Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-4, Issue-2, pp-98-112
www.jiengtech.com
Research Paper Open Access

Manufacture of connecting rod of a single-cylinder, four-stroke, 8 horse power (8HP) diesel engine by reverse engineering technique

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ABSTRACT: *In order to boost local production of major internal combustion (IC) engine components in Nigeria, this project work was aimed at producing connecting rod of a single-cylinder, four-stroke, 8hp diesel engine by reverse engineering method using lost wax casting and machining processes. The connecting rod is required to transmit the compressive and tensile forces from the piston, and rotate at both ends. The manufactured connecting rod was interchanged with the original rod in the generator. Performance tests were carried out on the manufactured connecting rod. The engine with the original connecting rod was used as the control engine to measure the performance of the engine with the manufactured connecting rod. The engine temperatures were taken for the control engine and the engine with the manufactured connecting rod under two experimental conditions of no-load and 3hp load. The temperatures were taken for a period of 1 hr. at an interval of 5mins. A graph of engine temperature against time was plotted for both engines. For the control engine, the results showed that there was a steady rise in temperature under the no-load condition and under a load of 3 hp. for the first 15mins of running the engine. After 20mins of running the control engine, the temperature dipped with 2^{o}C under the no-load condition and 1^{o}C under a load of 3hp. The engine temperature began to rise again after 25mins under both experimental conditions. However, both experimental conditions recorded the highest temperature difference at 45mins, with the engine under no-load condition recording an increase of 47^{o}C and the engine under a load of 3hp recording a temperature rise of 49^{o}C within the same space of time. After 1 hour of running the control engine, the engine under a load of 3hp recorded the highest temperature of 200oC while the engine under no-load condition recorded a temperature of 190^{o}C. For the engine with manufactured connecting rod, the results showed similar trend in temperature rise. However, the engine under no-load condition recoded its lowest temperature rise of 2^{o}C at 20mins. Again, under the no-load condition, there was 0^{o}C temperature rise between 25mins and 30mins as the temperature was stable at 69^{o}C. The engine under load of 3hp recorded the highest temperature of 201^{o}C after I hour while the engine under no-load condition recorded a temperature of 19^{o}C. The results also showed that the engine speed reduced with 3.06% under 3hp load condition as against the value of 250 rpm when the control engine was under no-load condition. The same decrease in value for the engine with the manufactured connecting rod was recorded. The speed of the engine reduced with 0.88% under 3hp load condition from the 793 rpm recorded under no-load condition. However, the reduction in speed was more for control engine than for engine with the manufactured connecting rod.*

***KEYWORDS**: Connecting rod; Internal Combustion; Engine; Temperature; Cast Iron.*

Date of Submission: 9-12-2023 Date of acceptance: 13-12-2023

I. INTRODUCTION

The manufacturing sector that is supposed to be the engine room of any economy is not properly harnessed in Nigeria, even when the country is greatly endowed with both human and natural resources. Although the country's economy has been rebased to make it the largest economy in Africa, however, the country still largely rely on importation of goods and services from other nations. This can easily be attributed to the dearth in technology and the lack of political will to revolutionize the manufacturing sector of the economy. The problem of dearth in technology is because the advanced nations do not transfer technological know-how to developing nations like ours. This challenge has been taken up by some local researchers on the need to locally develop the manufacturing sector by first developing the technological know-how through reverse engineering technique (or copy creativity). Copy creativity of this kind requires a good knowledge of manufacturing processes, ingenuity, patience and a strong will to succeed [5, 8]. The aim of this work is to produce by reverse engineering method, the connecting rod of a single-cylinder, four-stroke, 8-hp diesel engine using lost wax casting and machining processes. Design of connecting rod depends upon the speed of the engine [22]. High speed engines uses connecting rod of I-Section and low speed engines uses connecting rod circular cross section. This design case study is of the circular cross section. Steel and aluminum are the materials most widely used to produce the connecting rod [22]. Certain materials, such as titanium alloy, magnesium alloy and beryllium, were also used in the fabrication of the connecting rod [22]. Cast iron can be used for cheaper, lower performance applications such as motor scooters. The reciprocating internal combustion engine must be by far the most common form of engine or prime mover. As with most engines, the usual aim is to achieve a high work output with a high efficiency [13].The term "internal combustion engine" should also include open circuit gas turbine plant where fuel is burnt in a combustion chamber. This is the key principle that applies to both engines of different types and those utilizing different operating principles. Crouse and Anglin defined an engine as a machine that converts heat energy to mechanical energy [3]. During which heat from burning fuel produces power which moves the vehicle [3]. Automotive engines are internal combustion (IC) engines because the fuel that runs them is burnt internally, or inside the engines. Engines are either reciprocating or have rotors that spin or rotate. Most automotive engines are reciprocating. The only such engine with rotor now used in automobile is the Wankel engine [3, 22]. All diesel engines today use solid injection of the fuel; the fuel is injected by a spring-loaded injector, the fuel pump being operated by a cam driven from the engine crankshaft [4]. The diesel engine is a kind of piston engines which is also known as the compression-ignition engine and it is different from the spark-ignition engines in that the method of ignition is by heat of compression. In this type of engines, the fuel mixes with air after it enters the engine cylinders. The piston compresses the air to as little as one-twenty second (1/22) of its original volume. Compressing the air this much raises its temperature to 1000oF (538oC) or higher. A light-oil called diesel fuel is then sprayed or injected into the hot air. The hot air or heat of compression ignites the fuel and it burns in the combustion chambers in the upper part of the cylinders. The high pressure produced by the burning fuel pushes the piston down. This rotates the crankshaft and the rotary motion is carried through shafts and gears to the drive wheels. The two main types of internal combustion engine are the spark ignition (SI) engines, where the fuel is ignited by a spark; and compression ignition (CI) engines, where the rise in temperature and pressure during compression is sufficient to cause spontaneous ignition of the fuel. The spark ignition engine is also referred to as the petrol, gasoline or gas engine from its typical fuels, and the Otto engine, after the inventor. The compression ignition engine is also referred to as the Diesel or oil engine; the fuel is also named after the inventor. The operating cycle of an I.C. engine may be completed either by the two strokes or four strokes of the piston. Thus, an engine which requires two strokes of the piston or one complete revolution of the crankshaft to complete cycle is known as two stroke engine. An engine which requires four strokes of the piston or two complete revolutions of the crankshaft to complete the cycle is known as four stroke engine. The two stroke petrol engines are generally employed in very light vehicles such as scooter motorcycles and three wheelers. The two stroke diesel engines are generally employed in marine propulsion. The four stroke petrol engines are generally employed in light vehicles such as cars, jeep and also in airplanes. The four stroke diesel engines are generally employed in heavy duty vehicles such as buses, trucks, tractors, diesel locomotives and in earth moving machinery.

