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Optimization and Cost Reduction by Finite Element Analysis of Connecting Rod Using Aluminum Composite

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Abstracts

In an engine the connecting rod connects the piston to the crankshaft. Connecting rods may also convert rotating motion into reciprocating motion. Generally connecting rod are manufactured using C70 steel. This Paper mainly focuses to reduce weight and manufacturing cost of the connecting rod by replacing existing steel material Connecting rod to Aluminium composite material connecting rod. The connecting rod is investigated with composite material that comprises aluminum as matrix and with various suitable reinforcements in order to reduce its weight and increasing its strength. The objective of this project is to make 3d model of connecting rod using CATIA V5 software and apply static analysis though Ansys 12.1 software. After perform analysis on steel material connecting rod and Aluminum material connecting rod result of both connecting rod Analysis is compared. After that cost calculation is performed. That cost calculation shows that Composite material connecting rod has good strength to weight ratio as compared steel material connecting rod with reduction in unit cost of connecting rod.

Keywords: ANSYS, Connecting Rod, Finite Element Analysis, Modeling, aluminum matrix composite, MMCs..

Introduction

Today everyone expect from automobile industry to develop vehicle with high full efficiency and more power but both are related inversely to fulfill the requirement new technologies are under investigation to develop automobile components with lighter materials, but all this cannot be done by risking passenger's safety. So we need to search materials with high strength and less weight as conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and density due to which they have failed

In principle, the substitution of aluminium metal-matrix composite (MMC) material for steel/Iron components provides a significant opportunity to reduce vehicle mass in a number of automotive applications. Aluminium MMCs possess light weight; high wear resistance characteristics and higher thermal conductivity, making them desirable for a number of automobile component. Therefore, this work is concerned with a novel idea of reducing vehicle weight and cost for better fuel economy attaining Socio-economic benefits by exploring automotive connecting rod for most optimum Aluminium matrix composite (AMC) composition with the support of computer aided engineering in a view of basic working and passenger's safety.

Wei Zhan Guo Liu linHao [1] has described the design of forestry harvesting machines connecting rod based on Finite Element Analysis. In operation, the connecting rod was subjected to both gas pressure and inertia loads, and therefore it must be adequately strong and rigid and light in weight as well

R. Bhagat et al. [2] described the seizure problem on piston four stroke engines by using FEA. The finite element analysis is performed by using CAD software. The main objective was to investigate and analyze the thermal stress distribution of piston at the real engine condition during combustion process. The paper describes the mesh optimization using finite element analysis technique to predict the higher stress and critical region on the component.

Christy V Vazhappilly et al. [3] presented a technique to explore weight and cost reduction opportunities in the design and production of a connecting rod by performing a detailed load analysis. A study was performed on a steel connecting rod; weight reduction performed under two cyclic loads comprising dynamic tensile and static compressive as the two extreme loads.

Ramesh et al. [4] presented composite engine valves subjected to high operating temperatures and stress conditions which affect durability. Weibull failure theory analysis was found a valid tool in predicting the

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probability of failure of the valves. Studies on Al-SiC and Al-TiC composites were selected as possible alternative materials for engine poppet valves. Mixtures of four different compositions (15, 20, 25, 30% by weight) of SiC were prepared and valves were fabricated by Powder Metallurgy (PM) technique, by placing these powder mixtures in layers (one weight per cent along the stem and one along the base) in a die.

Manoj Singla et al. [5] developed aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two step-mixing method of stir casting technique has been adopted and subsequent property analysis has been made.
Pravardhan S. Shenoyet al. [6] presented the FE analysis procedure for connecting rod optimization for weight and cost reduction. Optimization study was performed on a C70 steel connecting rod with a consideration for improvement in weight and production cost. Since the weight of the connecting rod has little influence on its total production cost, the cost and the weight were dealt with separately. Reduction in machining operations, achieved by change in material, was a significant factor in manufacturing cost reduction

Prof. Pushpendra Kumar Sharma et al. [8] performed static FEA of the connecting rod using CAD software and identified fatigue strength as the most significant design factor in the optimization process. Then the combination of finite element technique with the aspects of weight reduction is to be made to obtain the required design of connecting rod and determined total deformation, fatigue analysis and optimize in the existing connecting rod.

