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Material Optimization of Connecting Rod Using Finite Element Analysis

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Abstract: ***Connecting rod is a major part inside the engine as it connects the piston to the crankshaft and also used to transfer power from the piston to the crankshaft. Connecting rods of vehicles are generally manufactured by the process of forging or casting (Either wrought steel or powdered metal). Under complex loading connecting rod of an automobile vehicle a high production component. The weight and design of the connecting rod have a good influence on performance of an automobile engine. Use of lighter material can increase the performance of an engine because of its less energy consumption than heavier material. Conventional materials have limitations in strength, stiffness and toughness, and because of this they have failed to fulfil the demand of saving of energy. This shows the need to work upon materials having high strength and less weight as compared to conventional materials. Use of composite material would help to reduce weight and improve fuel consumption without sacrificing the safety of the vehicle. In this current work, connecting rod has been designed by using computer aided design (CAD) software CATIA and was analysed using a finite element analysis (FEA) software ANSYS to understand the exact behaviour of the connecting rod under different material properties.***

Keywords: Connecting Rod, ANSYS, FEA, CATIA

1. Introduction

A connecting rod is an engine component which transfers motion from the piston to the crankshaft.It functions as a lever arm. It converts reciprocating motion into rotating motion. As connecting rod is rigid, and it may transmit either a push or a pull. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required to push.

A combination of axial and bending stresses act on the rod in operation. The axial stresses produced arethe product of cylinder gas pressure and the inertia force, which arising on account of reciprocating motion. Whereas bending stresses produce due to the centrifugal effects.

A typical connecting rod consist of a pin –end, a shank section, and crank end. A pin end and crank end pin holes are machined to permit accurate fitting of bearings. One end of the connecting rod is connected to the piston by the piston pin. The classification of connecting rod is made by the cross sectional point of view i.e. I – section, H – section, Tabular section, Circular section.

Kuldeep et al. (2013) carried out FEA analysis by considering two materials. Various parameters were obtained from ANSYS software like von misses stress, von misses strain and displacement. In the results when the analysis was compared to the former material the new material found to had less weight and better stiffness. It resulted in reduction of 43.48% of weight, with 75% reduction in displacement.

Ramani et al (2014) carried out a study in which the main idea was to do analysis of connecting rod and get idea of stress producing during compressive and tensile loading. In the results they give idea about weight reduction opportunities for a production steel connecting rod. The study had two subjects, first, load and stress analysis of the connecting rod, and second, optimization for weight reduction. The first part of the study consists of, loads acting on the connecting rod and find out stress-time history at some critical point. The results were also used to determine the variation of Tensile and Compressive loading the component was optimized for weight reduction subject to space constraints and manufacturability.

Tiwari et al (2014) took the phenomenon that fatigue should be taken into account during the development, in order to guarantee the connecting rod required lifetime. Numerical tools had been extremely used during the connecting rod development phase. All the work showed the complete connecting rod Finite Element Analysis (FEA) methodology to explore weight and cost reduction opportunities for a production of forged steel connecting rod. It was also performed a fatigue study based on Stress Life (SxN) theory, considering the Modified Goodman diagram.

Savanoor et al (2014) compared the von mises stress and total deformation of 2 different aluminium alloys with the forged steel. FEA analysis was carried out by considering three materials. The parameters like von misses stress and displacement were obtained from ANSYS software. Then compared the aluminium alloys with the forged steel. In the results Al5083 alloy found to have less weight with reduction of 63.19% of weight.

2. Development of Geometry

According to Rankine formulae:-

$$W_{cr} \text{ about X axis} = \frac{[\sigma c \times A]}{1 + a[\frac{L}{Kxx}]^2} = \frac{[\sigma c \times A]}{1 + a[\frac{l}{Kxx}]^2}$$

$[\therefore for both ends hinged L = l]$

W_{cr} about Y axis $= \dfrac{[\sigma c \times A]}{1 + a[\dfrac{L}{Kyy}]^2} = \dfrac{[\sigma c \times A]}{1 + a[\dfrac{l}{2Kyy}]^2}$

[$\therefore$ *for both ends* fixed $L = \dfrac{l}{2}$]

In order to have a connecting rod equally strong in buckling about both the axis, the buckling loads must be equal. i.e.

$$\frac{[\sigma c \times A]}{1 + a[\frac{l}{Kxx}]^2} = \frac{[\sigma c \times A]}{1 + a[\frac{l}{2Kyy}]^2} \text{ Or, } [\frac{l}{Kxx}]^2 = [\frac{l}{2Kyy}]^2$$

