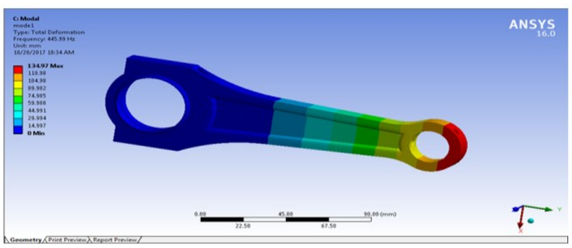


MODEL ANALYSIS:

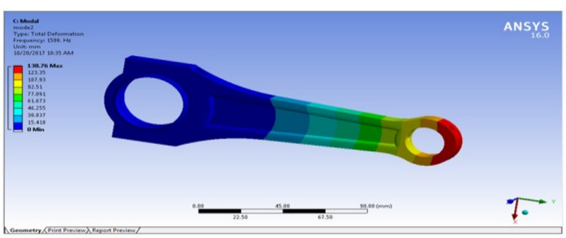
Modal analysis has performed on six different mode

Material: 42CrMo4 (steel alloy)

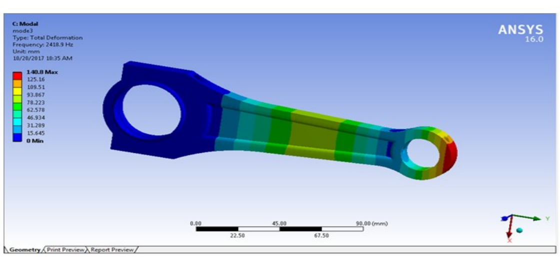
Mode1



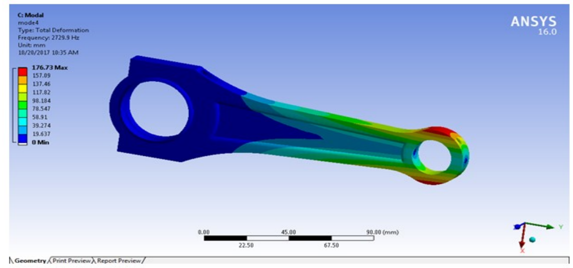
Mode2



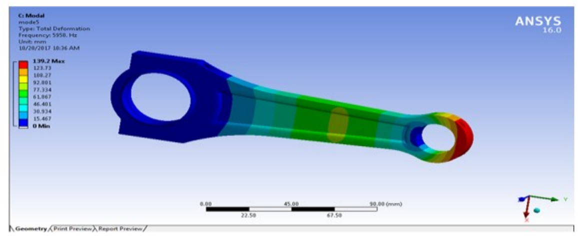
Mode3



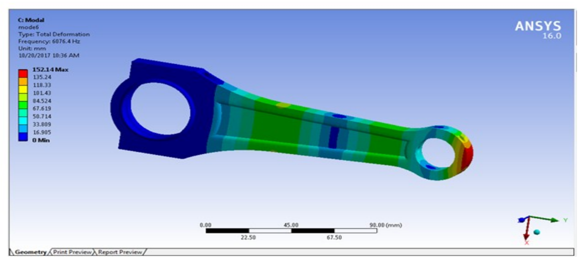
Mode4



Mode5

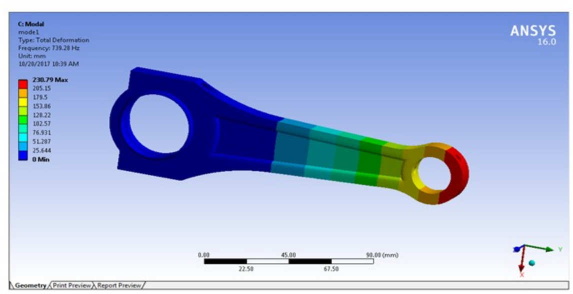


Mode6



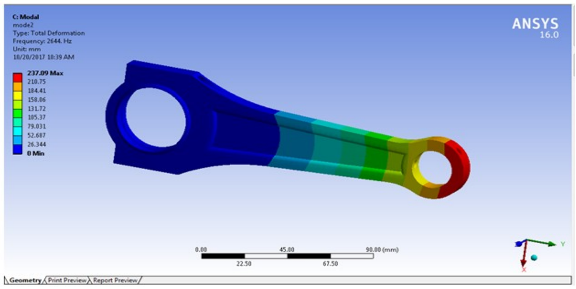
Material: (Aluminium alloy+5% boron carbide)

