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# Production of Permanent Mould for Casting Motorcycle Connecting Rod Through Reverse Engineering Approach

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## *Abstract*

***A two-cavity permanent mould was designed and manufactured to cast Frajend 80 motorcycle connecting rod via reverse engineering concept. To achieve this, mild steel plates (cope and drag) were used for producing the mould with specifications 140mm by 140mm by 26mm and 140mm by 140mm by 16mm for the cope and drag respectively.The method adopted for the production of the mould is machining operations which include drilling, milling and turning operations. The shape of the connecting rod was marked out on the mild steel plates before performing the machining operations stated above to achieve the desired cavities.Performance and functional suitability tests were conducted on the produced mould in the Department of Production Engineering Foundry Workshop. The tests were successful as the mould gave the desired products of the connecting rods after casting.***

**Keywords:**Permanent Mould, Casting, Connecting Rod.

## 1.0 Introduction

The Connecting Rod is an essential part of automobile engines and is a rod linking the piston and the crankshaft in an engine. It is mostly made of aluminum alloy through the process of forging or casting.

The process of production of the connecting Rod adopted in this project is casting process which can be achieved via copy manufacture and substitution approach.

The approach/concept can be applied to other machine parts which may be obsolete but still needed in operating and maintaining functioning machines and equipment in developing countries. The refined name for Copy Manufacture and Substitution Approach is Reverse Engineering.

## 1.1 Reverse Engineering

Reverse engineering is the reversal of design engineering. It is applied to both hardware and software engineering systems where design parameters (specifications) from a "Data Bank" are not available [1]. The concept of reverse engineering which has been used in many areas and with many persons includes:

i. The Military, where it is used to copy other nation's technology, parts of which have been obtained by intelligence operations [2].
ii. Innovators, where they use it to determine a product's structure in order to develop competing or interoperable products [2].
iii. Researchers, academics and students, where they use it as a teaching tool [3].
iv. Asia and China in particular, where it has been used successfully to copy motorcycles and vehicle body shapes [4].

In Africa and Nigeria in particular, it has also been used successfully to copy western shoe patterns, suit patterns and ladies hand bag patterns (Cuttings), etc.

## 1.2 Advantages of Reverse Engineering

The following advantages of Reverse Engineering can be harnessed:

i. Considerable foreign exchange may be acquired and saved by resorting to indigenous manufacture of spare parts.
ii. Imported equipment and machinery which have broken down and whose manufacturing specifications are not provided to the user may be put back into operation by resorting to reverse engineering.

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iii. A nation's industrialization may be improved through reverse engineering practice.
iv. Unemployment could be gradually reduced and job creation increased if reverse engineering is practiced [5].

## 2.0 Literature Review

A four-cavity permanent mould for casting 3HP petrol engine pistons via Reverse engineering was designed and manufactured in the Production Engineering Department. The manufactured mould was tested and was observed to have the service requirements.
Reverse Engineering approach was employed to manufacture a 3HP reciprocating internal combustion petrol engine connecting rod. The manufactured connecting rod was tested for performance and functional suitability in the engine. The engine performed satisfactorily with the use of the produced part [1].
The critical parts of a 3 HP petrol engine were manufactured by casting technique through copy manufacture and substitution approach. The produced spare parts were tested individually and collectively. The engine performed well with the use of the manufactured spare parts [1].
Metal casting is probably one of the most ancient processes of manufacturing metallic components. Also; with few exceptions, it is the first step in the manufacture of metallic components. The process involves the following basic steps:

1. Melting the metal
2. Pouring it into a previously made mould or cavity which conforms to the shape of the desired component.
3. Allowing the molten metal to cool and solidify in the mould.
4. Removing the solidified component from the mould, cleaning it and subjecting it to further treatment, if necessary.

The solidified piece of metal, which is taken out of the mould is called "Casting". A plant where the castings are made is called a "Foundry". It is a collection of necessary materials, tools and equipment to produce a casting. The casting process is also called "Founding". The word "Foundry" is derived from latin word "fundere" meaning "Melting and pouring". If sand moulds are used, they are destroyed upon solidification of the metal. If permanent mould is used, it is merely separated to remove the casting.
It is gratifying to note that the Ife and Benin bronzes of Nigeria cast by the lost-wax method rank among the finest in the world [6]. Before the Ife and Benin bronzes there were those of Igbo-Ukwu of Nigeria. Up till this moment this ancient method of metal casting still strives in Benin City, where Igun Street, is the nerve centre of the trade. Unfortunately, the traditional lost-wax process has not gone beyond the level of producing art objects. It would have been expected that the process being an indigenous one, would have permeated the society to the extent that the process would have been able to meet the challenges posed by the scarcity of some industrial products such as bush bearings, machinable stock, hardware and plumbing fittings, pulley wheels, pump parts, household items, machine parts and so on [6].