$K^2xx = 4K^2yy$ Or, $Ixx = 4Iyy$ [$\therefore I = A \times K^2$]

This shows that the connecting rod is four times strong in buckling about x-axis than about- y-axis. If I xx > 4Iyy, Then buckling will occur about y-axis and if I xx < 4Iyy, then buckling will occur about x-axis .In Actual practice I xx is kept slightly less than 4Iyy. It is usually taken between 3 and 3.5 and the Connecting rod is designed for buckling about x-axis. The design will always be satisfactory for buckling about y-axis. The most suitable section for the connecting rod is I-section with the proportions shown in fig. 4.1.

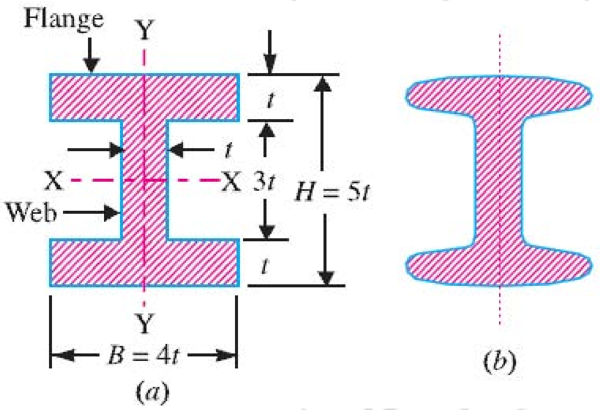


Figure 1.1: I section dimensions ratio

Area of the cross section = 2[4t x t] + 3t x t =11t^2

Moment of inertia about x-axis $= \dfrac{1}{12}(BD^3 - bd^3)$

$= \dfrac{1}{12}(4t(5t)^3 - 3t(3t)^3) = \dfrac{419}{12}(t^4)$

Moment of inertia about y-axis =

$Iyy = \dfrac{2 \times 1}{12} \times t \times (4t)^3 + \dfrac{1}{12}(3t)t^3 = \dfrac{131}{12}(t^4)$

$\therefore \dfrac{Ixx}{Iyy} = \dfrac{419}{12} \times \dfrac{12}{131} = 3.2$

Since the value of $\dfrac{Ixx}{Iyy}$ lies between 3 and 3.5, therefore I-section chosen is quite satisfactory.

Table 1.1: Engine Specification taken into Consideration

Company	*Bajaj pulsar 220*
Engine type	Air cooled 4 stroke
Bore X Stroke(mm)	67x62.4
Displacement	220 CC
Maximum power	21.05 bhp@8500rpm
Maximum torque	19.12 Nm@7000rpm
Compression ratio	9.35:1
Explosion pressure	4.1 Mpa
Weight of piston assembly	0.3 Kg
Working temperature	-30 ^{0}C to 180 ^{0}C

3. Materials and Methods

Table 1.2: Material Properties Selected

Properties	**Al 10% SiC**	**Al 20% SiC**	**Al 30% SiC**
Density (Kg m^{-3})	2742	2784	2826
Young's modulus (MPa)	93010	1.0901 E+05	1.1721 E+05
Poisson ratio	0.295	0.29	0.3
Coefficient of thermal expansion (C^{-1})	21.04	14.994	12.4
Tensile Strength (MPa)	460	572	589
Compressive strength (MPa)	350	430	460
Thermal Conductivity ($Wm^{-1}K^{-1}$)	92.993	124	124
Specific heat ($Jkg^{-1}K^{-1}$)	929.89	914	800

Properties	**Forged Steel**
Density (g/cc)	7.7
Average hardness (HRB)	101
Modulus of elasticity (Gpa)	221
Yield strength (Mpa)	625
Ultimate strength (Mpa)	625
Poison ratio	0.29

Design Calculations

Calculation of buckling load

Buckling load, W_b = maximum gas force x factor of safety

$$= \frac{3.14 \times D^2}{4} \times P \times fos = \frac{3.14 \text{ x } (67 \times 10^{-3})^2}{4} \times 4.1 \times 10^6 \times 6 = 86687.079\text{N}$$

