DESIGN AND FATIGUE ANALYSIS ON METAL MATRIX COMPOSITE CONNECTING ROD USING FEA

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ABSTRACT

Composite materials are now a day widely used in the engineering field. The general characteristics possessed by the composite materials are found to be the reason for using it in the automotive applications. The objective of the project is to design and fatigue analysis of metal matrix composite (MMC) connecting rod. The connecting rods are commonly used in the internal combustion engines and are subjected to millions of varying stress cycles leading to fatigue failure. While the Composite connecting rods are lighter and may offer better compressive strength, stiffness and fatigue resistance than conventional connecting rods and their design still represents a major technical challenge. In that project both the standard steel and composite connecting rods are modeled and analyzed using Pro-E Wildfire 2.0 and ANSYS 10.0 software respectively.

A comparative study was undertaken to predict the structural behavior of connecting rods using three dimensional finite element stress and fatigue analysis model, and to determine the most cost effective modeling and analysis approach. The finite element results verify that the performance is same as that of standard steel connecting rod. The stress and fatigue analysis of the composite connecting rods is found to be better than that of the standard connecting rod. The connecting rod is modeled by using Pro-E and the part option is used to model this connecting rod. It is exported as IGES(.iges) file format to import into ANSYS software.

Keyword: - *Metal matrix composite, Engine, Stiffness, Fatigue, Compressive strength, Connecting rod*

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1. INTRODUCTION

Connecting Rod is an intermediate member between the piston and the crankshaft. Its primary function is to transmit the push and pull from the piston pin to the crank pin and thus converts the reciprocating motion of the piston into the rotary motion of the crank. It consists of a long shank a small end and a big end. The cross-section of the shank may be rectangular, circular, tubular "I section and H section". Generally circular sections are used for low speed engines where I section is preferred for high-speed engines.

The length of the Connecting Rod (l) depends upon the ratio of *l/r* where r is the radius of the crank. It may be noted that smaller length will decrease the ratio *l/r*. This increases the angularity of the Connecting Rod which increases the side thrust of the piston against the cylinder liner which in turn increases the wear of the liner. The larger length of the Connecting Rod will increase the ratio *l/r*. This increases the angularity of the Connecting Rod and thus decreases the side thrust and the resulting wear of the cylinder. But the larger length of the Connecting Rod increases the overall height of the engine. Hence the ratio *l/r* is generally kept as 3 to 5.

The small end of the Connecting Rod is usually made in the form of eye and is provided with the bush, generally phosphor bronze. It is connected to the piston by means of the piston pin. The big end of the Connecting Rod is mounted on the crank pin bearing shells. The Connecting Rods are usually manufactured by drop forging process and it should have adequate strength stiffness and minimum weight. The material mostly used for Connecting Rod varies from mild carbon steels (0.35 to 0.45 % of Carbon) alloy steels (chrome-nickel or chrome – molybdenum steels) forged steels. The carbon steel having 0.35% carbon has an ultimate tensile strength of about 650 Mpa. When properly heat treated and carbon steel with 0.45% of carbon has an ultimate tensile strength of 750 Mpa. The alloy steels have an ultimate tensile strength of about 1050 Mpa. The main advantages are the mass reduction that is a crucial topic for a components subjected to very high inertial loads. Furthermore, the very good fatigue behavior of such materials, meets very well the requirement to withstand cyclic loads. Connecting Rod design is a quite complex task because engine operates at wide variable conditions, and load on crank slider mechanism are produced both by pressure and inertia.

Assuming that the Connecting Rod has to replace the original component of an existing engine, The main objective is material replacement for Principal design constraints are fatigue strength and buckling strength. Other design data are required and are the cylinder pressure at service RPM, load, reciprocating mass, slider-crank mechanism geometric parameters. The design problem consists in the evaluation of objective and constraint functions once design parameters are chosen. The way to obtain desired functions is quite complex: Stress analysis results are then processed to obtain fatigue stress histories at each point for each RPM, and fatigue damage at each location is obtained.