## 2.1 Cast Metals and Applications

Virtually any metal or alloy that can be melted can be cast. The most common ferrous metals include gray iron, ductile iron, malleable iron and steel. Alloys of iron and steel are used for high performance application, such as temperature, wear and corrosion resistance. The most common non-ferrous metals include aluminum, copper, zinc and magnesium and their alloys. The production and application of ductile iron and aluminum castings are steadily increasing. Aluminum has recently overtaken steel in terms of production by weight. The consumption of magnesium alloys is rapidly increasing in the automobile sector, owing to its high strength to weight ratio, important for higher fuel efficiency. Table 2.1 shows the common cast metals and their uses.

**Table 2.1:** Major Cast Metals [7]

| **Metal** | **Uses %** | **Properties** | **Applications** |
|---|---|---|---|
| Gray Iron | 53 | Heat resistance, damping, low cost, high fluidity, low shrinkage | Automobile cylinder block, clutch plate, brake drum, machine tool beds, housings |
| Ductile Iron | 21 | Strength, wear and shock resistance, dimensional stability, machinability | Crank shafts, camshafts, differential housing valves, brackets, rollers |
| Aluminum | 11 | Strength to weight ratio, corrosion resistance | Automobile pistons, oil and fuel pumps, connecting rod, clutch housing |
| Steel | 9 | Strength, machinability, weldability, treatable | Machine parts, gears, valves |
| Copper | 2 | High ductility, corrosion resistance | Machine impellers, valves, hydraulic pump parts. |

**Table 2.2:**Capabilities of Major Casting Processes [8]

| Type ofCasting | LabourCost/ Casting | Equipment Cost | SurfaceFinish (Ucla) | Usual Accuracy(mm) | MinimumSection Thickness(mm) |
|---|---|---|---|---|---|
| **Sand (green)** | Medium | Low | 500 – 100 | ±2.50 | 5.0 |
| **Shell** | Low | Medium | 100 – 300 | ±0.25 | 2.5 |
| **Centrifugal** | Low | Medium | 100 – 500 | ±0.70 | 8.0 |
| **Investment** | Low | Medium | 25 – 125 | ±0.06 | 0.6 |
| **Shaw** | Medium | Medium | 80 – 180 | ±0.08 | 3.0 |
| **Gravity dieCasting** | Low | Medium | 100 – 250 | ±0.40 | 2.5 |
| **Low-pressure diecasting** | Low | High | 40 – 100 | ±0.05 | 1.2 |
| **Pressure dieCasting** | Very low | Very high | 40 – 100 | ±0.05 | 0.5 |
| **ContinuousCasting** | Low | High | 100 - 200 | ±0.12 | 8.0 |

## 3.0 Methodology

1. The mould was designed by taking into consideration product shape and size, shrinkage allowances, casting material, production economics, etc.
2. Mould material shall be procured from steel shop in Benin City.
3. Mild steel will be the material for the mould such that there shall be no weld between the mould wall and the casting due to melting temperature differentials that exist between the two materials.
4. The mould shall be manufactured by machining operations such as drilling, milling, turning, boring, etc. shall be carried out on the mild steel in the production/faculty workshop, engineering.
5. The casting material shall be aluminum base.
6. The manufactured mould shall be tested by melting the aluminum base in the furnace and pouring the molten metal charge into the mould.
7. The cast shall be machine finished by turning and boring on the lathe machine.

## 3.1 Design Considerations

There were some important design considerations made when designing the mould for the Fraject 80 motorcycle connecting rod. The most important ones were:

1. Material selection.
2. Type of usage i.e. for jobbing or for mass production of parts.
3. Initial cost.
4. Required surface finish of product.

As a result of these considerations, two concepts for producing the mould for the connecting rod were developed. These concepts are:

- Using cast iron for making the mould.
- Using mild steel for making the mould.

## 3.2 Material Selection

The choice of material is the major starting point in any design job. Good choices of material give the desired functionality requirement and production at minimum cost and also, enhance the design life of the product when in use. As the connecting rod was made of aluminum alloy, mild steel as an alternative to cast iron - was selected as the permanent mould material due to the following reasons; It has an excellent wear resistance, Strength, etc, as highlighted in the Table 3.1.

**Table 3.1:** Characteristics of Pattern Material

| Characteristics | Wood | Aluminum | Steel | Plastic | Cast Iron |
|---|---|---|---|---|---|
| **Machinability** | E | G | F | G | G |
| **Wear resistance** | P | G | E | F | E |
| **Strength** | F | G | E | G | G |
| **Weight** | E | G | P | G | P |
| **Repairability** | E | P | G | F | G |
| **Corrosion** | P | E | E | E | E |
| **Resistance to swelling** | E | E | P | E | P |

E, excellent; G, Good; F, Fair; P, Poor

## 3.3 Material Specification

The mould is designed to produce two connecting rods at a time with specifications shown in the figure below.