Mode1

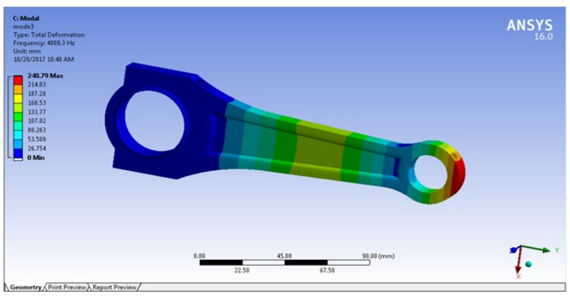


Mode2

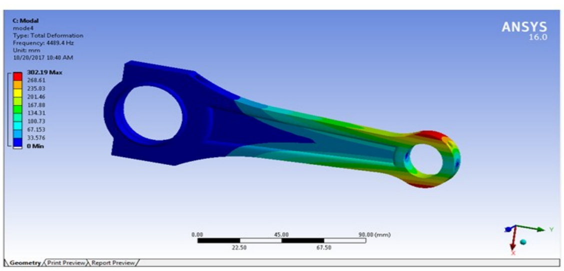
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue-17
December 2017



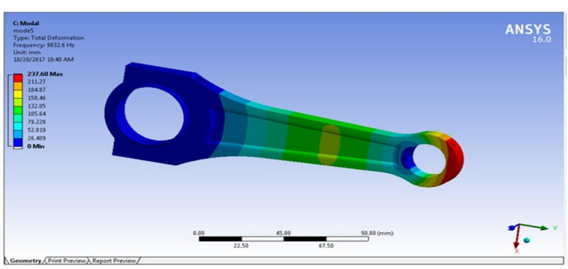
Mode3



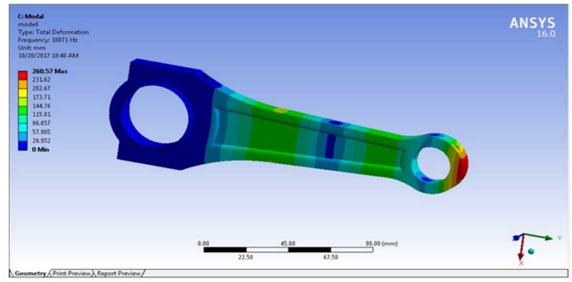
Mode4



Mode5

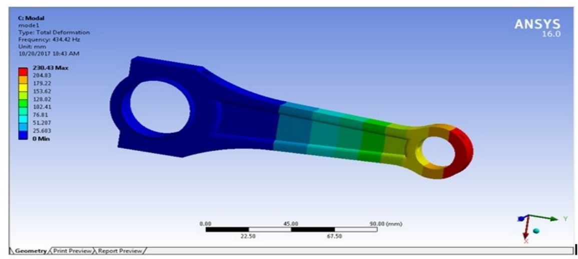


Mode6



Material: Aluminium Silicon Magnesium Alloy

Mode1



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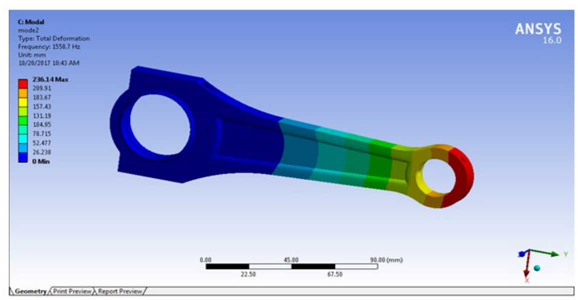
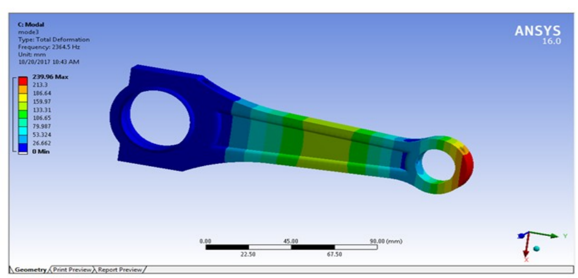
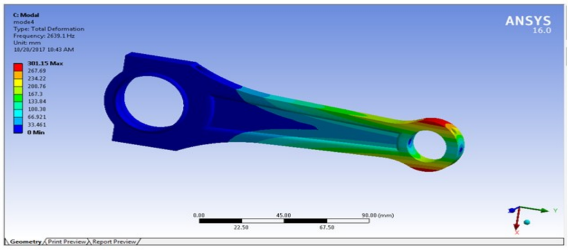


