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Comparision Of Manufacturing Methods And Analysis Of Connecting Rod For Reducing Cost

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Abstract

This Paper mainly focuses to reduce weight and manufacturing cost of the Air compressor connecting rod while maintaining or improving strength. The connecting rod is one important part of compressor. Existing steel material Connecting rod is manufactured by using Forging Process. Other S.G. iron material connecting rod is manufactured by sand casting Process. The objective of this project is to make 3d model of connecting rod using Pro Engineer software and apply static analysis, Buckling analysis and Fatigue analysis though Ansys 12.1 software. After perform analysis on steel material connecting rod and S.G. iron material connecting rod result of both connecting rod Analysis is compared. After that cost calculation is performed. That cost calculation shows that S.G. Iron material connecting rod has same strength as steel material connecting rod with reduction in unit cost of connecting rod.

Key words: Connecting Rod, S.G. iron ,Pro/E wildfire 4, Finite Element Analysis, Ansys 12.1, cost calculation.

1. Introduction

Connecting rod is an important component in an engine. Connecting rod used to connect between piston and crankshaft. In a reciprocating piston engine, the **connecting rod** connects the piston to the crank or crankshaft. Together with the crank, they form a simple mechanism that converts linear motion into rotating motion.

Manufacturing costs and strength of a connecting rod depend on various service conditions, geometry, types of materials and manufacturing processes. Therefore, material and manufacturing processes are attempted in this study as key points.

To aid decision-making when a choice Is to be made among various alternatives for geometric, material or process parameters, an early cost estimation tool is useful and perhaps even essential on manufacturing cost. It can also be used during design iterations to verify if the targeted ost can be.

2. Manufacturing Methods

A connecting rod in a compressor is subjected to inertial forces. It should be able to withstand these forces for a fatigue strength. The connecting rod undergoes cyclic tension, compression stress. Furthermore the connecting rod is subjected to a large compressive load so that it is imperative that buckling does not occur. So for this purpose there are mainly three methods of manufacturing.

2.1 Sand csting process

Sand casting, also known as sand molded casting, is a metal casting process characterized by using sand as the mold material. The term "sand casting" can also refer to an object produced via the sand casting process. Sand castings are produced in specialized factories called foundries. Over 70% of all metal castings are produced via a sand casting process.

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2.2 Forging

Forging is a manufacturing process involving the shaping of metal using localized compressive forces. Forging is often classified according to the temperature at which it is performed: "cold", "warm", or "hot" forging**.**

2.3 Powder Forging

Powder forging (P/F) is used to produce components essentially free of internal porosity. The associated properties are equivalent to those developed in conventional precision forged products made from billets. The P/F process is performed in three steps with the first two similar to normal Powder Metallurgy (PM) processing. A preform is pressed as a conventional PM compact.

3 Materials

A connecting rod is one of the most mechanically stressed components in air acompressor. The objective of the activity is to select the appropriate material for a connecting rod where the constraints are to make the product as light and cheap as possible and yet strong enough to carry the peak load without failure in high cycle fatigue.

3.1 Mechanical Properties of C40 steel

Density	= 7800 kg/m^3
Youngs Modulus	= 210000 mpa
Possions Ratio	= 0.3
Tensile Ultimate strength	= 680 mpa
Tensile Yield strength	= 330 mpa

3.2 Mechanical Properties Of EN-GJS-600-3 OR ISO 1083 600-3 OR IS 1865 SG 600/3 S.G. Iron material

Density	= 7100 kg/m^3
Youngs Modulus	= 174000 mpa
Poissions Ratio	= 0.275
Tensile Ultimate strength	= 600 mpa
Tensile yield strength	= 370 mpa

4. Modeling of connecting rod

3D model of connecting rod is created using Pro Engineer 4 software. Different view are shown below.

