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Design and Fatigue Analysis of Connecting Rod with Composite Material Using ANSYS

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Abstract

A connecting rod is an important component of an internal combustion engine to transfer the reciprocating motion of the piston into the rotary motion of the crank shaft. The possibility of fatigue failure is higher when it experiences alternative tensile and compressive cyclic loading as compared to steady load. Hence, it is very crucial to find out the fatigue life of the connecting rod's materials. In this work, a new composite material of aluminum alloys reinforced with silicon-carbide (Al6061+20% SiC) is investigated for the design of a connecting rod. The geometric model of the connecting rod is developed in CATIA V5. The fatigue analyses are performed for two cases by fixing small and big ends alternatively in the ANSYS environment. The equivalent stress, mass of materials and number of cycles (life) of the considered composite material are compared with other existing materials like 42CrMo4, EN-8D and Al 6061 alloy. From the analysis, it is concluded that there is a significant reduction in the mass of the connecting rod as compared to other selected materials, with some loss of strength.

Keywords

Connecting rod, Fatigue, Composite, ANSYS

Introduction

For every internal combustion engine, there is a need for a connecting rod to transfer reciprocating motion of the piston into rotational motion of the crank and consequently transport the piston loads to the crankshaft [1]. With the support of a gudgeon pin, the larger end is attached to the crankshaft and the smaller end to the bottom of the piston [2]. The connecting rod experiences high compressive loads due to the fuel combustion in the cylinder at a high temperature. It results in the development of inertia that causes tensile loads [3]. In comparison to the compressive loads, the inertia forces in the connecting rod are very small and considered negligible. Gas pressure generated through combustion causes tensile and compressive stresses, while eccentricity causes bending stresses [4]. The connecting rod has a variable load which varies with time during its service life. Sumukh et al. [5] have compared a connecting rod of standard dimensions made up of steel with composite materials like aluminum-beryllium alloy, Al-SiC composite, and titanium alloy. Chakrapani et al. [6] investigated the mechanical properties of an aluminum matrix composite depending upon the deposition of the silicon-carbide reinforcements. The material selection criteria of the connecting rod are critical, and it is always challenging to get the desired features. It is well known that alternating load leads to fatigue failure of the component. Hence, cyclic loading is a very important factor to be considered in the design of the connecting rod. Different research has been presented on connecting rods for structural analysis with different materials [7-9]. Limited work has been done on fatigue analysis with different composite materials like metal matrix composite. The more work that had to be done with structural steel and aluminum alloy for fatigue analysis. In this work, a new composite material of aluminum alloys reinforced with silicon-carbide (Al6061+20% SiC) is investigated for the design of a connecting rod. The geometric model of the connecting rod is developed in CATIA V5. The fatigue analyses are performed for two cases by fixing small and big ends alternatively in the ANSYS environment. The equivalent stress, mass of materials and number of cycles (life) of the considered composite material are compared with other existing materials like 42CrMo4, EN-8D and Al 6061 alloy.

The rest of the paper is arranged in the following sequence: The modeling of connecting rod and material properties is covered in Section 2. In section 3, the meshing, boundary conditions, and reversible load applied are presented. The simulation results are presented and discussed in Section 4. The conclusion and future scopes are summarized in section 5.

Experimentation

Modeling of connecting rod

In this section, the design parameters for geometric construction and the different required mechanical properties of selected materials for connecting rods are presented.

Geometric construction

The part that connects the two ends of the connecting rod is known as the "shank". It may be of different cross-section for different applications depending upon the design requirement. These are I, H, circular and rectangular sections. In table 1, the design parameters selected are presented. The 3D model of the connecting rod developed in CATIA is shown in figure 1.

Materials

Materials selected for the connecting rod are 42CrMo4, EN-8D, and aluminum alloy due to their better flexural strength and higher Young's modulus, which make them more reliable for completely reversible cyclic loading [10]. Table 2 shows the comparative mechanical properties of selected materials for connecting rods.

Material 42CrMo4, EN-8D, and aluminum alloy are isotropic materials, so it has same magnitude of longitudinal as well as in transverse direction. But Al 6061+20% SiC is an anisotropic material. Due to this, it has different magnitudes in different directions. The Young's modulus of the material is greater in both directions as compared to the aluminum alloy.