Fig. 1: Connecting Rod with piston [11] **Fig. 2: Pictorial View of Connecting Rod [5, 6]**

This work is concerned with the production of internal combustion (IC) engine parts which has a very wide range of application which include, powering of motorcycles, automobiles, locomotives, ocean vessels, airplanes, turbines, alternators for electric generators, industrial machines, to drive general-purpose machines used for powering cassava mills, pepper grinders, vulcanizing compressor and so on.

1. Design Process

This research study is centered on the development of local manufacturing sector by the use of locally sourced materials, labor, skills and tools to carry out a reverse engineering production of an internal combustion engine part (connecting rod) for local consumption. The IC engine part to be produced i.e. connecting rod was sourced from an 8hp diesel engine generator. The dimensions of the connecting rod were taken and recorded and a hand sketch of the connecting rod was made (Fig. 3).An engineering drawing was produced from the connecting rod sketch that was made. A pattern made of wax was produced from a pattern-mold box made of ceramics. The mold that was used to cast the connecting rod was made of green sand.

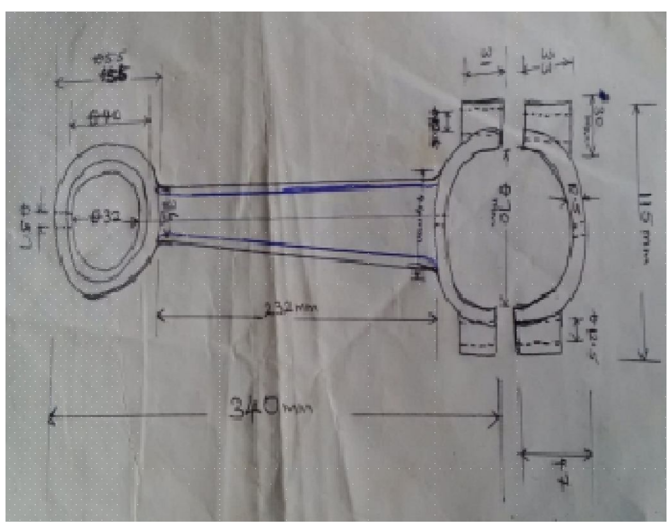

Fig. 3 Hand Sketch Drawing of the Sample-Connecting Rod

Cast iron was used for the production of the connecting rod, bronze was used to produce the journal bearing that was force-fitted into the connecting rod end that the piston rod goes through and mild steel was used to produce the connecting rod bolt. The connecting rod that was produced was interchanged in the IC engine to replace the original connecting rod and the engine was tested for speed and temperature rise.

II. MATERIALS AND METHODS

The materials for this study were selected in line with the materials that were used to produce the original connecting rod that is being reverse engineered. The connecting rod that was sourced from the IC engine generator which is the sample was produced with cast iron. This informed the use of cast iron as the connecting rod material for this study. The connecting rod bushing for the sample-connecting rod was made from mild steel with outer surface coated with bronze. However, for this study, bronze was used to make the entire connecting rod bushing. Wax was used to make the connecting rod pattern while green sand was used to make the mold for casting the connecting rod. Steel and aluminum are the materials most widely used to produce the connecting rod.