The mould design incorporated principal factors such as steel coefficient of heat accumulation, thermal conductivity, thickness of the mould and the mould dimensions for they affect the solidification time, $t_s$, of the charge, which is given as;

$$t_s = 8.004\left(\frac{V}{A}\right)^2 \qquad (3.1)$$

Where A = Area of part to be cast

V = Volume of part to be cast

Since $\left(\frac{V}{A}\right)^2$ is a function of thickness (T), equation (3.1) becomes

$$t_s = 8.004\,x\,T^2 \qquad (3.2)$$

Equation (3.2) expresses solidification time, $t_s$, as a function of mould thickness, T. Designing for twenty seconds (20 sec) solidification, the thickness, T is:

$$T = \frac{20}{8.004} = 1.58x10^{-2}m = 1.6cm = 16mm$$

Hence one half of the mould's thickness is 16mm. Furthermore, the mould production was by machining (drilling, milling and turning) operation technique to the desired cavity for casting the Frajend 80 motorcycle connecting rod.

## 3.4 Riser Design

In the design of any type of mould, it is very imperative for the mould to have adequate riser design to assume molten metal flow and also to offset losses ascribable to shrinkage of cast. Thus, the main task of a riser is to prevent the formation of shrinkage cavity and porosity in castings.

The risers' function can be performed effectively under the following conditions:

i. The risers should be sufficiently large enough to make molten metal remain in molten state as poured metal solidifies into ingot.

ii. The shape and location of the risers should ensure free access of the molten metal to the casting or hot spot,

iii. The risers should contain a sufficient amount of molten metal to feed up the casting all the time to full solidification.

iv. The dimensions and mass of the risers should be as small as possible.

A basic riser design consideration is rooted on the idea that:

$$\text{Cooling Rate} = \frac{K}{A} \qquad (3.3)$$

$$\text{Heat Retention Capacity} = \frac{C_1}{V} \qquad (3.4)$$

Where K, $C_1$ = Constants of proportionality

$$\text{Thus, solidification time, } t_s = \frac{1}{A} \qquad (3.5)$$

Riser length or Riser height = 26mm

Riser diameter = 10mm

Since, the amount of heat content is proportional to the volume and the rate of heat dissipation depends upon the surface area of the riser. Thus, the risers should be designed with a high V/A (volume/surface area) ratio, for a given size. This will minimize the loss of heat, so that the riser will remain hot and the metal in the molten state as long as possible.

Many relations have been suggested for determining the riser size.

**1. Chvorinov's rule [9]**

$$\text{Solidification time or freezing time, } t_s = C_1 x\left(\frac{V}{SA}\right)^2 \qquad (3.6)$$

Where SA = Surface area of casting

$C_1$ depends upon composition/properties of cast metal (including its latent heat), pouring temperature and mould material etc.

Since, the metal in the riser must be the last to solidify, to achieve direction solidification.

$$\left(\frac{V}{SA}\right)_{Riser} > \left(\frac{V}{SA}\right)_{Casting} \qquad (3.7)$$

In practice,

$$\left(\frac{V}{SA}\right)_{Riser} = (1.10\ to\ 1.15)\left(\frac{V}{SA}\right)_{Casting} \qquad (3.8)$$

Chvorinov's formula is not very accurate, because, it does not take into account the solidification contraction or shrinkage.

**2. Caine's formula**

Relative freezing time or freezing ratio is defined as

$$X = \frac{\left(\frac{SA}{V}\right)_{Casting}}{\left(\frac{SA}{V}\right)_{Riser}} \quad (3.9)$$

Volume ratio, Y, is given as

$$Y = \frac{\text{Volume of riser}}{\text{Volume of casting}}$$

Then, Caine's formula is given as

$$X = \frac{a}{Y-b} + C_2 \quad (3.10)$$

Where a = Freezing characteristics constant
b = Liquid – solid solidification contraction
$C_2$ = Relative freezing rate of riser and casting

## 3.5 Gating Design

Gating system is basically designed to prevent "aspiration". "Aspiration" is the process of air entering into a casting as the molten metal is poured through the gate. To achieve this, the pressure at the entrance of the gate should be greater than that at the bottom of the gate (which is basically atmospheric).

Gates are used in casting to achieve the following objectives:

- Forestall mould following metal flow.
- Forestall formation of dross (oxide).
- Forestall formation of air bubbles in casting (aspiration).
- Prevent sand entry into casting as molten metal is poured and flows into casting.