2. BASICS OF METAL MATRIX COMPOSITE MATERIALS

From the literature review for automotive application especially connecting rods are made by metal matrix composite materials. Metal composite materials have found application in many areas of daily life for quite some time. Often it is not realized that the application makes use of composite materials. These materials are produced from the conventional production and processing of metals. Here, the structure, which results from welding two types of steel by repeated forging, can be mentioned. Materials like cast iron with graphite or steel with a high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials. For many researchers the term metal matrix composites is often equated with the term light metal matrix composites (MMCs).

Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. In traffic engineering, especially in the automotive industry, MMC shave been used commercially in fiber reinforced pistons and aluminum crank cases with strengthened cylinder surfaces as well as particle-strengthened brake disks .These innovative materials open up unlimited possibilities for modern material science and development. The characteristics of MMCs can be designed into the material, custom-made, dependent on the application. From this potential, metal matrix composites fulfill all the desired conceptions of the designer. It becomes interesting for use as constructional and functional materials, if it property profile of conventional materials either does not reach the increased standards of specific demands, or is the solution of the problem. However, the technology of MMCs is in competition with other modern material technologies, for example powder metallurgy.

3. ANALYSIS OF CONVENATIONAL CONNECTING ROD

3.1 SOILD MODEL

The connecting rod is modeled by using Pro-E and the part option is used to model this connecting rod. It is exported as IGES(.iges) file format to import into ANSYS software. The solid model generated in Pro-E as shown below in figure 3.1

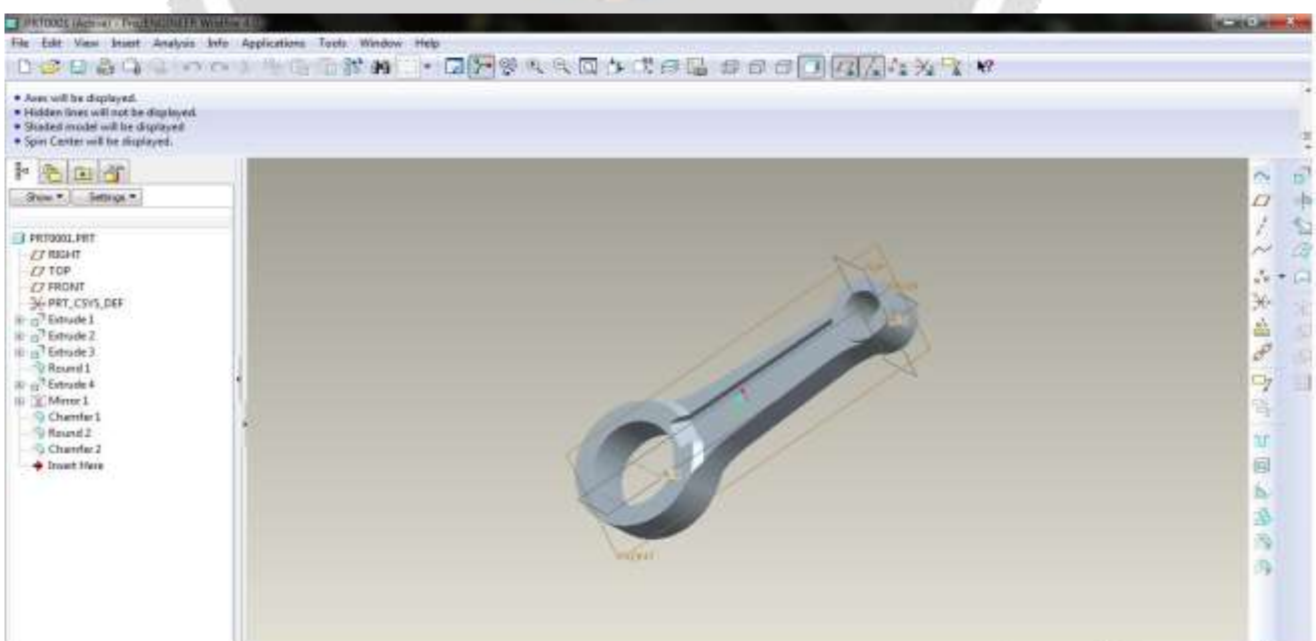

FIG 3.1: Isometric view

3.2 FATIGUE ANALYSIS

Taking number of cycles of failure N along x-axis and stress in y-axis. Considering number of failure 10,000cycles and stress ranging from 0 to1250 MPa. The results is shown in figure 3.2

