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 this paper both the standard steel and composite connecting rods are modeled and analyzed using Pro-E Wildfire 4.0 and ANSYS WORKBENCH 11.0 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. In order to drive out the major failures in an engine and its cause and effects, we have under gone a number of surveys in the automobile gallery. Results predict the wear and tear of the moving parts does the major role. In spite of that, the forged intermediate member that often fails due to its translation from reciprocating to rotation deforms and buckles it. This mechanism is studied under investigation, dealt with an engineering approach for its reason for failure and repeated replacements, frequently. After an establishing survey, the conclusion in focusing towards replacement forged carbon steel into metal matrix composite (MMC) of connecting rod

Index Terms—Composite Materials, Metal Matrix Composite, Finite Element Analysis

I. INTRODUCTION

A 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 common Forces that act on the connecting rod are as follows

1. Force on the piston due to gas pressure and inertia of the reciprocating parts.
2. Force due to inertia of the connecting rod or inertia bending forces.
3. Force due to friction of the piston rings and of the piston.
4. Forces due to friction of the piston pin bearing and the crank pin bearing.

From the literature review, for automotive application especially connecting rods are made by metal matrix composite materials. For many researchers the term metal matrix composites is often equated with the term light metal matrix composites (MMCs). The reinforcement of light metals opens up the possibility of application of these materials in areas where weight reduction and good strength has first priority. Increase in yield strength and tensile strength at room temperature and above while maintaining the minimum ductility or rather toughness, increase in creep resistance at higher temperatures compared to that of conventional alloys, increase in fatigue strength, especially at higher temperatures, improvement of thermal shock resistance, improvement of corrosion resistance, increase in Young's modulus, reduction of thermal elongation etc.

II. FACTORS FOR ANALYSIS

The following two factors are mainly considered for analysis of conventional and MMC connecting rod.

1. Buckling
2. Fatigue

Buckling

Buckling loads are critical loads where certain types of structures become unstable. Each load has an associated buckled mode shape. This is the shape that the structure assumes in a buckled condition.

Fatigue

The term fatigue is defined as premature failure under the action of repeated stress (i.e.) dynamic loading. A component subjected to repeated loading develops a characteristic behavior, fundamentally different from the behavior of a metal part subjected to steady loads. Fatigue is important form of behavior in all materials including plastics, rubber, and concrete and even in rotating parts.

The behavior of fatigue can be explained by

1. Loss of strength
2. Loss of ductility
3. Increased uncertainty in both strength and service life

Mechanism of Fatigue

A fatigue fracture always starts as a small crack which, under repeating loading of stress grows in size. As a crack expands, the load carrying cross-section of the metal component is reduced, as a result stress rises. Ultimately, a point is reached where the remaining cross-section is no longer strong enough to carry the load and finally results in fracture. The cracks start at visible discontinuities. The events that lead to fatigue include Crack nucleation Crack growth, and finally Fracture.

III. ANALYSIS OF CONVENTIONAL 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. The IGES (.iges) format of connecting rod model is imported into ANSYS by using import/export command. The connecting rod has various curved areas and so that were not modeled in ANSYS.