A. Development of the Connecting Rod Pattern

The pattern was made of wax. The wax pattern was formed to shape by ceramic mold constructed from the dimensions obtained from the engineering drawing of the sample-connecting rod as shown in Fig. 4.

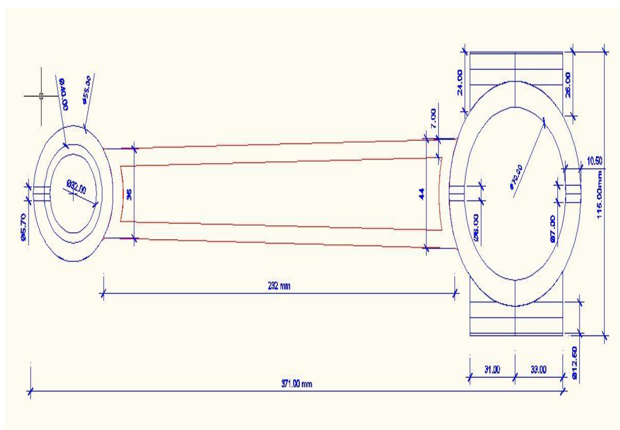

Fig. 4: Dimension of the Sample-Connecting Rod

Two mold boxes were fabricated for the two patterns that were made of wax. The patterns were the connecting rod pattern mold box and the cap pattern mold box as shown in Fig.5 and Fig.6.

Fig. 5: Pattern Mould Box for the Connecting Rod

Fig. 6: Pattern Mould Box for the Connecting Rod Cap

B. Pattern Size

The material for the pattern was wax. The following pattern allowances were considered during the development of the pattern size:

(i) Linear shrinkage allowance
(ii) Machining allowance, and
(iii) Draft allowance.

Galetto and Vezzetti (2006) and Ibhadode (2001) provide the recommend values for a cast iron with the dimensions of the connecting rod as [5, 9]:

(i) Linear shrinkage allowance 0.01042 mm
(ii) Machining allowance, and 3 mm
(iii) Draft allowance 1^o

The size and dimension of the pattern was computed from the dimension of the sample-connecting rod as shown in Fig. 3 and Fig. 4. the computations were done in two categories that is, the connecting rod and connecting rod cap.

(a) Connecting Rod

1. Length of Pattern : 340 + 0.01042 + 3 + 1 = 344.01mm
2. Inner diameter of bearing shell: 70 + 0.01042 + 3 + 1 = 74.01mm
3. Outer diameter of bearing shell: 91 + 0.01042 + 3 + 1 = 95.01mm
4. Inner diameter of the short-arm:40 + 0.01042 + 3 + 1 = 44.01mm
5. Outer diameter of the short-arm: 55 + 0.01042 + 3 + 1 = 59.01mm
6. Length of connecting rod shaft: 232 + 0.01042 + 3 + 1 = 236.01mm
7. Breadth of the long-arm of the connecting rod shaft: 44 + 0.01042 + 3 + 1 = 48.01mm
8. Breadth of the short-arm of the connecting rod shaft: 36 + 0.01042 + 3 + 1 = 40.01mm
9. Width of the long-arm of the connecting rod shaft: 35 + 0.01042 + 3 + 1 = 39.01mm
10. Width of the long-arm of the connecting rod shaft: 25 + 0.01042 + 3 + 1 = 29.01mm
11. Width of the of the connecting rod bearing shell: 54 + 0.01042 + 3 + 1 = 58.01mm
12. Width of the short-arm of the connecting rod : 48 + 0.01042 + 3 + 1 = 52.01mm
13. Length of the thread that attaches the cap to the connecting rod: 64 + 0.01042 + 3 + 1 = 68.01mm.
14. Diameter of the thread that attaches the cap to the connecting rod: 30 + 0.01042 + 3 + 1 = 34.01mm.

(b) Connecting Rod Cap

1. Length of connecting rod cap: 47 + 0.01042 + 3 + 1 = 51.01mm

2. Breadth of connecting rod cap: 115 + 0.01042 + 3 + 1 = 119.01mm
3. Width of connecting rod cap: 54 + 0.01042 + 3 + 1 = 58.01mm

Other parameters that would be necessary for the design of mold parameters are stated as follow:

1. Mass of the sample-connecting rod 2.981 kg

1. Density of cast iron 7.15×10^3 kg/m^3
2. Specific heat capacity of cast iron 500 J/kg ^{o}C
3. Volume of sample-connecting rod = $\frac{Mass\ of\ sample-connecting\ rod}{Density\ of\ sample-connecting\ rod}$ (1)

∴ Volume of sample-connecting rod = $\frac{2.981}{7.15 X 10^3}$ = 4.17×10^{-4}m^3.