I Section profile calculations

$$W_b = \frac{(\sigma_c \times A)}{1 + a\left(\frac{L}{Kxx}\right)^2}$$

Where, W_b= Buckling load, A = area of I section = $11t^2$

L= Length of connecting rod = 2 x stroke length = 2x62.4 = 125 mm

$$Kxx = \frac{Ixx}{A} = 1.78t\,,$$

$$a = \text{constant for material} = \frac{\sigma_c}{\pi^2 \times E}\,,$$

σ_c= compressive yield strength

By substituting value of σ_c, W_b, a, K_{xx}, A and L we can calculate (thickness of profile)

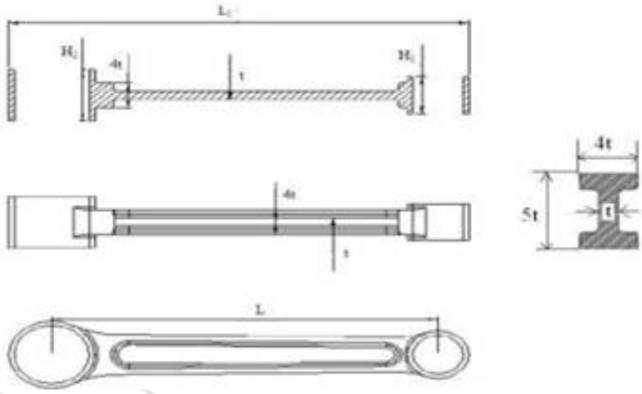


Figure 1.2: Dimensions of Connecting Rod

Table 1.3: Dimensions obtained From Design Calculations

Dimensions → / Material ↓	t (mm)	B (mm)	H (mm)	H_2 (mm)	H_1 (mm)
Al + 10% SiC	5	20	25	27.5	22.5
Al + 20% SiC	4.5	18	22.5	24.8	20.3
Al + 30% SiC	4.3	17.2	21.5	23.7	19.4
Forged Steel	3.3	13.2	16.5	18.2	14.9

Working force on the connecting rod

$$F_m = F_p + F_i$$

Where, F_m= Maximum force, F_p= Pressure force, F_i= Inertia force

Now, F_p = Area of piston head x Explosion pressure

$$= \frac{3.14 \times D^2}{4} \times P \times = \frac{3.14 \text{ x } (67 \times 10^{-3})^2}{4} \times 4.1 \times 10^6 \times = 14448\text{N}$$

$$\begin{Bmatrix} D = 67mm \\ P = 4.1MPa \end{Bmatrix}$$

$$F_i(\max) = m_r \times \omega^2 \times r\left(1 + \frac{1}{n}\right)$$

Where, m_r = mass of reciprocating parts

= mass of piston assembly + $\frac{1}{3}$rd mass of connecting rod

Mass of piston assembly = 0.3 kg

ω = Angular velocity of crank = $\frac{2\Pi N}{60} = \frac{2 \text{ x } 3.14 \text{x} 8500}{60} = 889 rad/\sec$

r = radius of crank = $\frac{\text{Stroke of piston}}{2} = \frac{62.4}{2} = 31.2\,\text{mm}$

n = ratio of length of connecting rod = $\frac{\text{length of connecting rod}}{\text{radius of crank}} = \frac{125}{31.2} = 4.006$

Table. 1.4: Forces Obtained from Design Calculations

Material		Total force (Fp +Fi) (N)
Forged Steel		26055
concept 1	Al+10%SiC	25171
concept 2	Al+20%SiC	24976
concept 3	Al+30%SiC	24904