Analysis

Meshing and boundary conditions

In meshing, for complex geometries, the most common meshed element is tetrahedral. It provides a more accurate result as compared to the others. Here, it is considered to be 5 mm in size for all the parts, and the number of nodes and elements are respectively 30967 and 17399. The mesh generated in the model developed is shown in figure 2. Initial conditions are set by fixing the small and big ends, then a completely reversible cyclic load is applied. Analysis is done in 25 steps, and each step lasts for 45 seconds.

Table 1: Design parameters of connecting rod [1].

Parameters	Values (mm)
Thickness (t)	7.26
Width (B = 4t)	28.89
Height (H = 5t)	36.17
Smaller end inner diameter	36.29
Smaller end outer diameter	47.17
Big end inner diameter	55.12
Big end outer diameter	79.90

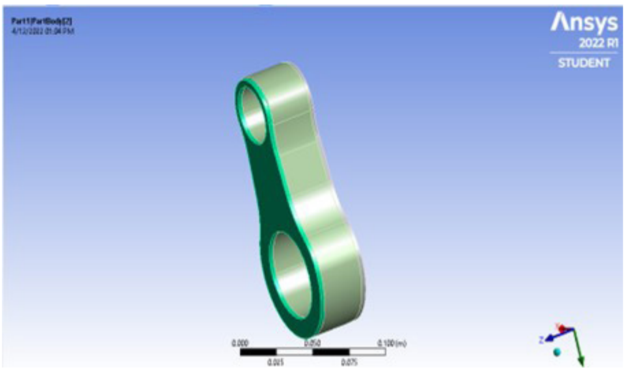

Figure 1: Design of connecting rod silicon-carbide reinforced composite material.

Figure 2: Meshing of connecting rod.

Reversible load

The magnitude of the applied reversible load is selected from the work [3] and it is 4319 N in magnitude. As shown in figure 3, the maximum and minimum loads are +4319N and -4319N, respectively, and vary over time.

Procedure

At first, the model with the required dimensions is developed in CATIA, and then it is transferred to the ANSYS workbench in IGS format. Engineering data is selected, and the geometry is linked to static structural. Here, geometry import is checked, and materials are assigned to the parts of the model. For the fatigue analysis, the global coordinate system is used, and two different boundary conditions, such as small end fixed and big end fixed, are chosen at random.

Table 2: Properties of different materials.

Properties	42CrMo4	EN-8D	Al 6061 alloy	SiC	AL6061+ 20% SiC
Density (kg/m^3)	7850	7800	2800	3100	2860
Young Modulus (GPa)	190	200	68.9	71.1	148
Poisson ratio	0.27	0.28	0.33	0.14	0.28
Yield strength (MPa)	750	830	276	-	-
Flexural strength (MPa)	440	340	96.5	550	450
Youngs Modulus (transverse) (GPa)	-	-	-	-	85.06

Results and Discussion

The fatigue analysis is done for two cases, namely case A and case B, by fixing the small and big ends of the connecting rod one by one. A complete reversible load of 4319 N is applied in each case, and equivalent alternating stresses are obtained as shown in figure 4 to figure 11. The maximum induced alternating stress is the endurance limit, which is equal to $0.5\sigma_{ut}$. The equivalent alternating stress induced in the connecting rod of different considered materials is studied and presented for each case.

Case A: Small end fixed

In this case, the equivalent alternating stress induced during the application of a completely reversible load for different materials is shown in figure 4 to figure 7.

Case B: Big end fixed

In this case, figure 8 to figure 11 illustrate the corresponding alternating stress induced by the application of a totally reversible load for various materials.

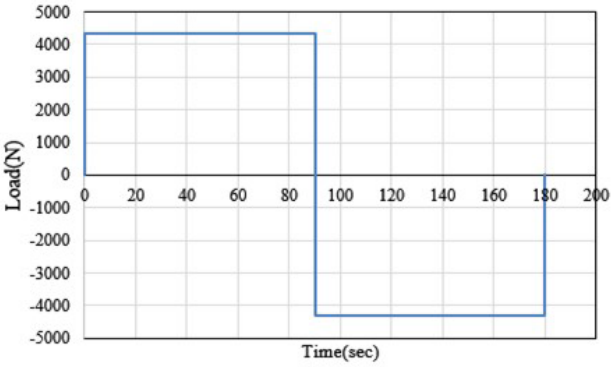

Figure 3: Completely reversible load applied along time.