The specifications for the ingate are as follows:

Pouring cup diameter = 15mm
Pouring cup height = 5mm
Diameter of ingate = 13mm
Height of ingate = 21mm

Two cases are considered in this design analysis:

**Case I: Uniform Cylindrical Ingate**

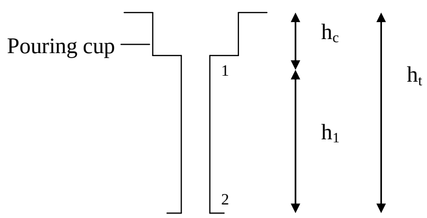



**Fig. 3.1:Uniform Cylindrical Ingate**

From Bernoull's equation, we have:

$$h_1 + \frac{V_1^2}{2g} + \frac{P_1}{W} = h_2 + \frac{V_2^2}{2g} + \frac{P_2}{W} \quad (3.11)$$

Where 1 and 2 are two distinct positions.

So, $$h_1 + \frac{V_1^2}{2g} + \frac{P_1}{W} = h_2 + \frac{V_2^2}{2g} + \frac{P_2}{W} \quad (3.12)$$

Where w = $\rho g$ (specific weight)
$\rho$ = density of molten metal
g = gravitational constant
h = elevation above reference point
v = velocity of molten metal
P = pressure at the elevation specified by subscript

By applying the boundary conditions:

$$h_2 = 0, P_2 = P_o = atmospheric\ pressure$$

From continuity equation: $V_1 A_1 = V_2 A_2$ (3.13)

Since $A_1 = A_2$ (for uniform cross-sectional area)

:. $V_1 = V_2$ (3.14)

Thus, from the relation:

$$h_1 + \frac{V_1^2}{2g} + \frac{P_1}{W} = h_2 + \frac{V_2^2}{2g} + \frac{P_0}{W}$$

$$h_1 + \frac{P_1}{W} = \frac{P_0}{W} \quad (3.15)$$

$$\frac{P_1}{W} = \frac{P_0}{W} - h_1 \quad (3.16)$$

$$P_1 = P_0 - Wh_1 \quad (3.17)$$

Clearly, since $W > 0, h_1 > 0$

Then $Wh_1 > 0$

Therefore, the pressure at point x ($P_1$), is less than atmospheric value $P_o$ by the quantity $Wh_1$ units.

Hence, uniform cross sectional area should not be used in gating system design because it will lead to:

- Mould damage
- Formation of dross (oxidation)
- Formation of air bubbles in casting due to aspiration and
- Sand entry.

**Case II: Non-Uniform Cylindrical Ingate**

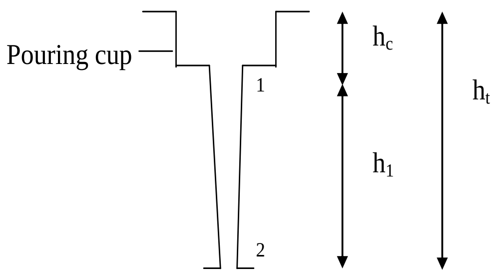



**Fig. 3.2: Non-Uniform Cylindrical Ingate**

From Bernoulli's equation:

$$h_1 + \frac{V_1^2}{2g} + \frac{P_1}{W} = h_2 + \frac{V_2^2}{2g} + \frac{P_2}{W} \quad (3.18)$$

By applying boundary conditions $h_2 = h_0 = 0$

So, $h_1 + \frac{V_1^2}{2g} + \frac{P_1}{W} = \frac{V_2^2}{2g} + \frac{P_2}{W}$ (3.19)

To prevent aspiration i.e. air entering into the casting as molten metal is poured and passes through the gate. $P_1$ should not fall below $P_0$ i.e. $P_1 \geq P_0$

In a particular situation; where $P_1 = P_0$; we have:

$$h_1 + \frac{V_1^2}{2g} = \frac{V_2^2}{2g} \quad (3.20)$$

$$h_1 = \frac{V_2^2 - V_1^2}{2g} \quad (3.21)$$

From continuity equation (3.13), we have:

$$A_1V_1 = A_2V_2 \quad (3.22)$$

$$V_1 = \left(\frac{A_2}{A_1}\right)V_2 \quad (3.23)$$

(For non-uniform cross-sectional area), substitute equation (3.23) into (3.21)

$$h_1 = \frac{V_2^2 - \left(\frac{A_2}{A_1}\right)^2 {V_2}^2}{2g} \quad (3.24)$$

$$h_1 = \frac{1}{2g}\left\{V_2^2 - \left(\frac{A_2}{A_1}\right)^2 {V_2}^2\right\} \quad (3.25)$$

$$h_1 = \frac{V_2^2}{2g}\left\{1 - \left(\frac{A_2}{A_1}\right)^2\right\} \quad (3.26)$$

$$\frac{2gh_1}{V_2^2} = 1 - \left(\frac{A_2}{A_1}\right)^2 \quad (3.27)$$

$$\left(\frac{A_2}{A_1}\right)^2 = 1 - \frac{2gh_1}{V_2^2} \quad (3.28)$$

$$\therefore \frac{A_2}{A_1} = \sqrt{1 - \frac{2gh_1}{V_2^2}} \quad (3.29)$$

From fig. 3.2, $h_1 = h_t - h_c$
Where $h_t$ = total head
$h_c$ = height to which pouring cup has been filled.