Modelling & Analysis

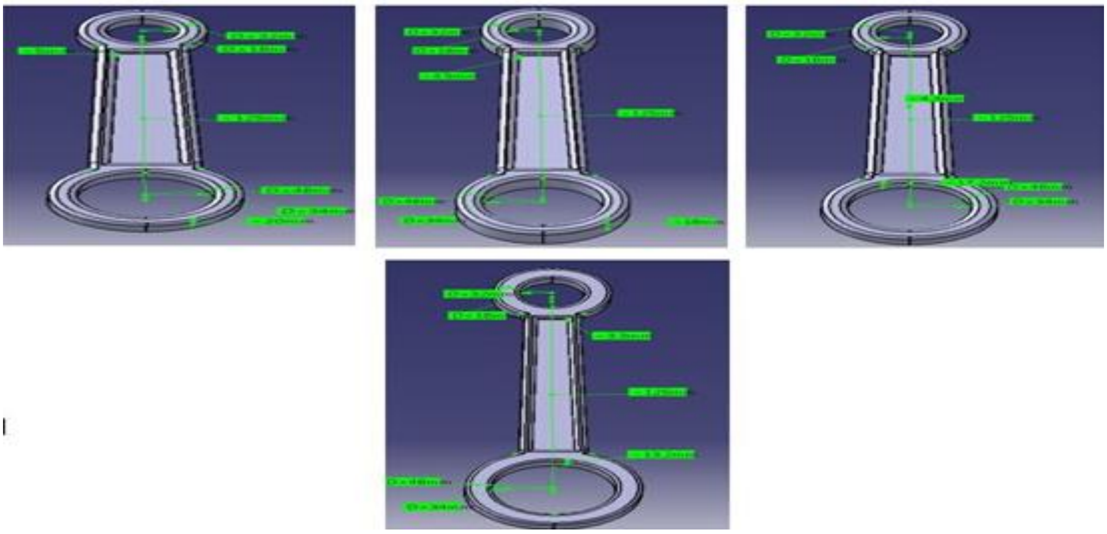
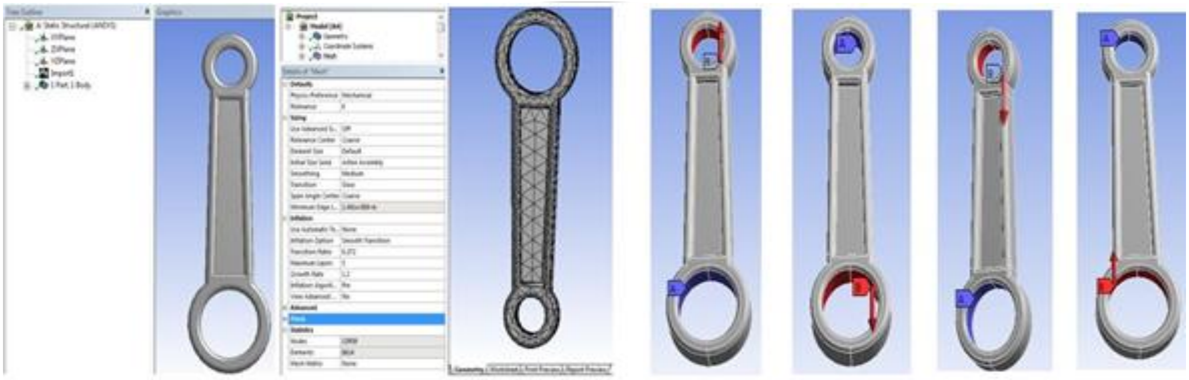
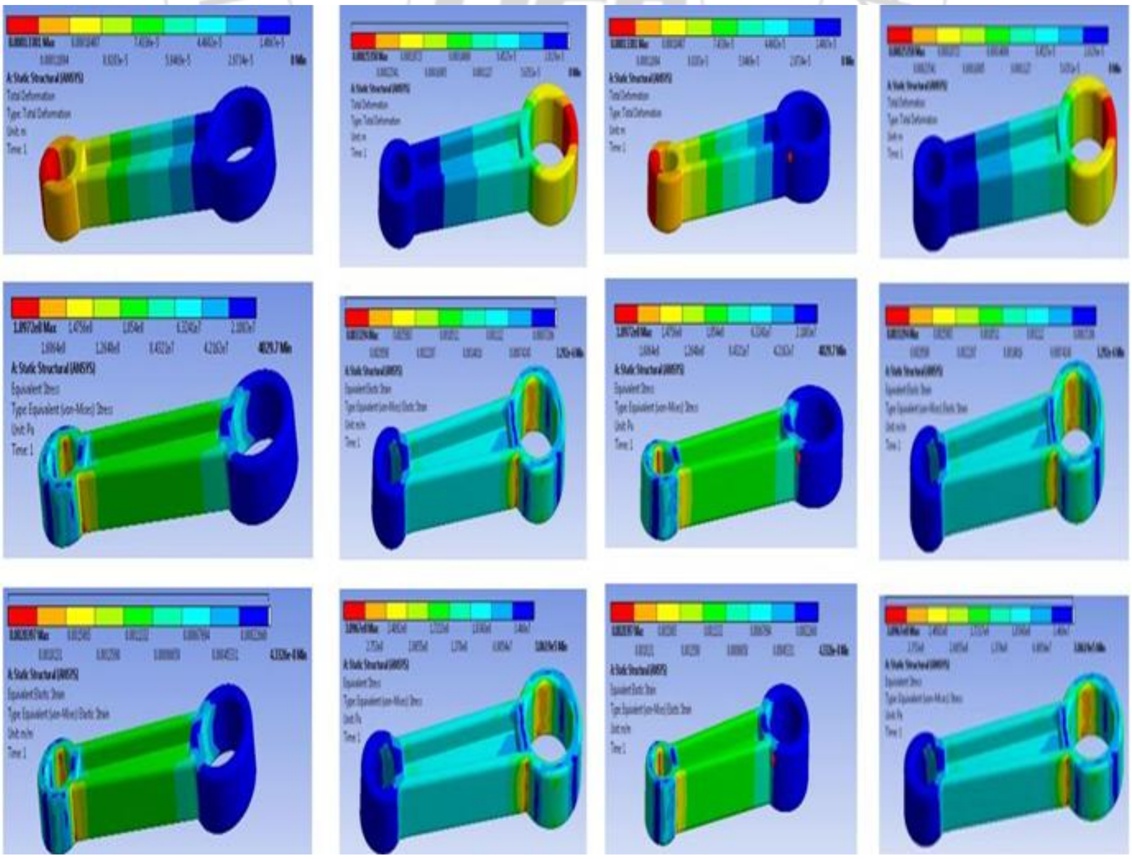