Mode3

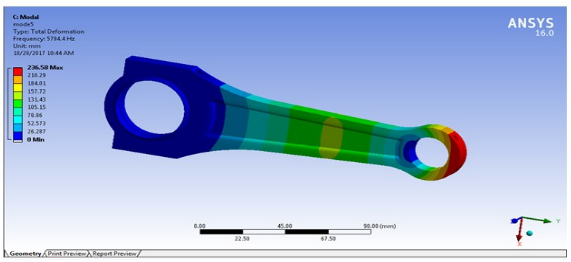


Mode4

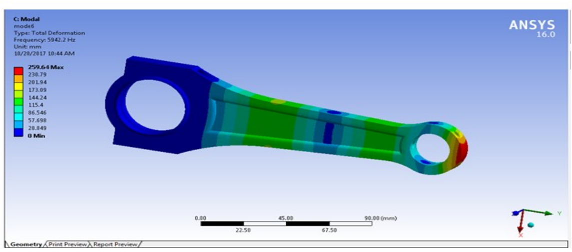
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue-17
December 2017



Mode5

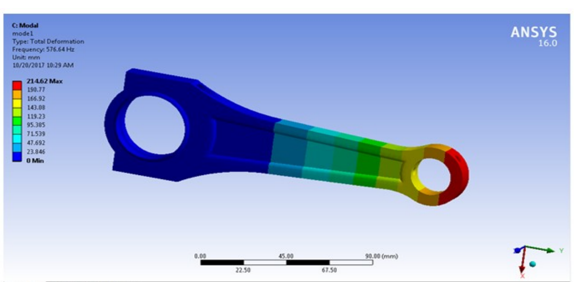


Mode6

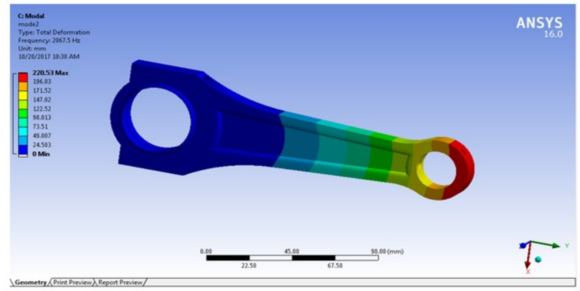


Material: Aluminium Silicon Carbide

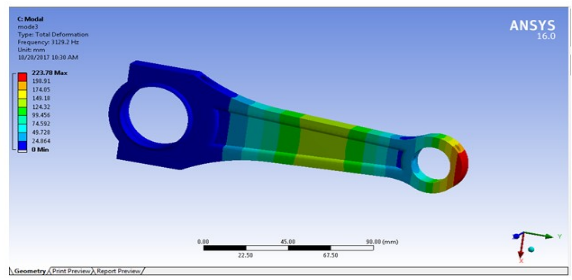
Mode1



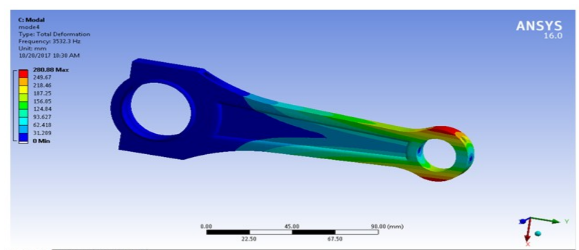
Mode2



Mode3



Mode4



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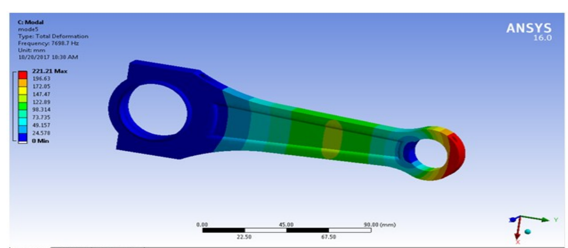