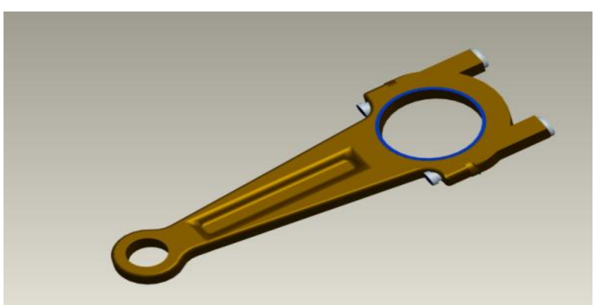

Fig 1-- The solid model generated in Pro-E

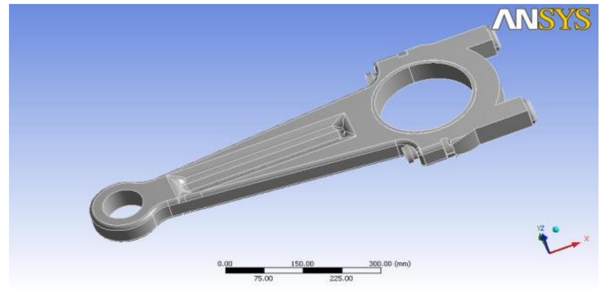

Fig 2 -- Model imported into ANSYS WORKBENCH

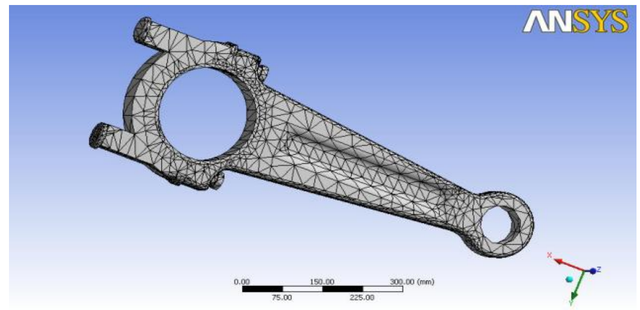

Fig 3 – Meshed Connecting Rod

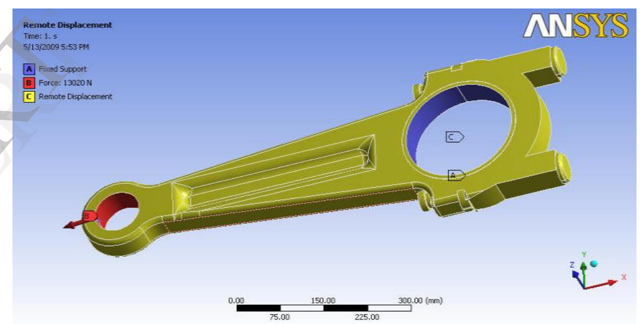

Fig 4 – Boundary Conditions

Static Analysis

Material Properties

Material type	:	C 40
Carbon	:	0.35-0.45
Manganese	:	0.60-0.90
Young's Modulus	:	380 N/mm^2
Poisson's Ratio	:	0.3
Density	:	8000 kg / m^3
Ultimate Tensile Strength	:	750 N/mm^2

Calculations

Specifications:

B.H.P	=	7.6
Bore	=	49 mm
Stroke	=	56 mm
Crank Radius	=	56/2 = 28 mm
Piston Diameter	=	48.5mm
Piston weight	=	65g (0.065 kg)
RPM	=	7500
Torque	=	0.8 kg – m

After calculation load acting on the connecting rod is W_B = 13020 N

Tensile Analysis

Boundary condition:

Bottom end (Big end)	-	Fixed
Top end (Small end)	-Application of load	
F_Y	-	+13020 N
U_X, U_Y, U_Z, ROT_X, ROT_Y	-	Fixed
ROT_Z	-	Free

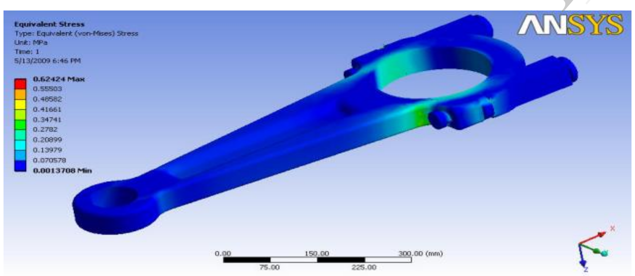

Fig 5 – Stress Analysis of Conventional Connecting Rod

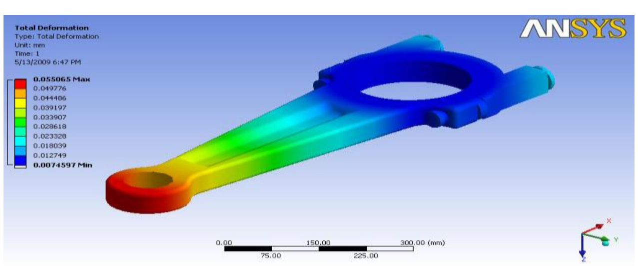

Fig 6 – Displacement Analysis of Conventional Connecting rod

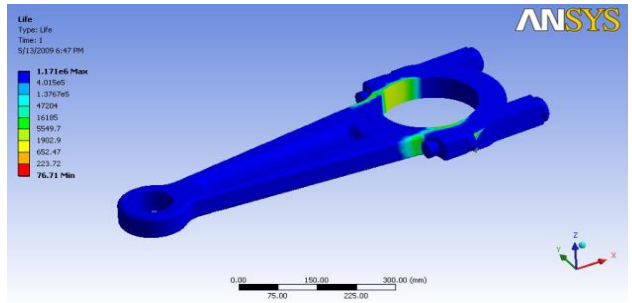

Fig 7 – Fatigue Analysis of Conventional Connecting Rod

Output

Displacement (mm)	0.05506
Maximum stress (MPa)	0.624
Weight in Grams	115.48

Fatigue Analysis results in Conventional Connecting Rod

Crack nucleation starts from the cycle 10000 cycles at the stress value of 0.250MPa. 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 0.160MPa this is because due to the discontinuities. At 30000 cycles the stress value slightly rises as a result of fatigue propagation after which the sudden down fall to 0.125MPa at 40000 cycles indicating inclusions and variations in cross-sectional area. At 50000 cycles the stress value reaches the highest stress value of 1.175MPa which is well above the working stress limit of 0.793. At this value the Connecting Rod fails. Then finally 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.