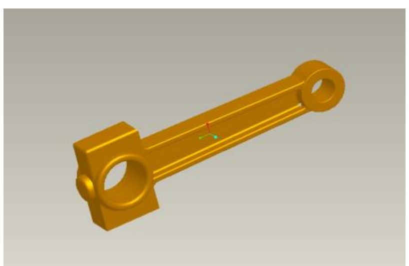

Figure 1 3D model

5 Analysis of Connecting rod

The first step in order to start the analysis with the Ansys program's help is to choose the type of analysis. The type of analysis will decide which type of results will be obtained. For the case of the connecting rod's analysis, a structural analysis will be performed. The model is made in Pro/E Wildfire 4.0 and saved within this program in *.STP format.

5.1 Theoritical static analysis of steel material connecting rod

Available data :-
Power P = 1 hp
RPM N = 750
Piston Dia. D = 65 mm
Conn. Rod length L = 182 mm
Weight Of Piston assembly = 0.6 kg
Weight Of Conn. Rod = 0.48313 kg
Length of stroke l = 64 mm
Crank radius r = 50 mm

Angular velocity $\omega = \frac{2\pi N}{60} = \frac{2\pi 750}{60}$ =78.5 rad/sec

Ratio $n_1 = \frac{L}{r} = 3.5$

Now from the applied thermodynamics $I_p = \frac{BP}{\eta} = \frac{1x748}{0.80} = 0.935$ Kw

Where, indicated power, $I_p = p_m \, l \, A \, n$

So, $p_m = \frac{I_p}{l\,A\,n} = 0.35\ \text{N/mm}^2$

$\therefore$ A = Cross section area of piston = $\left(\frac{\pi D^2}{4}\right)$

$\therefore \quad = \left(\frac{\pi * 65^2}{4}\right) = 3316\ \text{mm}^2$

$\therefore$ Max explosion pressure, $P_{max} = 9 * p_m$
$= 3.17\ \text{N/mm}^2$

✓ **Force on the piston due to gas pressure**

$$FL = \left(\frac{\pi D^2}{4}\right) P_{max}$$

$$= 10518\ \text{N}$$

✓ **Inertia force of Reciprocating Parts**

$$FI = m_r \omega^2 r \left[\cos\theta + \frac{\cos 2\theta}{n_1}\right]$$

Where, the angular velocity of the crank is, $\omega = \left(\frac{2\pi N}{60}\right)$
And the mass of reciprocating parts is given by,

$\therefore$ m_r = [mass of piston assembly + (1/3) mass of connecting rod] = 0.76 kg

The inertia force on the connecting rod will be maximum at the top dead centre position where ($\theta = 0$). So when $\theta = 0$ then $\cos\theta = 1$ and $\cos 2\theta = 1$ and substituting the above values and get;

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∴ $FI = m_r\,\omega^2 r\left[1+\frac{1}{n_1}\right]$

∴ FI = 301 N

∴ FN (net force) = FL - FI = 10217 N

∴ $\sigma 1 = \frac{FN}{(30-16)17}$ = 42.92 N/mm^2

5.1 Theoritical static analysis of S.G. Iron material connecting rod

Power P = 1 hp
RPM N = 750
Piston Dia. D = 65 mm
Conn. Rod length L = 182 mm
Weight Of Piston = 0.6 kg
Weight Of Conn. Rod = 0.43977 kg
Length of stroke l = 64 mm
Crank radius r = 50 mm
Angular velocity **ω** = 78.5 rad/sec
Ratio n1 = 3.5

Now from the applied thermodynamics $I_p = \frac{BP}{\eta} = \frac{1x748}{0.80}$ = 0.935 Kw