Materials and methods

Designing of connecting rod

A connecting rod is a machine member which is subjected to alternating direct compressive and tensile forces. Since the compressive forces are much higher than the tensile force, therefore the cross-section of the connecting rod is designed as a strut and the Rankine formula is used. Since in all high speed connecting rods lightness is essential in order to keep the inertia forces as small as possible and ample strength is required to withstand the momentary high gas pressure therefore, the 'I' section is generally found most suitable as cross-section of connecting rod A connecting rod subjected to an axial load W may buckle with X-axis as neutral axis in the plane of motion of the connecting rod,{or} Y-axis is a neutral axis. The connecting rod is considered like both ends hinged for buckling about x-axis and both ends fixed for buckling about y-axis. A connecting rod should be equally strong in buckling about either axis.
According to Rankine formulae:-
W_{cr} 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 =

$$\frac{[\sigma c \times A]}{1+a[\frac{L}{Kyy}]^2} = \frac{[\sigma c \times A]}{1+a[\frac{l}{2Kyy}]^2}$$

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

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

$$\frac{[\sigma c \times A]}{1+a[\frac{l}{Kxx}]^2} = \frac{[\sigma c \times A]}{1+a[\frac{l}{2Kyy}]^2} \quad \text{Or,} \quad [\frac{l}{Kxx}]^2 = [\frac{l}{2Kyy}]^2 \quad \text{Or,} \quad K^2xx = 4K^2yy \quad \text{Or,}$$

$$Ixx = 4Iyy \qquad [\therefore I=A\times K^2]$$

This shows that the connecting rod is four times strong in buckling about y-axis than about-axis. If I xx > 4Iyy, Then buckling will occur about y-axis and if I xx < 4Iyy, then buckling will occur about x-axis . The most suitable section for the connecting rod is I-section with the proportions shown in fig. 1.1.

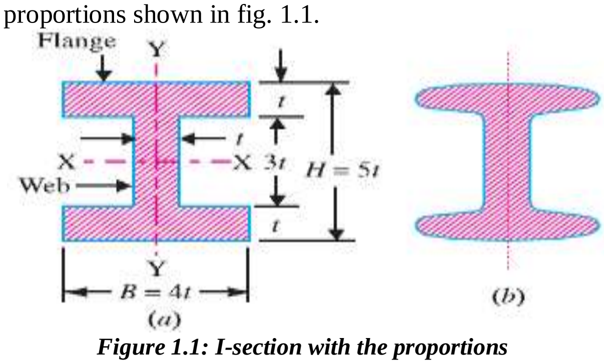

Figure 1.1: I-section with the proportions

Area of the cross section=

$$2[4t \times t] + 3t \times t \quad =11t^2$$

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

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

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Moment of inertia about y-axis =

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

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

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

For designing reference an engine of 150 CC of Suzuki Company is used, specification of the engines is given in table:

Table 1.1: Designing reference an engine of 150 CC of Honda Company

Company	HONDA unicorn
Engine type	Air cooled 4-stroke
Bore X Stroke(in)	2.26 in × 2.28 in
Displacement	149.1CC
Maximum power	13.8 bhp@8500rpm
Maximum torque	13.4Nm@6000rpm
Compression ratio	9.35/1
Weight of piston assembly	2.9Mpa
Working temperature	-30 ^{0}C to 180 ^{0}C

Calculation of Explosion pressure:

Explosion pressure can be calculated by gas equation:

$P = \frac{MrT}{V}$, Where, P = Explosion pressure

V= 149.5 x 10^{-6} m^3

M = mass of gas

= Density xvolume

= 737.22 x 149.5 x 10^{-6}

= 0.11 Kg

$\{\text{Density of petrol} = 737.22\ \text{Kg/m}^3\}$

$$r = \frac{\text{R(gas constant)}}{M_w\text{(Molecular weight)}} = \frac{8.3143}{.114228}$$