Figure 1.3: Models of Connecting Rod according to Design Calculations



(Case 1) (Case 2) (Case 3) (Case 4)

Figure 1.4: Meshed Model & Different Loading Cases Taken into Consideration



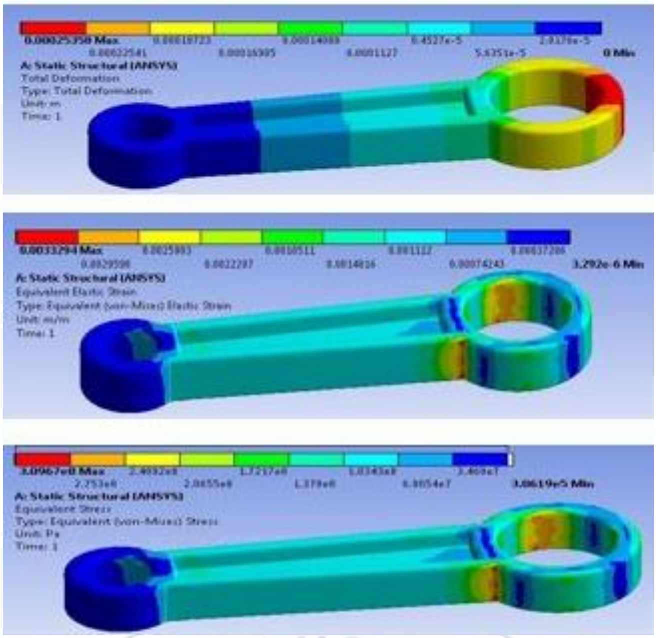


Figure 1.5: Total deformation, Equivalent Stress & Equivalent Strain obtained for Al + 10% SiCunderLoading Case 1, Case 2, Case 3 and Case 4

Table 1.5: Combined Analysis Report for Al + 10% SiC with all Loading Cases

	Maximum stress (MPa)	Maximum Strain	Total deformation (m)
Case 1	189.72	0.0020397	0.00013381
Case 2	309.67	0.0033294	0.00025358
Case 3	189.72	0.0020397	0.00013381
Case 4	309.67	0.0033294	0.00025358