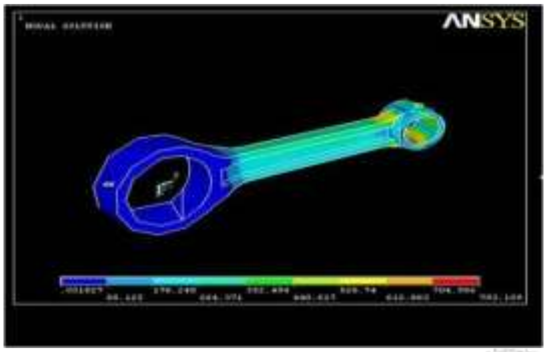

Fig 3.2 Tensile stress analysis

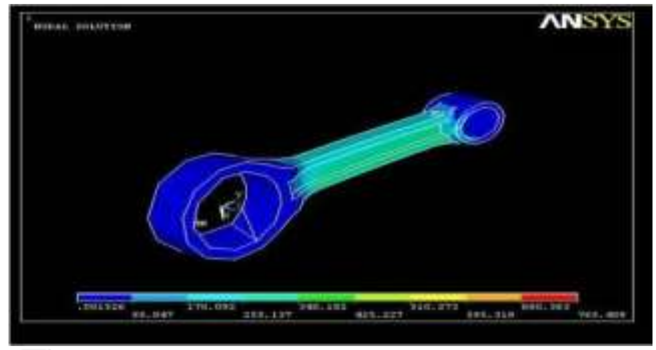

Fig 3.3 Compressive stress analysis

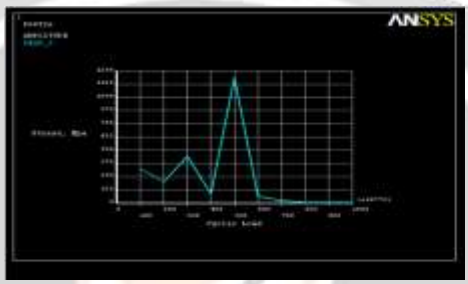

Fig 3.3 Fatigue analysis on conventional connecting rod

4. ANALSIS OF COMPOSITE CONNECTING ROD

4.1 SOILD MODEL

The metal matrix composite connecting rod is modeled in Pro-E.The MMC properties are added in the modeling itself by using composite mode in the Pro-E software. The model is exported as same as conventional connecting rod model and By using same FEA method the composite connecting rod is analyzed

4.2 MATERIAL PROPERTIY

Aluminum and magnesium casting reinforced with fiber are being developed for high performance automotive application. while they are lighter and may offer better compressive strength, stiffness, and fatigue resistance than conventional engine materials .the material properties are shown in below table 4.1.

Table 4.1 material properties of MMC

PROPERTIES	VALUE
Tensile Modulus along X direction, (E_X), MPa	20700
Tensile Modulus alongY,Zdirection, MPa	14400
Shear Modulus along XY direction, (G_{xy}), MPa	48000
Shear Modulus along YZ direction, (G_{xy}), MPa	5520
Shear Modulus along ZX direction, (G_{xy}), MPa	2760
Poisson ratio along XY direction, (NU_{xy})	0.244
Poisson ratio along YZ direction, (NU_{yz})	0.17
Poisson ratio along ZX direction, (NU_{zx})	0.3
Mass Density of the Material,(ρ),Kg/mm^3	5e-6

4.3 FATIGUE ANALYSIS

Taking number of cycles of failure N along x-axis and stress in y-axis. Considering number of failure 10,000cycles and stress ranging from 0 to 850 MPa. The results is shown in figure 4.3