So, $p_m = \frac{I_p}{l\,A\,n}$ = 0.35 N/mm^2

∴ A = Cross section area of piston = $\left(\frac{\pi D^2}{4}\right)$

= $\left(\frac{\pi * 65^2}{4}\right)$ = 3316 mm^2

∴ Max explosion pressure, P_{max} = 9 * p_m
= 3.17 N/mm^2

- ✓ **Force on the piston due to gas pressure**

$$FL = \left(\frac{\pi D^2}{4}\right) P_{max}$$

= 10518 N

- ✓ **Inertia force of Reciprocating Parts**

$FI = m_r\omega^2 r\left[\cos\theta + \frac{\cos 2\theta}{n_1}\right]$

∴ m_r = [mass of piston assembly + (1/3) mass of connecting rod] = 0.74 kg

$FI = m_r\,\omega^2 r\left[1+\frac{1}{n_1}\right]$

∴ FI = 295 N

∴ FN (net force) = 10223 N

∴ $\sigma 1 = \frac{FN}{(30-16)17}$ = 42.95 N/mm^2

∴

5.2 Buckling load of connecting rod (steel)

The connecting rod is a slender engine component that has considerable length in proprtaion to its width and breadth. It is subjected to axial compressive force equal to maximum gas load on the piston. The compressive stress is of significant magnitude. Therefire, the connecting rod is designed as a column or strut.

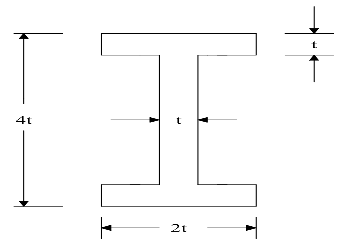

Figure 2 Cross section of connecting rod

Moment of inretia about X-axis Ixx = $\frac{bh^3 - b1h1\text{^}3}{12}$

= 10566 mm^4

Radious of gyration about X-axis Kxx

Kxx^2 = $\frac{Ixx}{A}$

Kxx = 8.07 mm

After deciding the proportions for I-section of the connecting rod, its dimensions are determined by considering the buckling of the rod about X-axis (assuming both ends hinged) and applying the Rankin's formula. We know that buckling load,

$P_{cr} = \frac{\sigma_c}{1+a\left(\frac{L}{K_{xx}}\right)}$

a = 1/7500 for steel σ_c = 300 N/mm^2

P_{cr} = 45545 N

5.2 Buckling load of connecting rod (s.g. iron material)

MoI about X-axis Ixx = $\frac{bh^3 - b1h1\text{^}3}{12}$ = 10556 mm^4

Radious of gyration about X-axis Kxx

Kxx = 8.07 mm

$$P_{cr} = \frac{\sigma_c}{1 + a\left(\frac{L}{K_{xx}}\right)}$$

a = 1/1600 for s.g. iron σ_c = 400 N/mm^2

P_{cr} = 49300 N

5.3 FEA Static Analysis (Steel)

Any continuous object has infinite degrees of freedom. Finite Element Method reduces this from infinite to finite by means of Meshing (i.e. creating nodes and elements). The goal of meshing in ANSYS Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. These tools have the benefit of being highly automated along with having a moderate to high degree of user control. Here Meshing element chooses is 10 nodes Tetrahedron named Solid187.

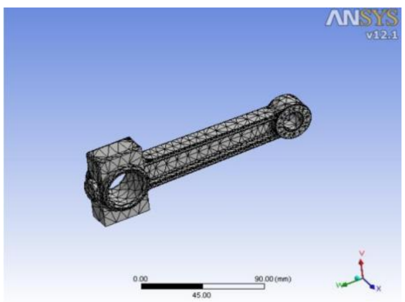

Figure 3 Apply meshing

- ✓ **Loading and Boundary Conditions**

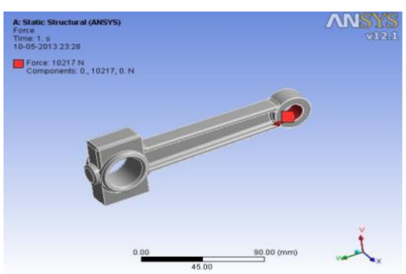

Figure 4 Force apply at piston end

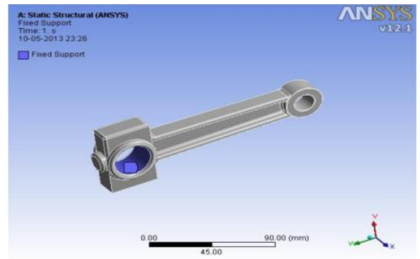

Figure 5 Fixed at crank end

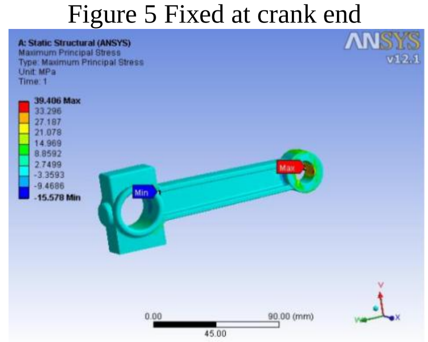

Figure 6 Max. Principal stress

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5.3 FEA Static Analysis (s.g. iron)