$= 72.76$ $\left\{\begin{array}{l} R = 8.3143 JK^{-1}mol^{-1} \\ Mw = 0.114228\ \text{Kg/mole} \end{array}\right\}$

T = 288.855 K

$$P = \frac{0.11\times 72.76\times 288.855}{149.5\ x\ 10^{-6}} = 15.5\ MPa$$

Calculation of buckling load

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

$$= 1 + \frac{3.14\times D^2}{4}\times P\times fos$$

$$= \frac{3.14\times(57\times 10^{-3})^2}{4}\times 15.5\times 10^6\times 6$$

$$= 237193.245N$$

[D = 57mm, P = 15.5Mpa, FOS = 6]

'I' Section profile calculations

'I' section profile dimensions depends upon the compressive strength and young's modulus of the material given by relation:-

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

Where, W_b= Buckling load

A = area of I section = $11t^2$

L= Length of connecting rod = 2 x stroke length = 112 mm

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

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

σ_c = compressive yield strength

E = young's modulus

By substituting value of σ_c, W_b, a, K_{xx}, A and L we can calculate't' (thickness of profile)

figure 1.2 shows the relations of profile dimensions in relation with 't'. Now we need to calculate value of 't' for all composite materials selected.

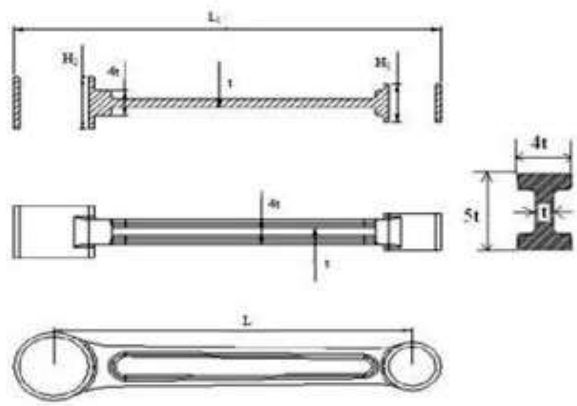

Figure 1.2: Relations of profile dimensions

Dimension calculation for Al + SiC Composite

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

Where W_b = 237 193.245N, σ_c = 440 MPa

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$$a = \frac{\sigma_c}{\pi^2 \times E} = \frac{440 \times 10^6}{(3.14)^2 \times 110 \times 10^9} = 0.0004056$$

$$237193.245 = \frac{(440 \times 11t^2)}{(1 + 0.0004056\,(\frac{112}{1..78t})^2}$$

Solving above equation for t, we get t = 7.11 $\approx$7.1 mm

Further, $B = 4t = 28.4\,mm$

$$H = 5t = 35.5\,mm$$

$$H_1 = 1.1H = 39.05 \approx 39\,mm$$

$$H_2 = 0.8H = 28.4\,mm$$

Moment of inertia about x axis :

Ixx= 34.91t4 = 88712.1784

Moment of inertia about y axis :

Iyy= 10.91t4 = 27724.144

Therefore Ixx/Iyy = 3.2

Dimension calculation for C70 steel:-

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

Where W_b = 237 193.245N, σ_c = 670 MPa

$$a = \frac{1}{7500}$$

$$237193.245 = \frac{(330 \times 11t^2)}{(1 + \frac{1}{7500}\,(\frac{112}{1..78t})^2}$$

Solving above equation for t, we get t = 5.718 $\approx$5.8 mm

Further, $B = 4t = 23.2\,mm$

$$H = 5t = 29\,mm$$

$$H_1 = 1.1H = 31.99 \approx 31.2\,mm$$

$$H_2 = 0.8H = 23.2\,mm$$

Moment of inertia about x axis :

Ixx= 34.91t4 =39505.8875

Moment of inertia about y axis :

Iyy= 10.91t4 =12346.2971

Therefore Ixx/Iyy = 3.2

Table shows the dimension calculated for various composite materials selected

Material → / ↓ Dimensions	t (mm)	B (mm)	H (mm)	H_1 (mm)	H_2 (mm)	Ixx / Iyy
C 70 steel	5.8	23.2	29	31.2	23.2	3.2
Al + SiC Composite	7.1	28.4	35.5	39	28.4	3.2