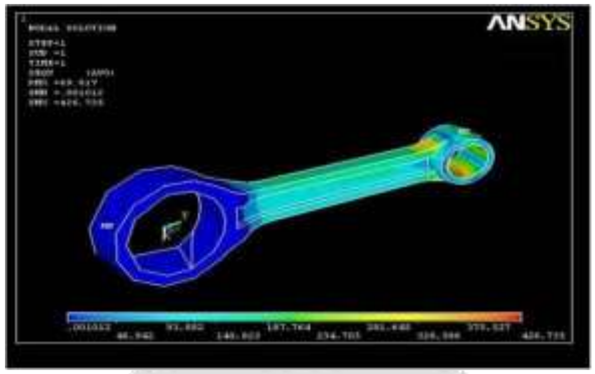

Fig 4.1 Compressive stress result on composite connecting rod

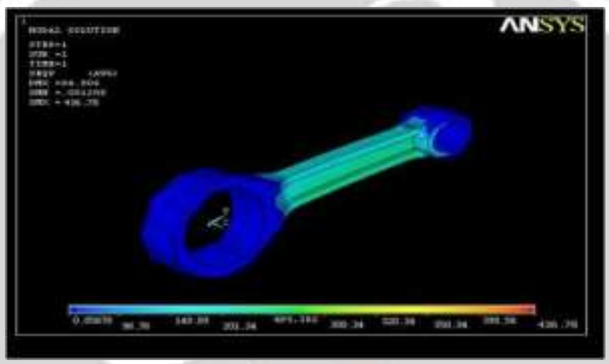

Fig 4.2 Tensile stress result on composite connecting rod

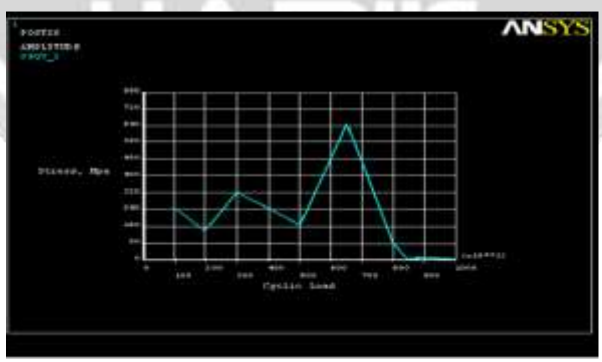

Fig. 4.3 Fatigue analysis on composite connecting rod

5. RESULT
5.1 STRESS ANALYSIS COMPARISION

The FEM value of conventional and MMC connecting rod is obtained and is shown in table .from the result it is clear that the conventional connecting rod stress are greater than the MMC connecting rod .The comparisons of stress in composite connecting rod.

Table 5.1 comparisons of stress

Stroke	Conventional connecting rod	Composite connecting rod
Tensile stress(MPa)	793.109	436.78
Compressive stress(MPa)	765.408	426.735

5.2 FATIGUE ANALYSIS OF CONVENATIONAL CONNECTING ROD

The Figure 4.3 and Table 5.2 clearly indicates the crack nucleation starts from the cycle 10000 cycles at the stress value of 250MPa, this is because the crack nucleation starts only after certain value or stress which high enough to generate a crack and to propagate it. Then at 20000 cycle stress value decreases to 160MPa this is because due to the discontinuities,

where as at 30000 cycle the stress value slightly rises as a result of fatigue propagation. After which the sudden down fall to 125MPa at 40000 cycles indicating inclusions and variations in cross-sectional area. At 50000 cycles the stress value reaches the highest stress value of 1175 MPa which is well above the working stress limit of 793.109. At this value the Connecting Rod gets failed.