- ✓ **Loading and Boundary Conditions**

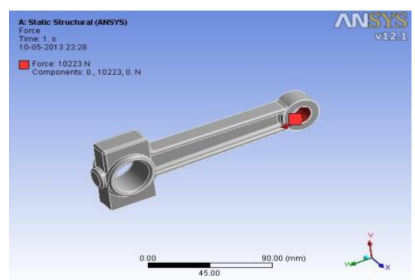

Figure 7 Force apply at piston end

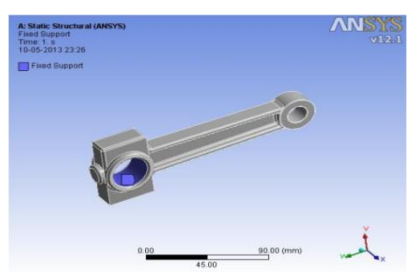

Figure 8 Fixed at crank end

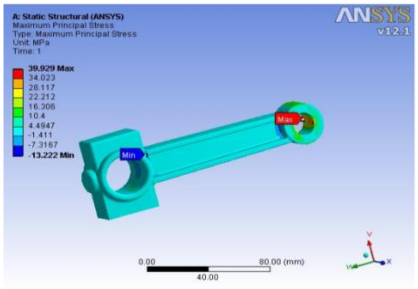

Figure 9 Max. principal stress

5.3 FEA Static Analysis result

- **Steel connecting rod**

Type OF Loading	Applied Net Force at	Fixed at	Max. Principal Stress (MPA)	Max. Principal Stress (MPA)
			Theoritical	FEA
compressive	Piston end	Cranck end	$\sigma 1 = 42.92$	$\sigma 1 = 39.40$

- **S.G. Iron Connecting rod**

Type OF Loading	Applied Net Force at	Fixed at	Max. Principal Stress (MPA)	Max. Principal Stress (MPA)
			Theoritical	FEA
compressive	Piston end	Cranck end	$\sigma 1 = 42.95$	$\sigma 1 = 39.92$

5.4 Buckling analysis (steel)

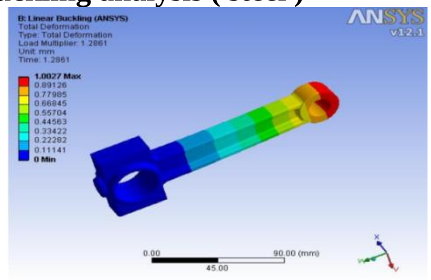

Figure 10 Buckling analysis

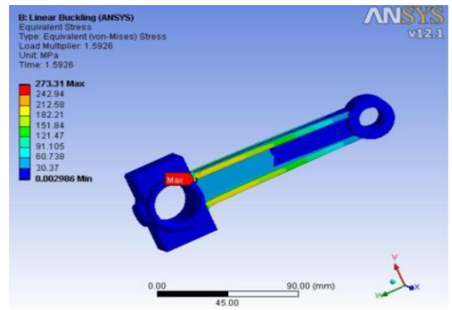

Figure 11 Equivalent stress

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5.5 Buckling analysis (s.g. iron)