Mode6

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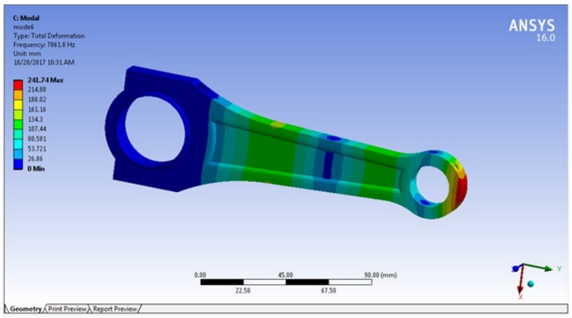
Volume 04 Issue-17
December 2017



RESULTS AND DISCUSSION:

Modeling of the connecting rod has done by using solid works 2016 premium software package. And therefore the model is saved in initial graphics exchange specification (iges) and is imported into the ansys work bench to perform static structural analysis and modal analysis. The results of the analysis have shown below.

Static Structural analysis

Table: Static analysis

Materials	Max Stress (N/mm^2)	Total Deformation (mm)	Max strain	Mass(kg)
42CrMo4	118.10	0.0035003	0.00057285	0.41811
Al+B4C	117.81	0.0037477	0.00060937	0.14340
Al Si Mg	117.66	0.010723	0.0017379	0.14418
Al Si C	118.10	0.0052817	0.00086441	0.16554

Table: Model Analysis –I

Material	Mode1		Mode2		Mode3	
	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)
42CrMo4	134.97	445.99	138.76	1598	140.80	2418.9
Al+B4C	230.79	739.28	237.09	2644	240.79	4009.3
Al Si Mg	230.43	434.42	236.14	1558.7	239.96	2364.5
Al Si C	214.62	576.64	220.53	2067.5	223.78	3129.2

Model Analysis

Table: Model Analysis –II

Material	Mode4		Mode5		Mode6	
	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)
42CrMo4	176.73	2729.9	139.2	5950	152.14	6076.4
Al+B4C	302.19	4489.4	237.68	9832.6	260.57	10071
Al Si Mg	301.15	2639.1	236.58	5794.4	259.64	5942.2
Al Si C	280.88	3532.3	221.21	7698.7	241.74	7861.8

CONCLUSION

Modeling and analysis of connecting rod is done, the analysis in ansys is extremely important prior to the fabrication of connecting rod hence Modeling of connecting rod is done in solid works 2016 design software and than file is saved as igs file to import in ansys workbench software,The static structural,and modal analysis has carried out in the ansys 16 software package for connecting rod by different materials in which one generaly used material alloy steell(42CrMo4) and three composite materials such as aluminum boron carbide (Al+B4C), Aluminium Silicon magnesium alloy , Aluminum Silicon Carbide The material properties and brief explanation about material has given.The utmost stress, strain ,deformation values and mass based upon respective materials are noted and tabulated in static structural analysis. From the above results we can conclude that from 16mpa i.e load condition on connecting rod that are applied on the connecting rod by assigning different materials , composite materials such as Al+B4C and Al Si Mg alloy less stress compare to generaly used alloy steel material.Even the weight of both the materials Al+B4C and Al Si Mg are very less than Alloy steel material.Here after analysis Aluminium Silicon Magnesium alloy is showing less stress value followed by Al+B4C.And Al+B4C is showing least weight followed by Al Si Mg Alloy.Due to nearly same stress value with Aluminium Silicon Magnesium Alloy and less weight to strenth ratio we can conclude that Aluminium Boron Carbide (Al+B4C) is the best composite material can used for Connecting Rod.Meanwhile modal(dynamic) analysis also performed on connecting rod to study its dynamic condition.Deformation on six different modes conditions with respective frequencies are noted and tabulated in modal analysis.Based on modal (dynamic) analysis very high frequency values are required to get respective deformation values , compare to other materials.Hence we can conclude that Aluminium Boron Carbide (Al+B4C) is the best composite materail for connecting rod , due to its high weight to strenth ratio and dynamic behaviour and economically too.

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