C. Design of the Mold Parameters

Mold parameters such as diameter of riser, diameter of sprue, mold filling time and molten metal pouring velocity were designed in this study.

D. Design of Riser Size

Ravi stated that, for an efficient shape of a riser for a certain size to be achieved, there must be minimum heat loss [12]. This will thus keep the metal in molten state hot as long as possible. A riser should be designed with the minimum possible volume while maintaining a cooling rate slower than that of the casting. The size of a riser should not be too large or too small. A riser too large would be a waste of casting material, and being large, it would have a slow cooling rate and might keep the area of the casting connected to it a hot spot which may be the cause of porosities. A riser too small would not be able to feed enough molten metal into the casting and shrinkage would occur. The best shape for general run of castings to achieve the above objective is a cylindrical shape. The ratio of riser height to diameter usually varies from 1:1 to 3:2 [12].
According to Ravi (2003), the feeder compensates solidification shrinkage of the hot spot region. This requirement is satisfied by the criterion [12]:

$\eta_f v_f = \alpha (V_c + V_f)$ (2)

where, V_f = volume of feeder (riser)
V_c = volume of casting
η_f = efficiency of feeder (riser)
α = volumetric shrinkage of cast metal

For cast iron, an open cylindrical riser is suitable and the following empirical data hold:
Riser height, $H = 1.5D$

Volumetric solidification shrinkage, α = 0.018 (for cast iron)
Efficiency, η_f = 0.14
Volume of casting, $V_c = 4.17 X 10^{-4} m^3$

Therefore, substituting these values into equation (3.2), we have:
0.14 V_f = 0.018 (4.17×10^{-4} + V_f)
$\therefore V_f = \frac{7.506 X 10^{-6}}{0.14}$
$V_f = 5.36 X 10^{-5} m^3$

To obtain the diameter of the cylindrical riser, the following relationship is applied, $V_f = \frac{\pi}{4} D^2 h$ (3)

Thus, $5.36 \ X \ 10^{-5} = \frac{\pi}{4} D^2 (1.5D)$

$\therefore \quad D = \sqrt[3]{\frac{4 \ X \ 5.36 \ X 10^{-5}}{\pi X \ 1.5}}$

That is, $D = 0.0357 \ m$.

Recall that the riser height, $H = 1.5D$. $\therefore H = 1.5 \ X \ 0.0357 = 0.054 \ m$

E. Time required for the Molten Metal to fill the Mold.

The mold filling time τ_f is expressed as a function of casting weight Win kg, section thickness tin mm and fluidity length L_f in mm. The correct mold filling time lies somewhere between the need to avoid premature freezing in thin sections before complete filling and the onset of surface turbulence which is a function of cast metal, weight, minimum section thickness and pouring temperature. Several empirical equations for determining the correct mold filling time for major metals have been developed by casting researchers, based on experimental investigations. A generalized equation for filling time can be written as [12]:

$$\tau_f = K_0 \ (K_f \ L_f \ / \ 1000 \ ) \ (\ K_s + K_t \ t \ / \ 20 \ ) \ (\ K_w \ W \ )^P \qquad (4)$$

Where, τ_f = mould filling time
K_o = overall coefficient, K_f = coefficients for fluidity, K_s = coefficients for size, K_t = coefficients for thickness, L_f = fluidity length, K_w = coefficients for weight, W = weight of casting, t = section thickness
The following values would be used for the determination of the mould filling time. Because the material is cast iron, the following values would be used as recommended by Ravi [12]: K_o = 1.0, K_f = 1.0, K_s = 1.1 (for castings of size 100-1000 mm), K_t = 1.4 (for wall thickness up to 10 mm), K_w = 1,P = 0.4, t = 39.01 mm, W = mass x acceleration due to gravity = 2.981 x 9.8 = 29.21 kgm/s^2, and L_f = 500mm for the cast iron.
Substituting these values into equation (3.4), thus:

$$\tau_f = 1 \left(\frac{1 \ X \ 500}{1000} \right) \left[1.1 + \left(\frac{1.4 \ X \ 39.01}{20} \right) \right] (1 \ X \ 29.21)^{0.4}$$

τ_f = 7.39 seconds.

F. Velocity of Pouring

The liquid metal pouring velocity, v is given by:

$$v = \sqrt{2gH_s} \qquad (5)$$

where, g = acceleration due to gravity (9.8 m/s^2)
H_s = mold metal static height (that is, cope height + ½ ingate diameter)

Thus, Hs = 40 + ($\frac{1}{2}$ x 32) = 56 mm or 5.6 x 10^{-2} m.

Therefore, $v = \sqrt{2 \ X \ 9.8 \ X \ 5.6 \ X \ 10^{-2}}$

v = 1.05 m/s.