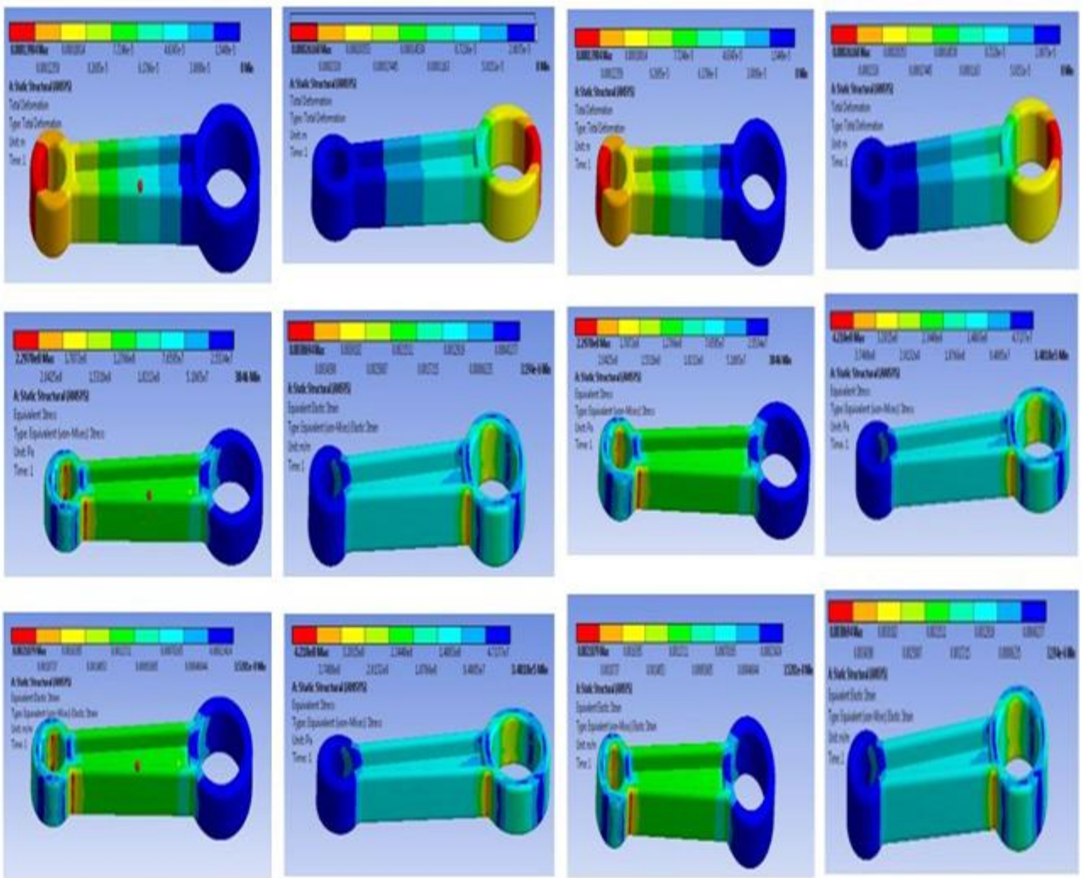


Figure 1.6: Total deformation, Equivalent Stress & Equivalent Strain obtained for Al + 20% SiCunderLoadingCase 1, Case 2, Case 3 and Case 4

Table 1.6: Combined Analysis Report for Al + 20% SiC with all Loading Cases

	Maximum stress (MPa)	Maximum Strain	Total deformation (m)
Case 1	229.78	0.0021079	0.00013904
Case 2	421.88	0.0038964	0.00026168
Case 3	229.78	0.0021079	0.00013904
Case 4	421.88	0.0038964	0.00026168