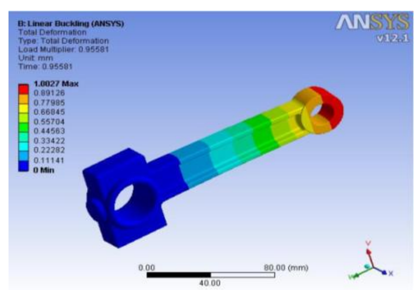

Figure 12 Buckling analysis

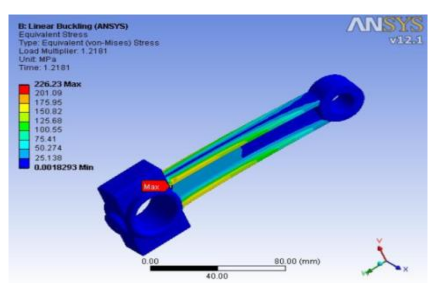

Figure 13 Equivalent stress

5.6 Fatigue Analysis of steel Connecting Rod

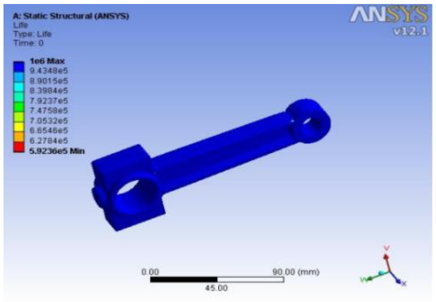

Figure 14 Fatigue Life analysis of steel

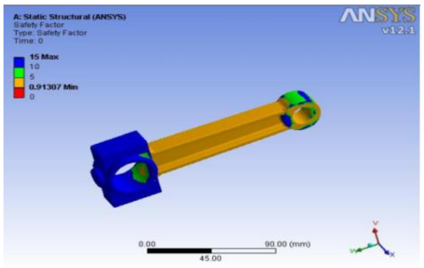

Figure 15 Fatigue safety factor analysis of steel

5.6 Fatigue Analysis of s.g. iron Connecting Rod

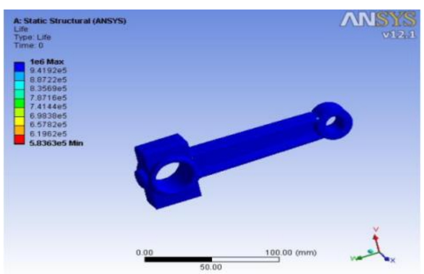

Figure 16 Fatigue Life analysis of S.G. iron

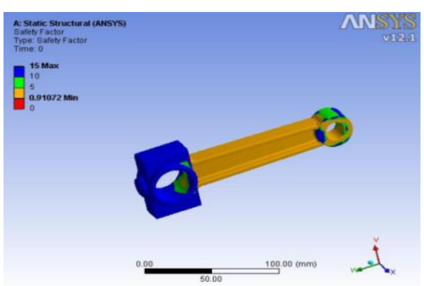

Figure 17 Fatigue safety factor analysis of S.G. iron

6 Cost calculation

6.1 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**.**

6.1.1 Material Cost

C material (C mat)= C direct + C indirect
C direct = C um * Wt * Fm* Fp * Ff
Cum (unit material cost) = 80 INR/ kg
Wc (casting weight) = 0.43977 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 = 0.1759 kg
Wt = Wc +Psc = 0.6156 kg
C direct = 80 * 0.6156 * 1.02 * 1.01 * 1.05
= 53.27 INR

C indirect = C ms + C cs

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 = 67.2 INR

6.1.2 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

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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 conn. rod = 0.5 hr
Total labour rate (1+2+3+4) = 78 INR
Total cost for labour charge = 0.5 * 78

Cl = 39 INR

6.1.3 Direct other expences

Pattern Cost = 10000 INR
Pattern Life = 3500 pieces
Pattern cost for one connecting rod (C p)
= 10000/3500 = 2.85 INR
Machining and cleaning cost (C ma) = 40 INR

6.1.4 Energy cost

C energy cost (C e)= C melting + C other energy
C melting = C ue * Fn * Wc * Fy * Fr * Fm * Fp * Ff
Cue = 6 INR/unit
Fn (Furnace efficiency) = 2
Wc = 0.49
Fy (over all yield factor) = 1.3
Fr (casting rejection factor) = 1.05
Fm = 1.05
Fp = 1.07
Ff = 1.07
C melting = 6 * 2 * 0.49 * 1.3 * 1.05 * 1.05 * 1.07 * 1.07 = 9.64 INR
C energy cost = C melting + C other energy
= 9.64 + 0
(C e) = 9.64 INR