G. Diameter of the Sprue

Sprue size is often selected so that it controls the pouring rate. The calculation usually reduces to determining the area of the narrowest cross section f_n of the sprue, after which the cross-sectional areas of all other elements of the system are determined.
The formula for finding the sprue choke area f_n, is given as [10]:

$$f_n = \frac{M}{\rho} \tau \mu \sqrt{2gH_s} = \frac{M}{\rho} \tau \mu v \qquad (6)$$

where M = mass of all casting in the mould including risers, runners ingates, and sprue well = 2.981 kg
ρ = molten metal density, τ = mold filling time
μ = discharge coefficient of the metal, usually $0 < \mu < 1$, g = acceleration due to gravity
H_s = static vertical distance from the axis of the ingates to the top of the cope flask.

Taking μ = 0.54; g = 9.8 m/s^2; ρ = 7.15 x 10^3 kg/m^3.
Therefore, substituting, we have:

$$f_n = \frac{2.981}{7.15 X 10^3} X 7.39 X 0.54 X 1.05$$

Therefore, f_n = 1.75 x 10^{-3} m^2.

This value is the sprue exit area. Therefore,

$$\frac{\pi}{4} d^2 = 1.75 X 10^{-3}$$

$$d^2 = \frac{4 X 1.75 X 10^{-3}}{\pi}$$

d= 47.20mm.

4. Manufacturing Process

The connecting rod was produced by reverse engineering the original connecting rod, which was acquired from 8hp diesel generator engine. A wax pattern was produced from the pattern mold that was made from ceramic material. The wax pattern was embedded into a green sand mold and heated to allow the wax to flow out of the mould thereby creating cavity the shape of connecting rod. The same procedure was used to make the green sand mould of the connecting rod cap. Lost wax (investment casting) process was used to produce the connecting rod and its cap as shown in Fig. 7. The produced pieces were machined to the dimensions of the original connecting rod and its cap.

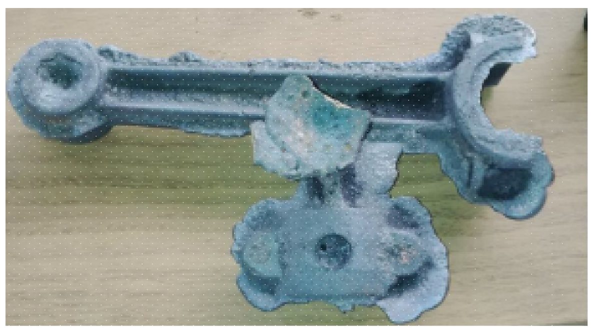

Fig. 7: Connecting Rod and Cap Produced by Lost Wax Casting before Machining

a. The Pattern

As earlier stated in chapter three, the pattern for this research work was made of wax. Two patterns were produced in whole, one wax pattern for the connecting rod and another one for the connecting rod cap as shown in Fig. 5 and Fig. 6 respectively. The pictorial view of the wax pattern that was produced from the pattern mould above is shown in Fig. 8. and its AutoCAD drawing in Fig. 9.

Fig 8: Pictorial View of Wax Pattern Produced

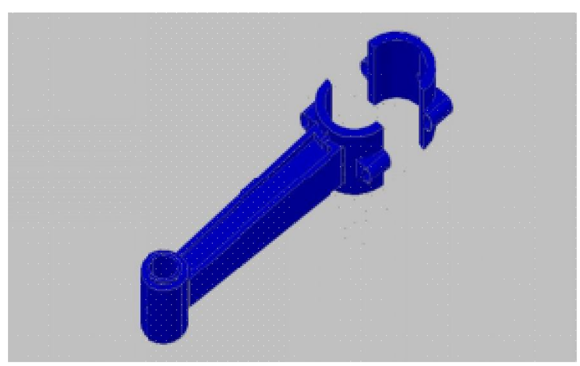

Fig 9: AutoCAD Drawing of the Connecting Rod

b. Connecting Rod Bushing

The connecting rod bushing which serves as a journal bearing inside the short-arm of the connecting rod was produced by machining a cylindrical block into the required shape of a hollow ring. Bronze was selected as the material for this item because the original connecting rod had its bushing made of mild steel coated with bronze.

c. Experimental Tests

In modern engineering design, testing of the engine is necessary to verify the performance of the engine as per the specification of the manufacturer. In the course of the study, performance test were carried out which include the pattern performance test, the engine temperature test and the engine speed test.

d. Tests for Engine Temperature

This test was carried out to measure the temperature rise of the diesel engine with respect to time using a digital read-out thermocouple. Series of tests were done under no-load condition and when a load of 3hp was applied to the engine two separate categories. First, engine temperature readings were taken when running the engine with the original components. Secondly, engine temperature readings were taken when the original connecting rod was interchanged for the reverse engineered connecting rod.

e. Engine Speed Test

The engine speeds were measured with a tachometer under the specified experimental conditions above and the readings were recorded.

f. Cost Estimate

The cost estimate for this study will take into consideration all expenditures involved in design and manufacturing, with all the related service facilities such as pattern making, tool making, as well as a portion of the general administrative and selling costs.