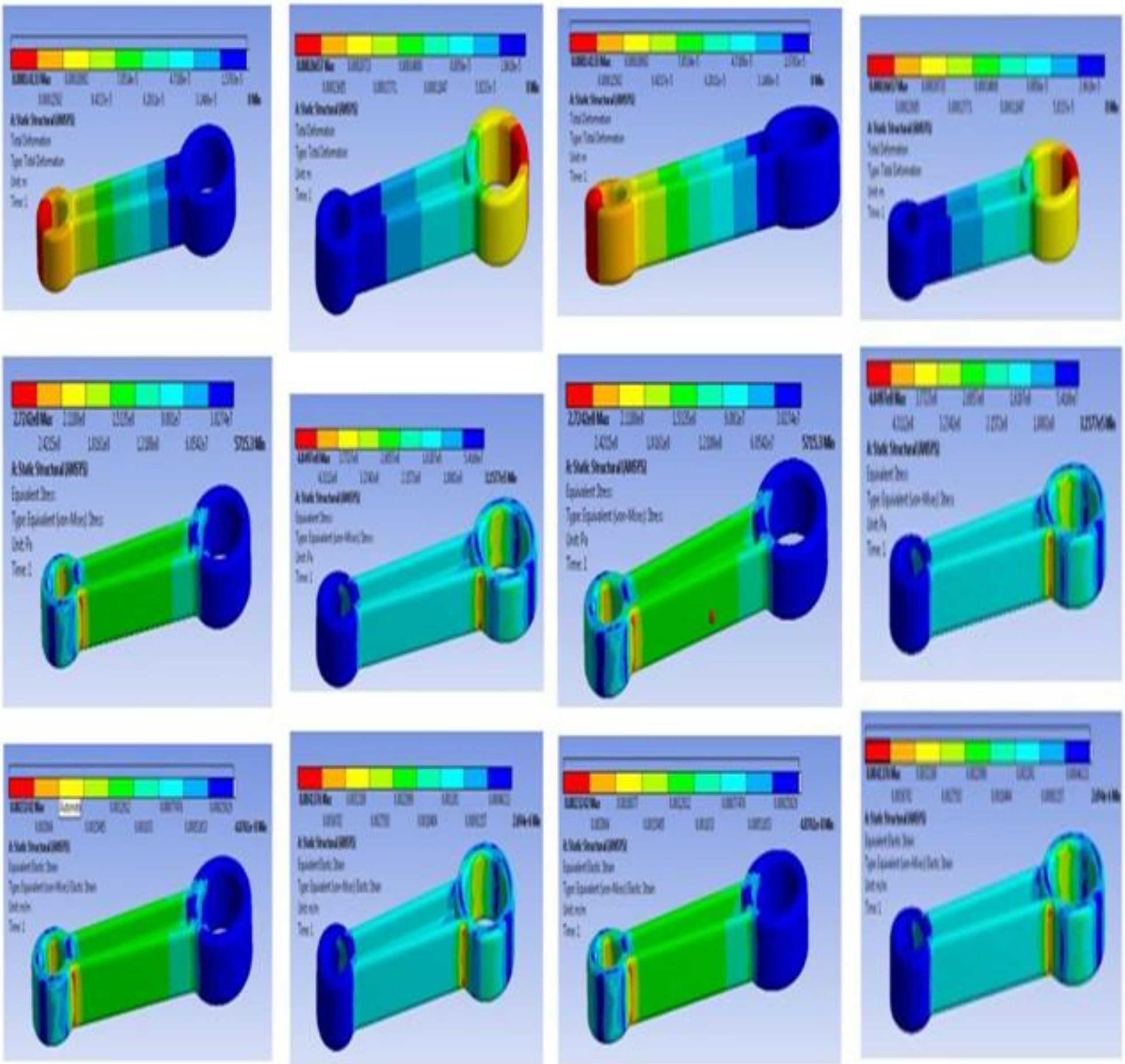


Figure 1.7: Total deformation, Equivalent Stress & Equivalent Strain obtained for Al + 30% SiCunderLoadingCase 1, Case 2, Case 3 and Case 4

Table 1.7: Combined Analysis Report for Al + 30% SiC with all Loading Cases

	Maximum stress (MPa)	*Maximum Strain*	*Total deformation (m)*
Case 1	272.42	0.0023242	0.00014133
Case 2	484.97	0.0041376	0.00026657
Case 3	272.42	0.0023242	0.00014133
Case 4	484.97	0.0041376	0.00026657