6.1.5 Overhead expences

Salery and wages of the staff for this one connecting rod **C o= 22.84 INR**

Total cost of casting connecting rod

Total cost = C mat + Cl + C p + C ma + C e + C o
= 67.2 + 39 + 2.85 + 40 + 9.64 + 22.84
= 181.53 INR

6.2 Forging cost calculation

Minimum order quantity is 1000 connecting rod.

Estimation of Cost of Forgings

The cost of a forged component consists of following elements :

1. Cost of direct materials.
2. Cost of direct labour.
3. Direct expenses such as cost of dies and cost of press.
4. Overheads.

6.2.1 Cost of Direct Material

Net weight w = 0.48313

- Shear (Ls) = 5 % of W = 0.0241563 kg
- Tonghold loss (Lt) = 0.025 * 3.14/4 * 0.030^2 = 0.13776 kg
- Scale loss (Lsc) = 6 % of W = 0.02898 kg
- Flash loss (Lf) = 2.298 * 10^-5 * 7800 = 0.1792 kg
- Sprue loss (Lsp) = 7 % of W = 0.03381 kg

Total material loss = Ls + Lt + Lsc + Lf + lsp

= 0.0241565 + 0.13776 + 0.02898 + 0.1792

+ 0.03381 = 0.4039 kg

Gross weight = Net weight + Material loss

= 0.48313 + 0.4039

= 0.8870 kg

Ratio of gross weigth to net weigth (C gr)

= 0.8870/0.4039 = 1.8359

C ut = Unit cost of material = 80 INR /kg

C material (C m) = W * C ut * C gr

= 0.48313 * 80 * 1.8359

C m = 70.96 INR

6.2.2 Direct labour cost

Direct labour cost (C ld) = t × l

Wh. t = time for forging per piece (in hours) = 0.5 hr

l = labour rate per hour.

N = no. Labours requires = 5

Rate of 1 labour for Heating billet = 21 INR /hr

Rate of 1 labour for Press operation = 32 INR /hr

Rate of 1 labour for Handling part = 16 INR /hr * 2 = 32 INR /hr

Rate of 1 labour for machining and cleaning = 26 INR /hr

Total labour rate = 21 + 32 + 32 + 26 = 111 INR /hr

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C ld = t * l = 0.5 * 111= **55.5 INR**

6.2.3 Direct expences

Let cost of Die = Rs. X = 30000

No. of components that can be produced using this die (i.e., die life) = Y components = 3000

Cost of die/component = Rs. X/Y = 30000/3000

= 10 INR

Let cost of press = Rs. A = 400,000

Life of press = n years 5

= n × 12 × 8 × 6 × 4 = 2304 n hours

(Assuming 8 hours of working per day, 6 days a week and 4 weeks a month in 12 months of year)

Hourly cost of press = $\frac{A}{2304\ n}$

No. of components produced per hour = N = 10

Cost of using press per component = Rs. $\frac{A}{2304\ n\ N}$

(C de) = 3.47 INR

6.2.4 Overheads cost

The overheads are generally expressed as percentage of direct labour cost. Overhead cost (Co) = 150 % of labour cost = 83.25 INR

<u>**Total Cost of Forging connecting rod**</u>

Total cost = C m + C ld + C de + C o

= 70.96 + 55.5 + 3.47 + 83.25

= 213.18 INR

7. Conclusion

The Air compressor connecting rod is generally made by steel material from forging process. This connecting rod can be replaced by S.G. iron material connecting rod which is made from sand casting process. Here in this research work, from various analysis i found that S.G. iron material connecting rod has same strength as steel material connecting rod. When no. of quantity require of connecting rod is less, then unit cost of connecting rod of S.G. iron material is less compare to steel material connecting rod. Cost reduction in per unit is near about 15 % cost of steel material connecting rod.

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