Then, $\frac{A_2}{A_1} = \sqrt{1 - \frac{2g(h_t - h_c)}{V_2^2}}$ (3.30)

From kinematics (for downward motion),

$V_2{}^2 = V_1{}^2 + 2aS$ (3.31)

Where $S = h_t, a = g, V_1 = 0, V_2^2 = 2aS$

:. $V_2^2 = 2gh_t$ (3.32)

Substitute equation (3.32) into (3.30)

$\frac{A_2}{A_1} = \sqrt{1 - \frac{2g(h_t - h_c)}{2gh_t}}$ (3.33)

$$\frac{A_2}{A_1} = \sqrt{\frac{2gh_t - 2gh_t - 2gh_c}{2gh_t}}$$

$$\frac{A_2}{A_1} = \sqrt{\frac{2gh_c}{2gh_t}}$$

:. $\frac{A_2}{A_1} = \sqrt{\frac{h_c}{h_t}}$ (3.34)

Since, $h_c < h_t$, this implies that to prevent aspiration, $A_2$should be less than $A_1$i.e. $A_2 < A_1$.
Then, the ingate should be tapered since design consideration is quite important in casting system.

**Heat Loss from Casting**

A major design consideration in casting is the heat loss. Mould/Risers should be designed in a manner that ensures that requisite temperature gradient (dθ/dx) is achieved.

A crucial focus here is the heat flow out of the casting through the molten metal, via the molten metal/mould interface to the surroundings. The derivation that follows presumes basic knowledge of the following.

1. The normal probability integral or the error function.

$erf\left(\frac{x}{2\sqrt{kt}}\right) = \frac{2}{\sqrt{\pi}}\int_0^{\frac{x}{2\sqrt{kt}}}\left(1 - a^2 + \frac{a^4}{2!} - \frac{a^6}{3!} + \cdots\right)da$ (3.35)

Radford and Richardson [8] applied a first order differential equation to the heat diffusion problem for conduction in one dimension x. They obtained;

$\frac{\partial^2\theta}{\partial x^2} - \frac{1}{K}\frac{\partial\theta}{\partial x} = 0$ (3.36)

Where, θ = temperature of molten metal
t = time of pouring
K = Thermal diffusivity

Also, Caslaw and Jaeger [10] derived a heat flow equation using the above first order differential equation. They employed the parameters.

$\theta_o$ = initial mould surface temperature
$\theta_1$ = final mould surface temperature (solidification temperature)
$\theta_x$ = temperature of molten metal at a distance x along the heat flow line.

They obtained the solution

$\theta_x = \theta_0 + (\theta_1 - \theta_0)\left\{1 - erf\left[\frac{x}{2\sqrt{kt}}\right]\right\}$ (3.37)

$\theta_x = \theta_0 + (\theta_1 - \theta_0) - (\theta_1 - \theta_0)erf\left[\frac{x}{2\sqrt{kt}}\right]$ (3.38)

To obtain the heat flow equation, we differentiate equation (3.38) with respect to x.

$\frac{\partial\theta_x}{\partial x} = -(\theta_1 - \theta_0)\frac{\partial}{\partial x}erf\left[\frac{x}{2\sqrt{kt}}\right]$ (3.39)

Where t is the time after pouring the molten metal into the mould and erf = error function.

So, $\frac{\partial\theta_x}{\partial x} = (\theta_0 - \theta_1)\frac{\partial}{\partial x}erf\left[\frac{x}{2\sqrt{kt}}\right]$ (3.40)

By expanding the error function, equation (3.35):

$erf\left(\frac{x}{2\sqrt{kt}}\right) = \frac{2}{\sqrt{\pi}}\left[a - \frac{a^3}{3} + \frac{a^5}{5\times 2!} - \frac{a^7}{7\times 3!} + \cdots\right]_0^{\frac{x}{2\sqrt{kt}}}$ (3.41)

By substituting the limits of integration:

So, $\frac{\partial \theta_x}{\partial x} = (\theta_0 - \theta_1)\frac{\partial}{\partial x}\left[\frac{2}{\sqrt{\pi}}\left(\frac{x}{2k^{1/2}t^{1/2}} - \frac{x^3}{3\times 8k^{3/2}t^{3/2}} + \frac{x^5}{5\times 2\times 32k^{5/2}t^{5/2}} - \frac{x^7}{7\times 6\times 128k^{7/2}t^{7/2}} + \cdots\right)\right]$

$$\frac{\partial \theta_x}{\partial x} = (\theta_0 - \theta_1)\frac{2}{\sqrt{\pi}}\left(\frac{1}{2k^{1/2}t^{1/2}} - \frac{x^2}{8k^{3/2}t^{3/2}} + \frac{x^4}{64k^{5/2}t^{5/2}} - \frac{x^6}{768k^{7/2}t^{7/2}} + \cdots\right) \quad (3.42)$$

By applying the boundary conditions to Eqn. (3.42) at the surface where $x = 0$:

$$\frac{\partial \theta_x}{\partial x} = (\theta_0 - \theta_1)\frac{2}{\sqrt{\pi}}\left(\frac{1}{2k^{1/2}t^{1/2}}\right) \quad (3.43)$$

$$\frac{\partial \theta_x}{\partial x} = \left(\frac{(\theta_0 - \theta_1)}{\sqrt{\pi k t}}\right) \quad (3.44)$$

Defining $J = \frac{\text{Heat flow}}{\text{Unit Area}} = -K\frac{\partial \theta_x}{\partial x}$ (3.45)

Where K = thermal conductivity

By substituting equation (3.44) into (3.45)

$$J = -K\left(\frac{(\theta_0 - \theta_1)}{\sqrt{\pi k t}}\right)$$

$$J = K\left(\frac{(\theta_1 - \theta_0)}{\sqrt{\pi k t}}\right) \quad (3.46)$$

But, Heat flow, $Q = A\int_0^{t_s} J dt = A\int_0^{t_s} K\left(\frac{(\theta_1 - \theta_0)}{\sqrt{\pi k t}}\right) dt$

$$\therefore Q = \frac{2AK(\theta_1 - \theta_0){t_s}^{1/2}}{\sqrt{\pi k}} \quad (3.47)$$

Also, the quantity of heat Q which flows through mould/molten metal interface is given as

$$Q = \rho V[L + C(\theta_p - \theta_1)] \quad (3.48)$$

Where, ρ = density of metal

V = Volume of metal

L = Latent feat of fusion of metal

C = Specific heat of metal

$\theta_p$ = Pouring temperature

By equating equations (3.47) and (3.48):

$$\frac{2AK(\theta_1 - \theta_0){t_s}^{1/2}}{\sqrt{\pi k}} = \rho V[L + C(\theta_p - \theta_1)] \quad (3.49)$$

$$t_s^{1/2} = \frac{\rho V[L + C(\theta_p - \theta_1)](\pi k)^{1/2}}{2AK(\theta_1 - \theta_0)} \quad (3.50)$$

By solving for $t_s$; we have:

$$t_s = \left\{\frac{\rho[L + C(\theta_p - \theta_1)]}{2K(\theta_1 - \theta_0)}\right\}^2 (\pi k)\left(\frac{V}{A}\right)^2 \quad (3.51)$$

$$t_s = B\left(\frac{V}{A}\right)^2 \quad (3.52)$$

Where $B = \left\{\frac{\rho[L + C(\theta_p - \theta_1)]}{2K(\theta_1 - \theta_0)}\right\}^2 (\pi k) = Mould\ constant$

If the time needed to solidify to specific depth, d is required, so, we have

depth, $d = \frac{\text{Volume. V}}{\text{Area, A}}$

$$d = \frac{V}{A} \quad (3.53)$$

By substituting (3.53) into (3.52), we have

$$t_s = Bd^2 \quad (3.54)$$

The importance of equation (3.54) is that solidification time, $t_s$, is a power function of the depth of solidification.

## 3.6 Venting

The air within the mould cavity should escape as fast as the metal enters the mould through the space between parting surfaces. This natural venting is usually inadequate. Additional venting may be achieved by:

i. Cutting vent channels about 0.13mm deep into a parting surface.

ii. Drilling small cluster of holes 0.20 to 0.25mm diameter in the mould wall at the location where venting is needed.

iv. Pin venting, that is, drilling one or more 6.35fnm diameter holes into the area requiring additional venting and driving into them square pins 6.35mm across the corners.

v. Plug venting, that is., drilling holes and inserting slotted plugs.

## 3.7 Mould Production

Mould production deals with the actual process of manufacturing the mould and testing.