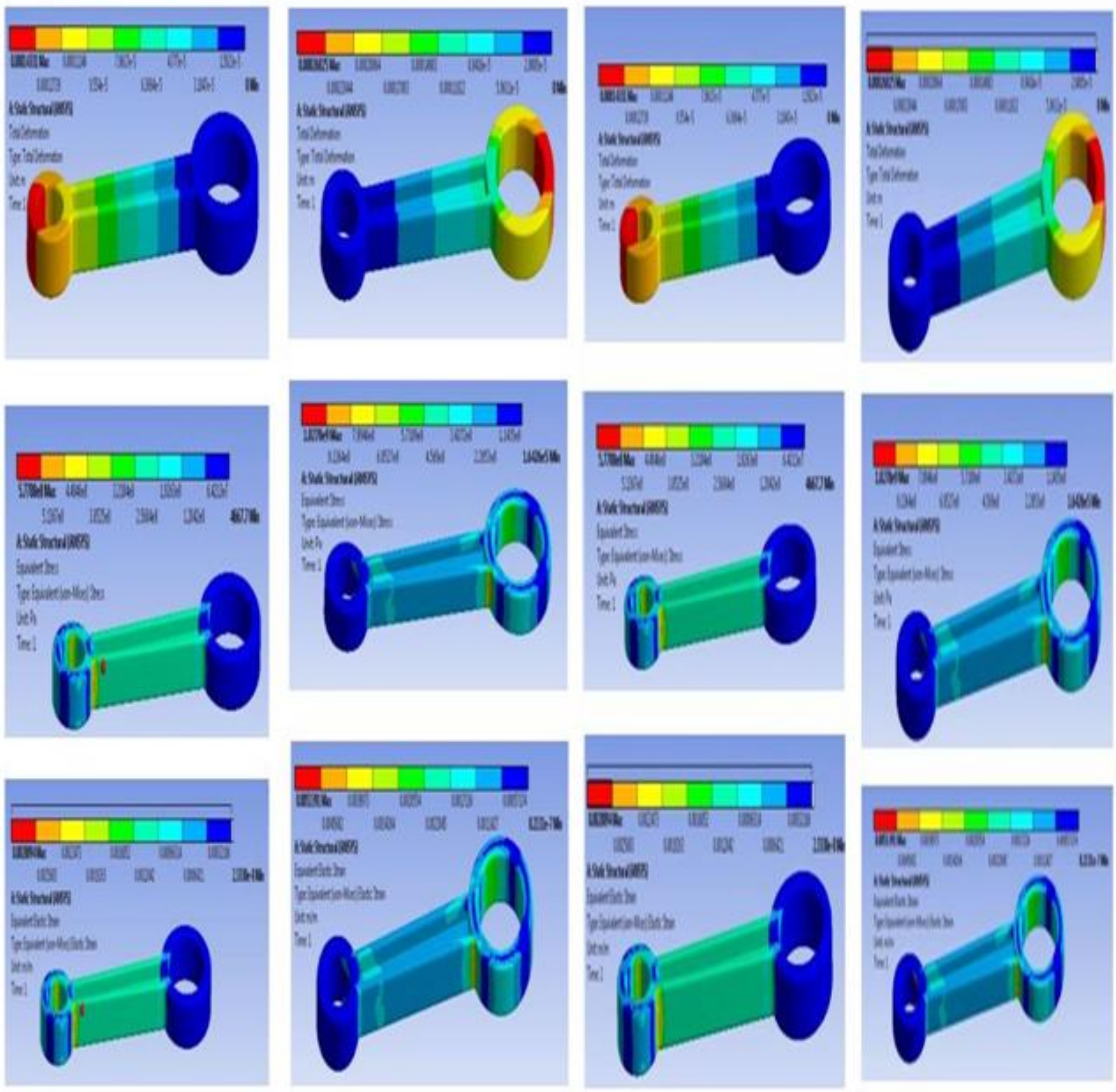


Figure 1.7: Total deformation, Equivalent Stress & Equivalent Strain obtained for Forged Steel underLoadingCase 1, Case 2, Case 3,and Case 4

Table 1.8: Combined Analysis Report for Forged Steel with all Loading Cases

	Maximum stress (MPa)	Maximum Strain	Total deformation (m)
Case 1	577.88	0.0028894	0.00014331
Case 2	1027	0.0051391	0.00026825
Case 3	577.88	0.0028894	0.00014331
Case 4	1027	0.0051391	0.00026825

Table 1.8: Mass of connecting rod with steel and composite materials

	Material Selected	weight (g)
Connecting rod	Forged steel	230
	Al + 10% SiC	144
	Al + 20% SiC	125
	Al + 30% SiC	118

4. Conclusion

In this work, exploration of connecting rod with metal matrix composite is done, aluminium is selected as matrix and various reinforcements were explored on the basis of property suitability and past usage. SiC is selected as suitable reinforcement with aluminium matrix for connecting rod to replace the forged steel connecting rod. Connecting rod is developed in CATIA software for dimensions obtained in designing of connecting rod as per properties of Al matrix and various percentage combinations of SiC.

Table 1.9: Results Obtained

Material	Maximum stress (MPa)	Maximum Deformation (m)	Maximum Strain (MPa)	Weight (g)
Forged Steel	577.88	0.0001433	0.0028894	230
Al + 10% SiC	309.67	0.0002536	0.0033294	144
Al + 20% SiC	421.88	0.0002617	0.0038964	125
Al + 30% SiC	484.97	0.0002666	0.0041376	118

On observing the table 1.9, Al + 10% SiC is selected as best composite material composition for connecting rod on the basis of maximum stress , strain, deformation and weight saving.

5. Nomenclature

A = cross sectional area of the connecting rod.
L = length of the connecting rod.
C = compressive yield stress.
W_{cr} = crippling or buckling load.
Ixx = moment of inertia of the section about x-axis
Iyy = moment of inertia of the section about y-axis respectively.
Kxx = radius of gyration of the section about x-axis
W_b= Buckling load
Kyy = radius of gyration of the section about y- axis respectively.
D = Diameter of piston
r = Radius of crank
n = ratio of length of connecting rod
ω = Angular velocity of crank
m_r = mass of reciprocating parts
F_m= Maximum force
F_p= Pressure force
F_i= Inertia force

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