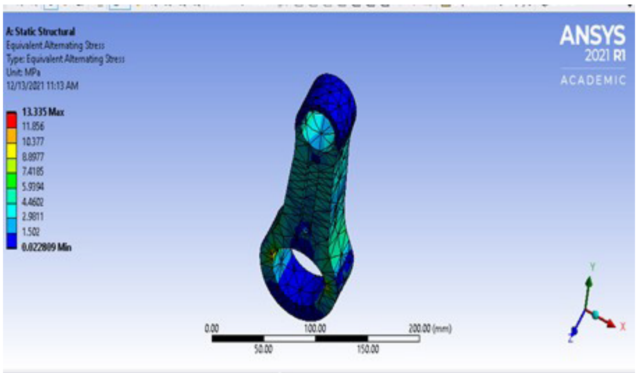

Figure 4: Equivalent stress of 42CrMo4 material for case A.

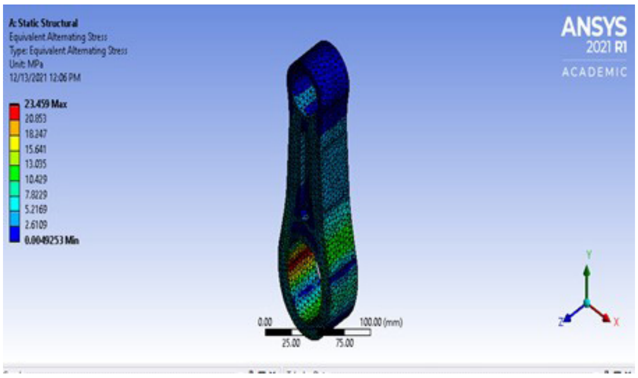

Figure 5: Equivalent stress of EN-8D material for case A.

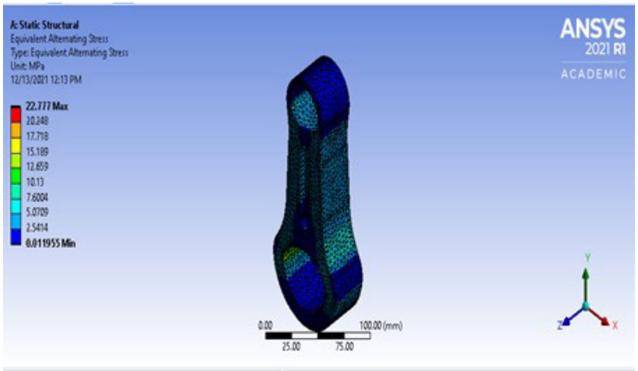

Figure 6: Equivalent stress of Al 6061 alloys material for case A.

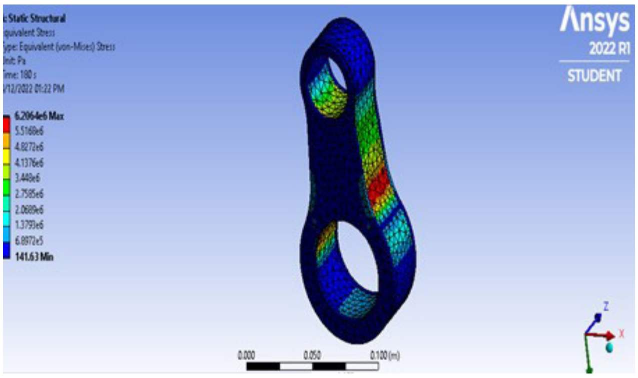

Figure 7: Equivalent stress of Al 6061+20% SiC material for case A.

In table 3, the equivalent stress and number of cycles for considered materials are compared for two cases under the given load. The mass (in kg) of the respective material is ob-

Table 3: Comparison of equivalent stress for considered materials.

Material	Load (N)	Mass (kg)	End Fixed	Equivalent Stress (MPa)	Life (No. of Cycle)
42CrMo4	4319	2.077	Small	13.12	10^6
			Big	23.43	10^6
EN-8D	4319	2.056	Small	23.459	10^6
			Big	22.752	10^6
Al 6061	4319	0.759	Small	23.391	10^8
			Big	22.77	10^8
Al 6061+20% SiC	4319	0.479	Small	6.20	10^7
			Big	6.55	10^7

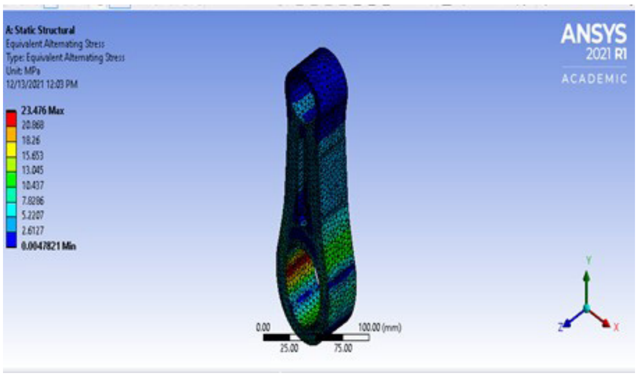

Figure 8: Equivalent stress of 42CrMo4 material for case B.