The major works carried out when machining the mould are outlined as follows:
(a) Smoothening of the mild steel plates edges and surfaces according to specification.
(b) Drilling of 4 through holes on both fastened parts of the plates to form the cope and the drag.
(c) Cutting of the desired shape of the connecting rod on both sides of the steel plates, 5mm on each side.
(d) Drilling of the risers and the ingate to the cope.
(e) Cutting of the steel rod (035mm x 300mm) into four parts, 75mm each.
(f) Turning of the rod parts: Two to 26mm and two to15mm, through a length of 45mm.

## 3.8 Smoothening of the Mild Steel Plates Edges and Surfaces According to Specification:

Here, great care was taken in order to obtain a dimension with close tolerance.
Two plates of mild steel of dimension 140mm x 140mm x 26mm and 140mm x 140mm x 16mm respectively that were procured were smoothened on the edges to the given dimensions with the use of a filling machine.

**Drilling Operation**
This is a very sensitive part of the machining process because here, accuracy of dimension is very important.
In carrying out this operation, both steel plates were fastened together. By the use of a drilling machine, 2 by 26mm through holes and 2 by 15mm through holes were drilled at the stipulated positions respectively. Three through holes of diameter 10mm, 10mm and 15mm each, were drilled on the cope to serve as the risers and .* the ingate respectively using a drilling machine also.

**Milling Operation**
First of all the shape of the connecting rod was marked out on the sheet metal plates with the aid of a scriber.
A milling machine was later used to judiciously cut off the marked out locations on the mild steel sheet metal plates to a depth of 5mm on each side of the plates respectively.

**Turning Preparation**
This is another sensitivity part of the machining process where accuracy of dimension is very essential.
In this stage of the fabrication process, 2 of the cut rod were straight turned to 26mm through a length of 45mm and the other 2 rods were straight turned to 15mm through a length of 45mm respectively.

## 3.9 Functions of Some Other Tools Used During the Manufacturing Process

**(1) The steel rule:** When a dimension is given on a drawing, it may be generally assumed that the dimension will be produced. The measurements made with steel rule depend on the quality of the rule.
The steel tape is the most popular measuring instrument in the workshop bench.
It was used in taking measurements on the steel plates: when taking measurements with the steel rule, it was held such that the graduation lines were as close as possible to the face being measured noting well that the steel rule cannot be used for precision measurements.
**(2) The vernier caliper:** This is a beam caliper with jaws at right angles to the bean and is used for measuring external and internal dimensions and the depth of slots and holes.
The vernier caliper was fully employed and utilized in the fabrication process for measuring the diameter of the holes and the rods regularly before attaining the desired dimensions.
**(3) The scriber:** It is a sharp pointed tool used for marking out positions or locations in which work is to be carried out. The dimensions of the connecting rod shape were marked out on the drag and cope surfaces of the mould, using the scriber.

## 3.10 Manufacture

A 10kg of aluminum block was procured and cracked to small bits with a hammer. The foundry in the production workshop was set up and the aluminum bits placed in a steel bowl and were heated in the enclosure for about 30 minutes and the aluminum were melted in the furnace for the casting test. The cores were properly installed in the cavities of the mould and the parting surfaces were fastened together. The mould was warmed and held at about 400°c, ready to receive the molten metal charge. It was necessary to warm and to control the mould temperature in order to ensure.
i. Free flow of the liquid metal charge into the cavities via the gates.
ii. Safe usage of the mould, accident through moisture blowing is eliminated.
iii. Smooth casting surface, and
iv. Long mould life.
The mould was fed with the molten metal at 700°c and pouring was stopped when the charge was seen appearing in the risers.

## 3.11 Post Manufacture Operation

Upon solidification of the molten metal, the mould was opened in order to remove the castings. The excess or scrap resulting from the risers, pouring basin, runners, sprue well and the ingates were cut off from the castings. A hacksaw is used to cut off the excess or scrap resulting from the risers, pouring basin, runners, sprue well and the ingates. The castings were surface finished by simple filing operation. The castings were subjected to thorough examinations for possible defects. The dimensional accuracy of .the cast product was high.

## 4.0 Testing

The performance test is the most important stage in any manufacturing process because, we have to know or determine the functionality of our designed product. It is an important aspect of quality control.

A crucible furnace was charged with aluminum scraps in production engineering foundry and was heated for about 45 mins. During the process, the aluminum scraps got melted inside the crucible pot which was removed from the furnace by means of a pair of tongs. The slags were removed while the mould was heated to ready it to receive the molten metal.

The mould was well positioned on the ground to allow free flow of the molten metal during pouring. After pouring, the mould was allowed to cool down before removing the produced component shown in appendix 3.

## 4.2 Cost Estimate

DEFINITION: This is the detailed analysis and allocation of all expense, direct and indirect, to jobs, process or services.

The classifications of costs for the manufacture of the permanent mouldfor the connecting rod of Frajend 80 motorcycle are as follows:

i. Direct material cost.
ii. Direct labour cost.
iii. Direct expenses.
iv. Indirect material cost.
v. Indirect labour cost.
vi. Fixed and miscellaneous cost.