Table 1.2: Dimension calculated for various composite materials

Material

On the basis of low weight, wear resistance, thermal conductivity, cost and past usage ; silicon carbide (SiC) and Alumina (Al_2O_3) could be best suitable reinforcements in Aluminium matrix for Connecting rod. To select the better of the two reinforcements and optimum percentage of reinforcement

Properties	Al+SiC COMPOSITE	C70 STEEL
Density (Kg m^{-3})	2784	7850
Young's modulus (MPa)	99974	205000
Poisson ratio	0.292	0.3
Coefficient of thermal expansion (C^{-1})	16.002	16.6
Tensile Strength (MPa)	615.63	966
Compressive strength (MPa)	400.3	210
Thermal Conductivity ($Wm^{-}K^{-1}$)	130	65.2
Specific heat ($Jkg^{-1}K^{-1}$)	919	2081

Table 2.1: Properties of material

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Finite element analysis of connecting rod

FEA is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. In this project FEA is applied on solid CAD model of connecting rod to evaluate stress, strain and deflection of connecting rod with different composite material

Analysis system: Static structural is selected, evaluates the stress, strain and total deformation under the application of force.

Engineering data: Composite material properties listed in table are feed into engineering database; properties for steel components are already present in Ansys engineering database.

Generating 3d model: Each connecting rod concepts are in imported in ANSYS work bench from CATIA. Fig. shows the imported model for Al + SiC COMPOSITE concept.

Meshing: Fig3.1shows the meshed connecting rod with meshing detail

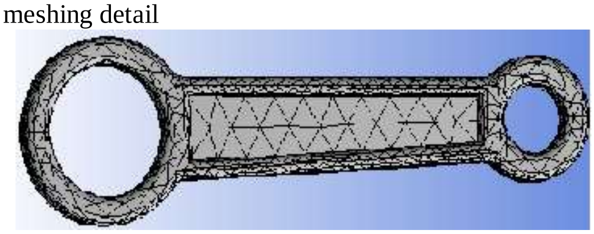
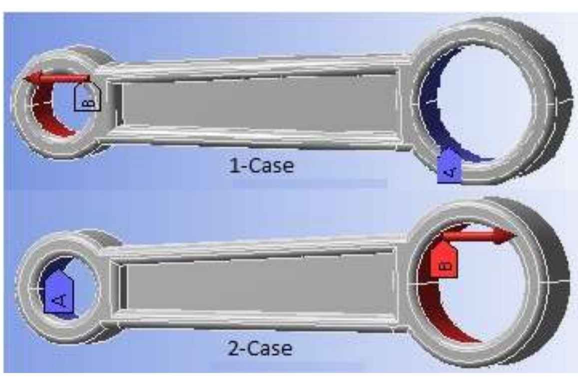


Figure 3.1: Mesh generation

Boundary Condition Connecting rod in a four stroke engine has two go through 4 stages; 2 for tension and 2 for compression and point of application of force also changes, fig. shows the four cases of boundary conditions applied the value of force for each concept is taken.



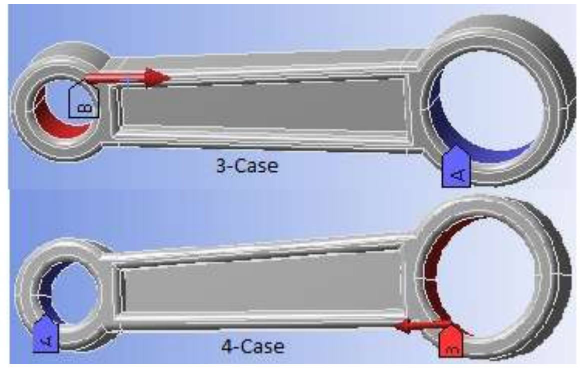
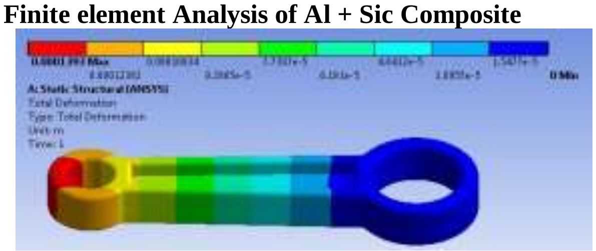