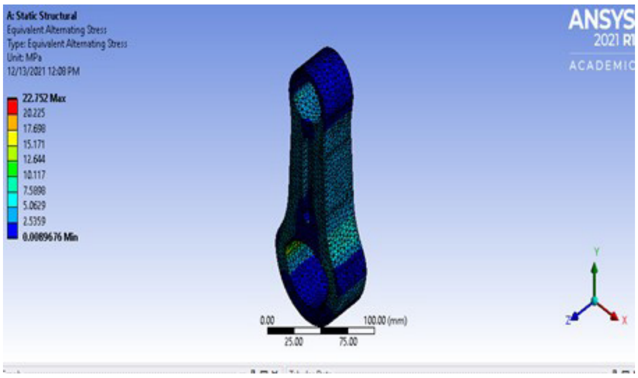

Figure 9: Equivalent stress of EN-8D material for case B.

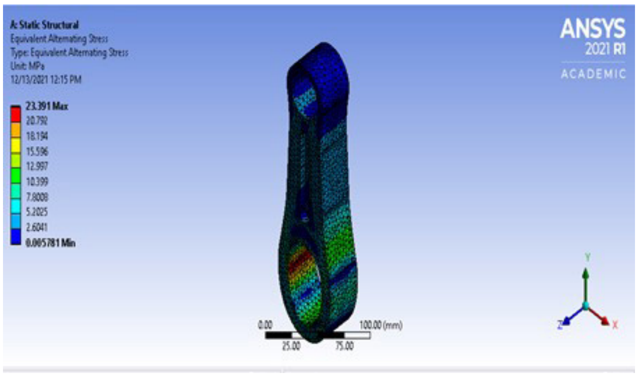

Figure 10: Equivalent stress of Al 6061 alloys material for case B.

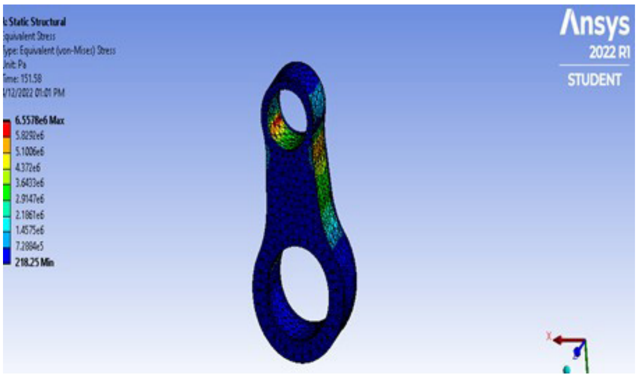

Figure 11: Equivalent stress of Al alloys+20% SiC material for case B.

tained for the same application of load. It suggests that the optimized mass may be achieved by the material Al 6061+20% SiC, which has a magnitude of 0.479 kg. It can be summarized that there is a significant reduction in mass of the connecting rod for a comparable life (number of life cycles) of the connecting rod made of composite material Al 6061+20% SiC. The relative percentage reduction in mass of the connecting rod with the considered material is respectively 76.94%, 76.7%, and 36.89% for 42CrMo4, EN-8D, and Al 6061 alloys, respectively. However, there is some loss in the equivalent stress as compared to other materials.

Conclusion

In this work, a new composite material, Al 6061+20% SiC, is investigated for the design of a connecting rod. The geometric model of the connecting rod was developed in CATIA V5. The fatigue analyses are performed for two cases by fixing small and big ends alternatively in the ANSYS environment. The equivalent stress and mass of the material under applied reversible cyclic load are compared with other common materials like 42CrMo4, EN-8D, and Al 6061 alloys. From the analysis, it is observed that there is a significant reduction in the mass of the connecting rod for a comparable life span with some loss in the equivalent stress.

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Conflict of Interest

Authors declare that they have no conflict of interests.

Credit Author Statement

Manav Kumar: Writing - original draft preparation; Sujeet Kumar: Conceptualization, Investigation, Writing - original draft preparation; Sharifuddin Mondal: Conceptualization, Writing - review and editing, Supervision. All the authors read and approved the manuscript.

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