**Table 4.1: Direct Material Cost**

| S/N | Material Description | UnitCost | No ofItems | TotalCost (N) |
|---|---|---|---|---|
| 1. | 140mm x 140mm x 26mm mildsteel plate | 800 | 1 | 800 |
| 2. | 140mm x 140mm x 16mm mildsteel plate | 600 | 1 | 600 |
| 3. | Cost of cutting the plates withOxygen | 600 | 2 | 1,200 |
| 4. | Aluminum sheet | 100/kg | 10KG | 1,000 |
| **Total** | | | | **N3,600** |

### 4.2.1 Direct Labour Cost

Three persons took active part in the manufacturing of the mould for the period of a month, suppose each staff receives N4,000 monthly.

Direct labour cost = 4000x3 = 12,000

:. Prime Cost = direct material cost + direct labour cost+ direct expenses 3,600 + 12,000

= N15,600

### 4.2.2 Factory Overhead Cost

#### 4.2.2.1 Fixed and Miscellaneous Expenditure

In the manufacture of the permanent mould, I consulted the foundry man at the departmental foundry, to gain knowledge from his wealth of experience.

I also paid transportation fairs to the place where I purchased the materials for the mould construction, [11].

Therefore, the fixed and miscellaneous expenditure was calculated to be N2,500.

Therefore, the total cost of producing the mould

= Prime cost + overhead cost

= N15,600 + N2,500

= N18,100

## 5.0 Conclusion

The work has shown that with the use of the permanent mould, the connecting rod of frajend 80 motorcycle can be manufactured locally via reverse Engineering Approach. The produced connecting rod is as shown in appendix 3.It is a perfect instance of reverse Engineering, it will provide employment and it will create wealth.

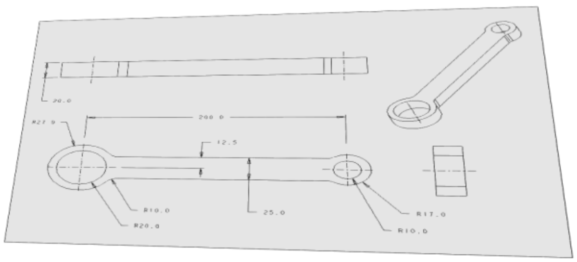
The following points are suggested for further work:

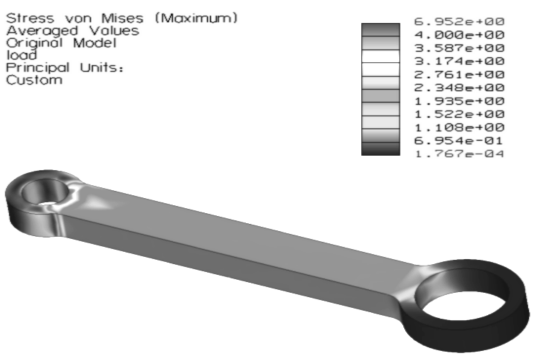
1. There is need to design the appropriate mould cooling medium.
2. There is need to design and manufacture automated mechanism for the opening and closing of the mould.
3. The University of Benin Authority to upgrade the standard of existing founding, machining equipment and laboratory facilities. These will help students to carry out research work according to the standard of the present age machining and founding.

## 6.0 Acknowledgement

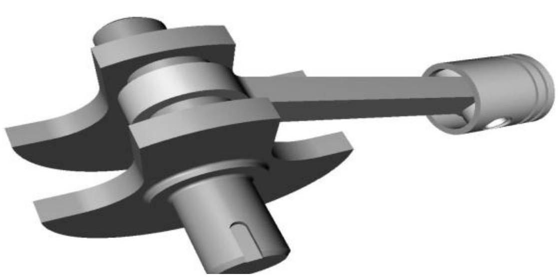
I wish to express my sincere gratitude to Engr (Prof) J.A. Akpobi for his great support, guidance and careful manner with which he reviewed this work. I would also wish to thank Engr. (Dr.) A.C. Igboanugo for his guidance and encouragement.

## Appendix 1

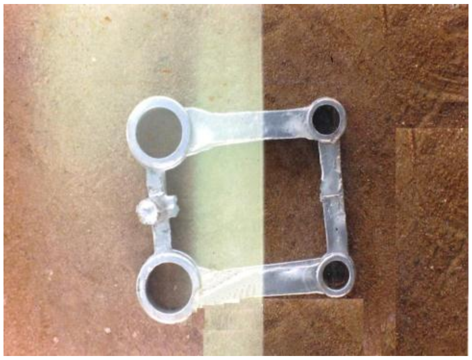





## Appendix 2



## Appendix 3



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