The cost structure for this research work was divided into these parts, namely:

i. Direct material cost
ii. Direct labor cost
iii. Overhead cost.
iv.

g. Direct Material Cost

The direct material cost includes the cost of materials used in the production of the connecting rod, cap and its bushing. Table 1 clearly captures the direct cost for this study.

Table 1: Direct Material Cost for the Production of the Connecting Rod

S/N	Description of materials/items	Quantity	Cost per Unit (₦)	Total Cost (₦)
1	Engine parts used for rehabilitating of the diesel generator engine		45,000	45,000
2	Ceramic pattern box for connecting rod and cap	1 No. each	20,000	40,000
3	Wax Pattern		5,000	5,000
4	Sample of complete connecting rod	1 No.	3,000	3,000
5	Cylindrical bronze block	1 No.	5,000	5,000
6	Diesel for running the generator	30 liters	160	4,800
7	Cast electrode	10 Nos.	150	1,500
8	Engine oil	8 liters		6,400
9	Cast iron ingot	5 kg	1500/kg	7,500
Total				**118,200**

h. Direct Labor Cost

The direct labor costs for this study were quantified monetarily and tabulated in Table 2.

Table 2: Direct Labor Cost

S/No.	Description	Amount (₦)
1	Pattern maker	15,000
2	Casting	20,000
3	Machinist	30,000
4	Diesel engine mechanic	25,000
5	AutoCAD designer	10,000
	Total	**100,000**

i. Overhead Cost

The overhead cost is usually expressed as a percentage of the prime cost. Therefore, for this study, the overhead cost would be estimated at 30% of the direct labour cost,

i.e. overhead cost = 0.3 x 100,000 = ₦30,000

j. Total Cost Estimate

The total cost for this research work derived from the three cost aspects, namely direct material cost, direct labour cost and the overhead cost is tabulated in Table 3.

Table 3: Total Cost Estimate for the Production of the Complete Connecting Rod

S/No.	Description	Amount (₦)
1.	Direct material cost	118,200
2.	Direct labor cost	100,000
3	Overhead cost	30,000
	Total	**248,200**

From the summary of the cost analysis in Table 3, the total cost of carrying out this research study is Two Hundred and Forty Eight Thousand Naira only.

III. RESULTS AND DISCUSSIONS

The results of the various tests that were done as stated in chapter four would be presented in this section.

A. Test Result 1 – Performance Tests of the Pattern Produced

The dimensions of the cast connecting rod (prior to machining) were checked to see if its shrinkage values (mm/mm) were within the recommended range of values by the following analysis:

1. Full length of original connecting rod = 387mm

Full length of designed pattern of connecting rod = 395.02 mm
Full length of cast connecting rod before machining = 392.21 mm
Contraction (length of design pattern of connecting rod – length of cast connecting rod produced) = 395.02 – 392.21 = 2.81 mm

Therefore, true contraction (mm/mm) i.e. $\left(\frac{contraction}{designed\ value}\right) = \frac{2.81}{395.02}$ = 0.007 mm

2. Width of the original connecting rod cap = 54 mm

Width of designed pattern of connecting rod cap = 58.01 mm
Width of cast connecting rod cap before machining = 57.45 mm
Contraction (width of designed pattern of connecting rod – width of cast connecting rod) = 58.01 – 57.45 = 0.56 mm

True contraction (mm/mm) = $\frac{0.56}{58.01}$ = 0.0096 mm.
The computations of the true contractions of the full length and width of the connecting rod that was cast showed an approximate value of 0.01 mm each. This value is within the recommended shrinkage value of cast iron of this size, found in standard texts. This shows that the pattern that was produced is satisfactory.

B. Test Result 2 - Performance Test for the Manufactured Connecting Rod

The connecting rod that was produced from this study, shown in Fig. 10, was subjected to performance test by interchanging it with the original connecting rod inside the diesel generator engine.

Fig. 10: Connecting Rod Produced from this Research Study

The engine was run for duration of one hour under no-load and another one hour under a load of 3hp, and the engine temperature and engine speed values were recorded after an interval of 5mins. Temperature distributions on the surface of a connecting rod big end bearing were measured to understand the margin to the allowable limiting temperature. The results show that the temperature difference between the bearing surface and the feed oil is independent of the engine load but quadratically increased with the engine speed, and that the bearing surface temperature on the rod side is higher than those on the cap side, and that the high temperature regions appeared near the edges on the rod side of the bearing under high speed operations.

C. Engine Temperature Results

The reading taken for the control engine (i.e. engine with original connecting rod) and engine with produced connecting rod temperatures with respect to time is shown in Table 4 and Table 5 respectively.