After then at 60000 cycles the stress values gradually decreases and reaches a low stress value remains even during the next cycle of loading till 100000 cycles of loading.Analysis up to 100000 cycles are tabulated below and the maximum stress observed as 1175MPa which exceeds the allowable ultimate strength 793.109 MP the failure occurs at
50000 cycles

Table 5.2 Cyclic loading Vs Stress value

Serial Number	CYCLIC LOAD in X-axis	STRESS VALUE in Y-axis
1.	0	0
2.	5000	0
3.	10000	325
4.	15000	250
5.	20000	200
6.	25000	315
7.	30000	440

8.	35000	250
9.	40000	100
10.	45000	625
11.	50000	**1175***
12.	55000	625
13.	60000	75
14.	65000	50
15.	70000	25
16.	75000	25
17.	80000	10
18.	85000	10
19.	90000	10
20.	95000	10
21.	100000	10
* Peak value exceeds the ultimate tensile strength, which implies 793.109MPa. At this Peak value 1175MPa connecting rod fails at 50000 cycles		

5.3 FATIGUE ANALYSIS OF COMPOSITE CONNECTING ROD

Taking number of cycles to failure N along x-axis and stress (MPa) along y-axis. Considering number of cycles up to 100000 cycles to failure and stress ranging 0 to 800 MPa.

The Figure 4.3 and table 5.3 clearly indicates the crack nucleation starts from the cycle 10000 cycles at the stress value of 250MPa, this is because the crack nucleation starts only after certain value or stress which high enough to generate a crack and to propagate it.

Then at 20000 cycle stress value decreases to 320MPa this is because due to the discontinuities, where as at 30000 cycle the stress value slightly rises as a result of fatigue propagation. After which the sudden down fall to 160MPa at 50000 cycles indicating inclusions and variations in cross-sectional area.

At 65000 cycles the stress value reaches the highest stress value of 650MPa which is well above the working stress limit of 436.78. At this value the Connecting Rod gets failed.

After then at 80000 cycles the stress values gradually decreases and reaches a low stress value remains even during the next cycle of loading till 100000 cycles of loading.

Analysis up to 100000 cycles are tabulated below and the maximum stress observed as 650MPa which exceeds the allowable ultimate strength 436.78 MP the failure occurs at 65000 cycles

Table 5.3 : Cyclic loading Vs Stress value

Serial Number	CYCLIC LOAD in X-axis	STRESS VALUE in Y-axis
1.	0	0
2.	5000	0
3.	10000	250
4.	15000	200
5.	20000	125
6.	25000	300
7.	30000	320
8.	35000	290
9.	40000	240
10.	45000	200
11.	50000	160
12.	55000	400
13.	60000	480
14.	65000	**650***
15.	70000	450
16.	75000	300
17.	80000	80
18.	85000	10
19.	90000	10
20.	95000	10
21.	100000	10
* Peak value exceeds the ultimate tensile strength, which implies 436.735MPa. At this Peak value 650 MPa connecting rod fails at 65000 cycles.		

5.4 FATIGUE ANALYSIS COMPARISION

After the fatigue life analysis made between the conventional Connecting Rod with composite connecting rod , to infer the solution in various view points.

Initially the conventional Connecting Rod subjected to analyzing with out the material replacement gives us the result as it has the fatigue life up to 50000 cycles reaching a maximum stress of 1175MPa which is higher than the working stress, 795.109MPa.

Subjecting the composite Connecting Rod to the fatigue analysis the result obtained is satisfactory. During 65000 cycle Connecting Rod reaches maximum stress of 650MPa where it fails and the stress value decreases. This clearly confers that the composite connecting rod as its fatigue life up to 65000 cycles, during the next cycle of loading the stress value reaches 450MPa and for further cycles of loading it remains in the low range of stress value. Apart form stress and fatigue analysis, there is weight reduction during the material replacement.

6. CONCLUSION

The conventional connecting rod used in the engines was replaced with a composite connecting rod . The conventional connecting rod and the Composite connecting rod were analyzed by finite element methods. From the results, it is clear that the stress induced in the composite connecting rod is found to be lower than that of the conventional connecting rod. Composite connecting rod material is replaced for good fatigue strength, minimizing weight and without violating the limiting constraint formed by induced stress. A reduction of 31.5% weight is achieved when a conventional connecting rod is replaced with composite connecting rod under identical conditions of design parameters.

7. REFERENCES

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