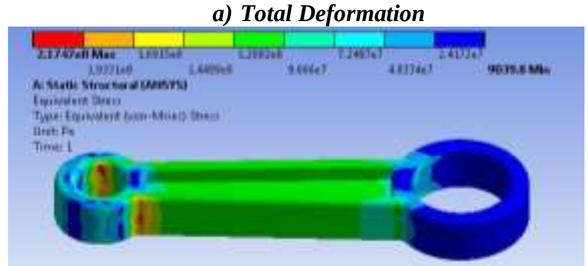
Figure 3.2: Boundary conditions on connecting rod

Solution: Connecting rod is evaluated for Stress, strain and total deformation for each case results of analysis for each concept are as follows:

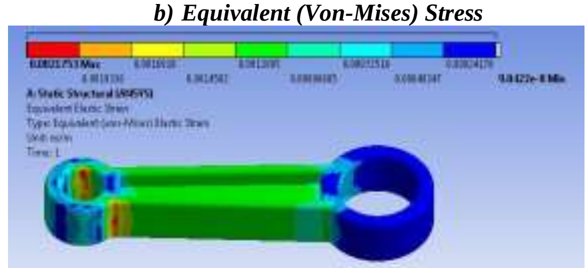
Finite element Analysis of Al + Sic Composite



a) Total Deformation



b) Equivalent (Von-Mises) Stress



C) Equivalent (Von-Mises) Strain

Figure 3.3: Result Plots: Al + Sic Composite

Case	Maximum stress (MPa)	Maximum Strain	Total deformation (m)
Case 1	217.47	0.0021753	0.0001393
Case 2	387.97	0.0038807	0.00026214
Case 3	217.47	0.0021753	0.0001393
Case 4	387.97	0.0038807	0.00026214

Table 3.1: Analysis Report Al + Sic Composite

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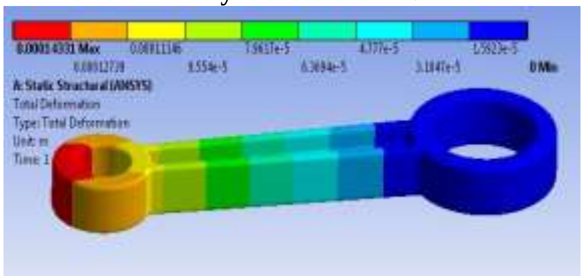
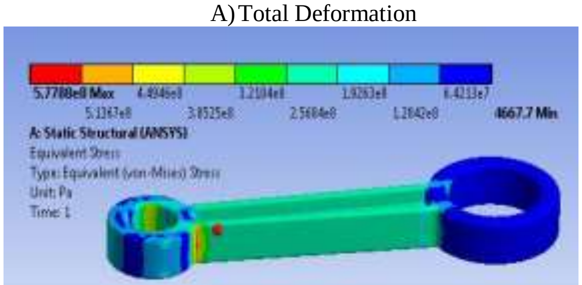
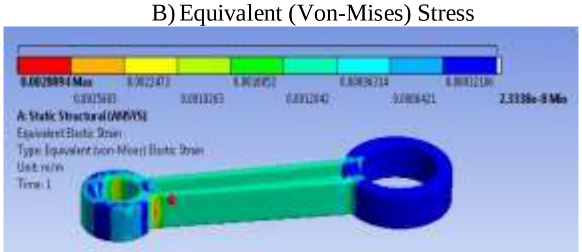
Finite Element Analysis of C70 Steel:



A) Total Deformation



B) Equivalent (Von-Mises) Stress



C) Equivalent (Von-Mises) Strain

Figure 3.4: Result Plots: C70 steel

	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 3.2: Analysis Report C70 Steel

Results

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 aluminum matrix for connecting rod to replace the 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 to find the percentage of reinforcement; connecting rod is analyzed for stress, strain and total deformation in ANSYS workbench. Analysis report of connecting rod on the basis of maximum stress, deformation, and strain and % percentage weight saving for Al+ Sic in various weight proportions is compiled

Material	Max. stress (MPA)	Max. Defor-mation (m)	Max. Strain	% weight Saving
C70 steel	577.88	0.0051391	0.0002682	Reference material
Al+SiC Composite	387.97	0.00026214	0.0038807	43

Table: Result for both materials

Cost estimation

Casting Cost Calculation

Minimum order quantity is 1000 connecting rod.