Table 4: Temperature of Control Engine

Time (mins)	Temperature (^oC) Under No-load Condition	Temperature (^oC) with Load of 3hp
0	22	22
5	28	30
10	36	37
15	50	49
20	48	48
25	62	63
30	69	75
35	89	95
40	120	123
45	167	172
50	172	181
55	180	189
60	190	200

Table 5: Temperature of Engine with Manufactured Connecting Rod

Time (mins)	Temperature (°C) Under No-load Condition	Temperature (°C) with Load of 3hp
0	22	22
5	28	30
10	37	37
15	51	49
20	53	48
25	69	63
30	69	75
35	89	95
40	120	123
45	167	172
50	172	181
55	180	189
60	198	201

Fig. 11 which shows a graph of engine temperature with time for the control engine and Fig. 12 which shows a graph of engine temperature with time for the engine with the manufactured connecting rod were further used to buttress the change in engine temperature with respect to time.

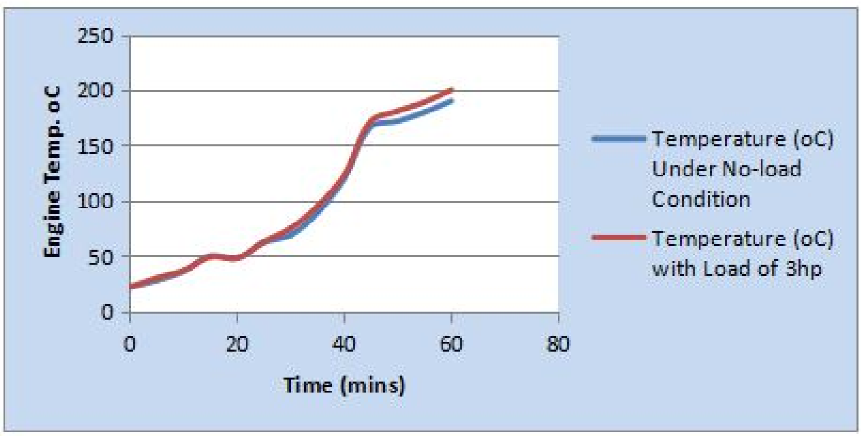

Fig. 11: Rate of Temperature Change for Control Engine

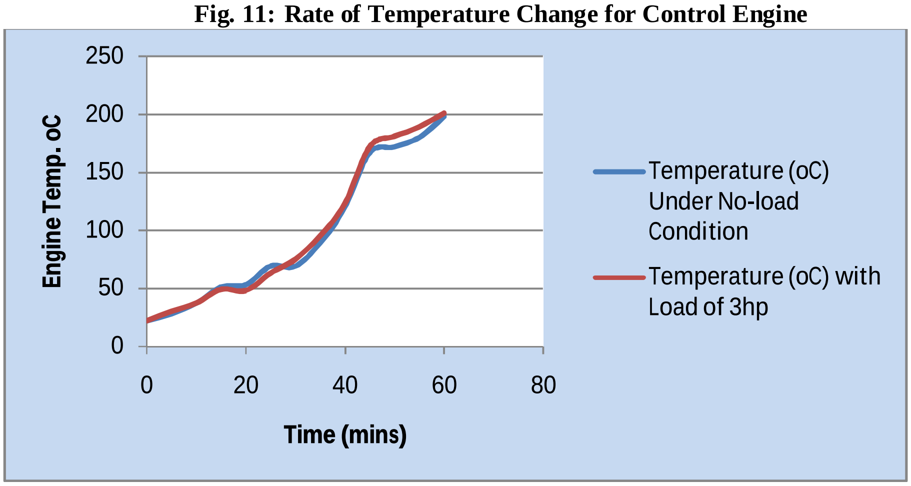

Fig. 12: Rate of Temperature change for Engine with Manufactured Connecting Rod

D. Engine Speed Results

The speed of the engine was measured using the tachometer. Readings were taken for the control engine and engine with the manufactured connecting rod under the no-load condition and under a load of 3hp. Table 6 and Table 7 show the respective results.

Table 6: Speeds of Control Engine

Operational Condition	Engine speed (rpm)
Under No-load Condition	850
Under a load of 3hp	824

Table 7: Speeds of Engine with Manufactured Connecting Rod

Operational Condition	Engine speed (rpm)
Under No-load Condition	793
Under a load of 3hp	786

Günter Mau categorizes diesel engines by their rotational speeds into three groups:

- High-speed engines (> 1,000 rpm),
- Medium-speed engines (300–1,000 rpm), and
- Slow-speed engines (< 300 rpm).

From the test result of the speed of both the Control and Manufactured Rod test Engine, a Medium – Speed engine is under consideration.