IV. ANALYSIS OF MMC CONNECTING ROD

The same connecting rod that was modeled for analysis in the previous section is taken here and the only changes are the values in the material properties. The following values are used for analysis of the MMC connecting rod.

PROPERTIES	VALUE
Tensile Modulus along X direction, (E_x), MPa	20700
Tensile Modulus along Y,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

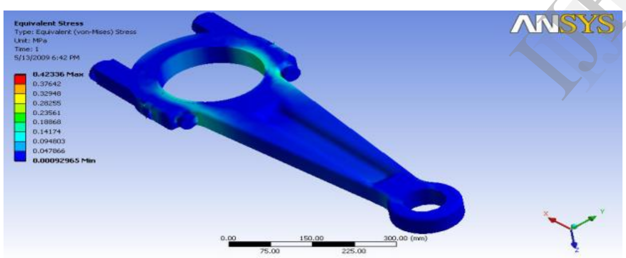

Fig 8 – Stress Analysis of MMC Connecting Rod

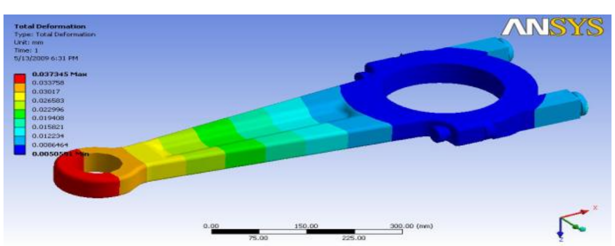

Fig 9 – Displacement Analysis of MMC Connecting Rod

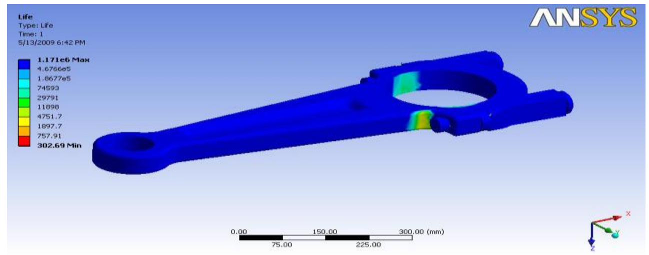

Fig 10 – Fatigue Analysis of MMC Connecting rod

Output

Displacement (mm)	0.0373
Maximum stress (MPa)	0.423
Weight in Grams	72.17

Fatigue Analysis of MMC Connecting rod

The crack nucleation starts from the cycle 10000 cycles at the stress value of 0.250MPa, 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 0.320MPa this is because due to the discontinuities, whereas at 30000 cycles the stress value slightly rises as a result of fatigue propagation. Then there is a sudden down fall to 0.160MPa at 50000 cycles indicating inclusions and variations in cross-sectional area. At 65000 cycles the stress value reaches the highest stress value of 0.650MPa which is well above the working stress limit of 436.78. At this value the Connecting Rod fails. 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.

V. COMPARISON OF RESULTS

After the fatigue life analysis made between the conventional Connecting Rod with composite connecting rod, let us infer the solution in various viewpoints. Initially the conventional Connecting Rod subjected to analysis without the material replacement gives us the result as it has the fatigue life up to 50000 cycles reaching a maximum stress of 1.175MPa which is higher than the working stress of 0.795MPa. Now when we subject the composite Connecting Rod to fatigue analysis, the result obtained is slightly better. Only after 65000 cycles, the Connecting Rod reaches a maximum stress of 0.650MPa at which it fails and the stress value decreases. This clearly confers that the composite connecting rod has its fatigue life of up to 65000 cycles which is way better than the conventional connecting rod. Apart from stress and fatigue benefits, there is also a significant weight reduction if the material is replaced. A comparison of the results is tabulated.

Stress	Conventional Connecting Rod	MMC Connecting Rod
Tensile Stress (MPa)	0.624	0.423
Life (Days)	76.71	302.69
Strength to weight Ratio	Lesser	Comparatively Greater
Mass (grams)	115.48	72.17

VI. CONCLUSION

The conventional connecting rod that is used in the engines nowadays if replaced with a composite connecting rod can give tremendous 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. Hence the number of working day for composite connecting rod is high. Hence the replacement of the connecting rod material with MMC, we can expect good fatigue strength, minimized weight and the induced stress in the structure. A reduction of 37.5% weight is achieved thereby increasing the strength to weight ratio drastically ultimately leading to higher efficiencies.

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