Estimation of cost of castings

The total cost of manufacturing a component consists of following elements:

1. Material cost.
2. Labour cost.
3. Direct other expenses.
4. Energy Cost.
5. Overhead expenses

Table shows the comparison of cost estimation of two materials:

Cost estimation for c70 steel connecting rod	**Cost estimation for Al+Sic composite connecting rod**
Material Cost Cmaterial (Cmat)= Cdirect + Cindirect C direct = Cum * Wt * Fm* Fp * Ff Cum (unit material cost) = 80 INR/ kg Wc (casting weight) = .230 kg Fm (melting loss factor) = 1.02 Fp (pouring loss factor) = 1.01 Ff (fettling loss factor) = 1.05 Psc (process scrap) = 40 % of weight of part = 0.092 kg Wt = Wc +Psc = 0.322 kg C direct = 80 * 0.322 * 1.02 * 1.01 * 1.05 = 27.86 INR	**Material Cost** Cmaterial (Cmat)= Cdirect + Cindirect Cdirect = Cum * Wt * Fm* Fp * Ff Cum (unit material cost) = 134 INR/ kg Wc (casting weight) = .132 kg Fm (melting loss factor) = 1.02 Fp (pouring loss factor) = 1.01 Ff (fettling loss factor) = 1.05 Psc (process scrap) = 40 % of weight of part = 0.0528 kg Wt = Wc +Psc = 0.1848 kg C direct = 134 * 0.1848 * 1.02 * 1.01 * 1.05