E. Discussion

The result in Table 4 (temperature of control engine) showed that there was a steady rise in temperature under the no-load condition and under a load of 3hp for the first 15mins of running the engine. After 20mins of running the control engine, the temperature dipped with 2^{o}C under the no-load condition and 1^{o}C under a load of 3hp. The engine temperature began to rise again after 25mins under both experimental conditions. However, both experimental conditions recorded the highest temperature difference at 45mins, with the engine under no-load condition recording an increase of 47^{o}C and the engine under a load of 3hp recording a temperature rise of 49^{o}C within the same space of 5mins. Again, the result showed that after 1 hour of running the control engine, the engine under a load of 3hp recorded the highest temperature of 200^{o}C while the engine under no-load condition recorded a temperature of190^{o}C. Fig. 11 showed a curve with sharp increase in temperature from 20mins to 50mins. The temperature curve became mildly slant between 50mins and the 1 hour mark, indicating a closer temperature difference at that range of time. Table 5 (engine with manufactured connecting rod) showed similar trend in temperature rise as that in Table 4, except that the engine temperature did not dip under a no-load condition but dipped with 1^{o}C under a load of 3hp at 20mins. However, the engine under no-load condition recoded its lowest temperature rise of 2^{o}C at 20mins. Again, under the no-load condition, there was 0^{o}C temperature rise between 25mins and 30mins as the temperature was stable at 69^{o}C. The engine under load of 3hp recorded the highest temperature of 201^{o}C after I hour while the engine under no-load condition recorded a temperature of 198^{o}C. Fig. 12 showed that the engine under load of 3hp had the steepest slope when compared with engine under no-load. Table 6 showed the values of the engine speeds under the two experimental conditions for the control engine. From the table, the engine speed reduced with 3.06% under 3hp load condition as against the value of 850 rpm when the control engine was under no-load condition. Table 7 showed the same decrease in value for the engine with the manufactured connecting rod. The speed of the engine reduced with 0.88% under 3hp load condition from the 793 rpm recorded under no-load condition. However, the reduction in speed was more for control engine than for engine with the manufactured connecting rod. Günter (1984) shows that due to its high compression ratio, the diesel engine has a high efficiency, and the lack of a throttle valve means that the charge-exchange losses are fairly low, resulting in low specific fuel consumption, especially in medium and low load situations. This makes the diesel engine very economical. Even though diesel engines have a theoretical efficiency of 75%, in practice it is much lower. In his 1893 essay Theory and Construction of a Rational Heat Motor, Rudolf Diesel describes that the effective efficiency of the diesel engine would be in between 43.2% and 50.4%, or maybe even greater. The power output of medium-speed diesel engines can be as high as 21,870 kW, with the effective efficiency being around 47 to 48%. [13]. Shigeo et al., revealed that temperature distributions on the surface of a connecting rod big end bearing were measured to understand the margin of the allowable limiting temperature. The results show that the temperature difference between the bearing surface and the feed oil is independent of the engine load but quadratically increased with the engine speed. The bearing surface temperature on the rod side is higher than those on the cap side. The high temperature regions appeared near the edges on the rod side of the bearing under high speed operations [14]. Subodh, Saini and Samria express that proper functioning of the internal combustion diesel engine. However, accurate piston temperature distribution is required because piston temperature has an important influence on ignition process of engine, ignition time delay, rate of burning, thermal efficiency, and production of pollutants. Knowledge of heat transfer in internal combustion engines is important to understand such systems. It contributes to engine development and design, processes simulation, and emissions reduction. As engine load increases, temperature of the piston and cylinder wall increases exponentially and has a positive relationship [15]. Can, Çelikten & Usta show that as the fuel temperature is decreasing, the energy level is also decreasing. Some reduction will occur in the engine power if the lower calorific value biodiesel is used in a diesel engine without modification [16]. Mamat et al., shows that the lowest temperature that can cause the energy content to decrease, results in the lowest brake thermal efficiency [17]. The higher fuel temperatures tend to produce higher injection pressure. When the fuel temperature is increased, the fuel density decreases [[17]. Kadhim and Idhas show that as fuel temperature increased, fuel density and viscosity were decreased, along with the lubrication capabilities of the fuel. There is a positive significant effect of fuel temperature on most of engine performance indicators including fuel consumption, exhaust gas temperature, noise intensity [18]. Aworanti, Agarry & Ajani show that as fuel temperature increased, the fuel density would be decreased that led to increase fuel consumption [19]. Oluwa defined load as external resistance which specify engine is subjected in practical engine operation, to produce useful work [20], Pawan also observed an increase in fuel consumption with presence of load, engine running with load consumed more fuel than running without load, due to increase in the external load caused an increase in the amount of power required to do same work, in order to overcome resistance due to external load [21].

IV. CONCLUSION

A replica of an 8hp diesel engine connecting rod has been produced locally using available skills and equipment at the Faculty of Engineering Workshop, Petroleum Training Institute (PTI), Effurun, Delta State, Nigeria. The values obtained for engine speeds and engine temperatures for the control engine and the engine with the manufactured connecting rod were very close under the two experimental conditions, which confirmed that the efficiency of the manufactured connecting rod is close to that of the original connecting rod.

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