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Cindirect = Cms + Ccs Mould box size = 0.35 m * 0.20 m * 0.20 m Volume = 0.014 m^3 Density of Green sand = 800 kg/ m^3 Weight of Sand = density * volume of box = 800 * 0.014 = 11.2 kg/m^3 Mould sand cost = 1.2 INR / kg **C ms** = 1.2 * 11.2 = 13.44 INR Core volume = 2.07*10^-4 m^3 Weight of the core = Volume * Density = 2.07*10^-4 * 800 = 0.1656 kg Cost of core sand = 3 INR / kg = 3 * 0.1656 **C cs** = 0.49 INR **C indirect = C ms + C cs** = 13.44 + .49 = 13.93 INR **C material = C direct + Cindirect** **= 27.86 + 13.93** **C mat = 41.79 INR**	= 26.78 INR **Cindirect = Cms + Ccs** Mould box size = 0.35 m * 0.20 m * 0.20 m Volume = 0.014 m^3 Density of Green sand = 800 kg/ m^3 Weight of Sand = density * volume of box = 800 * 0.014 = 11.2 kg/m^3 Mould sand cost = 1.2 INR / kg **C ms** = 1.2 * 11.2 = 13.44 INR Core volume = 2.07*10^-4 m^3 Weight of the core = Volume * Density = 2.07*10^-4 * 800 = 0.1656 kg Cost of core sand = 3 INR / kg = 3 * 0.1656 **C cs** = 0.49 INR **C indirect = C ms + C cs** = 13.44 + .49 = 13.93 INR **C material = C direct + Cindirect** **= 53.27 + 13.93** **C mat = 40.71INR**
Labour cost **Requires no. Of labour** Core making = 1 Mould preparation = 2 Handling and pouring = 2 Machining and cleaning = 1 **Rate of Labour charge** Core making (1) = 14 INR /hr * 1 = 14 INR Mould preparation (2) = 15 INR /hr * 2 = 30 INR Handling and pouring (3) = 12 INR /hr *2 = 24 INR Machining and cleaning (4) = 10 INR /hr * 1 = 10 INR Average total time for making 1 connecting rod = 0.5 hr Total labour rate (1+2+3+4) = 78 INR Total cost for labour charge = 0.5 * 78 **Cl = 39 INR**	**Labour cost** **Requires no. Of labour** Core making = 1 Mould preparation = 2 Handling and pouring = 2 Machining and cleaning = 1 **Rate of Labour charge** Core making (1) = 14 INR /hr * 1 = 14 INR Mould preparation (2) = 15 INR /hr * 2 = 30 INR Handling and pouring (3) = 12 INR /hr *2 = 24 INR Machining and cleaning (4) = 10 INR /hr * 1 = 10 INR Average total time for making 1 connecting rod = 0.5 hr Total labour rate (1+2+3+4) = 78 INR Total cost for labour charge = 0.5 * 78 **Cl = 39 INR**
Direct other expenses Pattern Cost = 10000 INR Pattern Life = 3500 pieces Pattern cost for one connecting rod (Cp) = 10000/3500 = 2.85 INR Machining and cleaning cost (Cma) = 40 INR	**Direct other expenses** Pattern Cost = 10000 INR Pattern Life = 3500 pieces Pattern cost for one connecting rod (Cp) = 10000/3500 = 2.85 INR Machining and cleaning cost (Cma) = 40 INR
Energy cost **C energy cost (Ce)= C melting + C other energy** **C melting = Cue * Fn * Wc * Fy * Fr * Fm * Fp * Ff** Cue = 6.4 INR/unit Fn (Furnace efficiency) = 2 Wc = 0.23 Fy (over all yield factor) = 1.3 Fr (casting rejection factor) = 1.05	**Energy cost** **C energy cost (Ce)= Cmelting + Cother energy** **C melting = Cue * Fn * Wc * Fy * Fr * Fm * Fp * Ff** Cue = 6.4 INR/unit Fn (Furnace efficiency) =1.79 Wc = 0.132 Fy (over all yield factor) = 1.3

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Fm = 1.02 Fp = 1.01 Ff = 1.05 C melting = 6.4 * 2 * 0.23 * 1.3 * 1.05 * 1.02 * 1.01 * 1.05 = 4.34INR C energy cost = C melting + C other energy = 4.34 + 0 (C e) = 4.34 INR **Overhead expenses** Salary and wages of the staff for this one connecting rod **C o= 22.84 INR** **Total cost of casting connecting rod** **Total cost = Cmat + Cl + C p + Cma + Ce + Co** **= 41.79 + 39 + 2.85 + 40 + 4.34 + 22.84** **= 150.82 INR**	Fr (casting rejection factor) = 1.05 Fm = 1.05 Fp = 1.07 Ff = 1.07 C melting = 6.4 * 1.79 * 0.132 * 1.3 * 1.05 * 1.02 * 1.01* 1.05 = 2.23 INR C energy cost = C melting + C other energy = 2.23 + 0 (C e) = 2.23 INR **Overhead expenses** Salary and wages of the staff for this one connecting rod **C o= 22.84 INR** **Total cost of casting connecting rod** **Total cost = Cmat + Cl + Cp + Cma + Ce + Co** **= 40.71 + 39 + 2.85 + 40 + 2.23 + 22.84** **= 147.63 INR**

Conclusion

- **Substantial weight reduction**: Disc brake rotor made of Al+SiC Composite material has provided the substantial weight reduction and is designed to carry the same loads as steel connecting rod. The developed model weighs 132 g while the reference existing model weighs about 230 g gives the weight reduction of 43%.
- **Engine efficiency:** due to low weight of connecting rod less power will be wasted in overcoming inertia forces also overall weight of vehicle will reduce will result in increase of efficiency engine.
- **Weight saving in mounting:** Due to decrease in weight of connecting rod ,overall weight of the engine will reduce hence less heavier mounting is required will add to overall weight saving of vehicle leading to cost saving in fuel.
- **Cost :** Due to reduction in weight there is about 20 % reduction in cost of material being used for manufacturing of connecting rod.

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