EVALUATION OF MECHANICAL PROPERTIES OF CAST ALUMINUM CONNECTING ROD FOR G-300 HONDA GENERATOR

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ABSTRACT

This paper evaluated the mechanical properties of cast aluminum connecting rod, produced from recycled similar aluminum rod, in relation to imported rod. This was done via a permanent casting technique after which the tensile and hardness properties of the produced connecting rod was determine using universal tensometer with serial number UTM 10584 and Avery universal hardness testing machine (ASTM D789) *respectively. Mechanical property characterizations show hardness value in the range 134 BHN – 139 BHN in the cast sample and 160 BHN – 162 BHN in the imported connecting rod. Tensile strength, percentage elongation, percentage reduction in area and yield strength in cast samples are 168 Nmm^{-2}, 3.7 %, 7.8 % and 146 Nmm^{-2} respectively which are about 11 %, 34 %, 42 %, and 19 % respectively lower than those of the imported connecting rod. The difference in method of production of the two connecting rods was presumed to have been the major factor responsible for the mark difference in properties of the two rods. Though from these results, it is however presume that locally produced connecting rod through permanent casting can be made to improve in properties and compete favourably in strength with imported rod when further metallurgically heat treated via age-hardening, normalizing and solution heat treatment.*

Keywords: Aluminum alloy; Connecting rod; Internal combustion engines; Mechanical properties; Permanent mould

1.0 INTRODUCTION

Engine of any sort need maintenance for sustainable service life and more importantly engine parts need to be replaced with time as a result of wear and or total damage. In addition to the increasing cost of engine parts and non-availability of the parts in the market, failure of any parts may bring about total grounding of the entire engine, moreover since most engines are imported into the country. The design of internal combustion engines (ICE) is such that it employs a variety of connecting rods depending on the type of the engine and arrangement of the cylinders (Roy, 2012). Connecting rods are made of alloy of steels and aluminums usually produced either by casting, forging, computer numerical machining (CNC) of blank and powder metallurgy (sintering) process (Demidov and Kolchin, 1984, kadiam, 2014 and Sayeed *et al*, 2014). It is an intermediate member between the piston and the crankshaft used to transfer thrust in either direction between the piston and the crankpin. It is used to convert the translational motion of the piston into the rotational motion of the crankshaft usually subjected to the effect of alternating gas and dynamic stresses which produce impact loads (Anusha and Vijaya, 2013, Kadiam, 2014, Leela and Venus, 2014, Roy, 2012 and Sudernshn *et al,* 2012).

Many authors like Guisseper, Muhammad, Sudershn *et al*, Kadiam and Leeala have researched into various aspect of connecting rod. One of the primary factors determining the connecting properties is the material that's being made of, as evidence in the work of Leela and Venus, 2014 titled; "Design and Analysis of Connecting Rod using Forged steel". Connecting rod manufactured from carbon steel was analyzed and compared with forged steel connecting rod. They reported that, the forged steel connecting rod has higher factor of safety, reduced weight, increase stiffness, reduced stress and stiffer than that of carbon steel. In a related work, Sudershn et al (2012), replaced existing carbon steel connecting rod with Aluminum reinforced with carbide and Aluminum 360 for Suzuki GS150R motorbike. It was found that, factor of safety of Aluminum boron carbide is nearer to theoretical factor of safety when compared with other materials while percentage reduction in weight is the same in both Aluminum 360 and Aluminum Boron Carbide. It was also reported that percentage reduction in stress for both Aluminum boron carbide and Aluminum 360 is the same and is more than that of Carbon Steel with Aluminum Boron Carbide most stiffer.

In a research carried out by Mohammed et al (2009), failure analysis of a fractured connecting rod was carried out using finite element technique and metallographic examination. The result of the findings shows that connecting rod failure was as a result of fatigue crack growth mechanism couple with gas porosity (i. e manufacturing defect) which resulted in catastrophic failure. They recommended that material free from manufacturing defect with improved mechanical properties defect should be selected for the production of connecting rod. Further work on the effect of connecting rod material properties was carried out by Giuseppe (2001). In his work connecting rod mould was developed and squeeze cast using metal matrix composite (MMC) for racing car engines and static tensile proof testing, radiographic and microscopic investigation on the sample cast were carried out. It was found that an increase of 20 % in strength and 29 % in stiffness of MMC squeeze cast connecting rod than those of its steel counterpart. The resulting improvement in the properties of the connecting rod may be explained based on the squeezing action of the production process coupled with the agglomeration of metal matrix composite. This squeezing effect on material strength corroborated with the work of Aweda and Kolawole (2014), where they obtained an increase in strength of aluminum and brass rod with corresponding increase in squeezing pressure as result of reduction in gas porosity and increase solidification rate favoring smaller grain structure for improved strength. Connecting rod properties is also dependent of the manufacturing routes. Kadiam (2014), in his work "comparative study of the connecting rod manufactured using forging and sintering", conducted a structural and thermal analysis on connecting of a two cylinder 4-stroke S217engine using solid modeling software. The result show that the von-mises stress, total deformation and strain energy for the forged connecting rod is higher than that of the sintered con rod due to higher density of forging process. However the present work is necessitated due to the present needs of the country and high cost of importation of engine parts with a view to produce machine parts to match the imported ones. Therefore, a connecting rod was developed and produced for G-300 Honda Generator using aluminum alloy.

2.0 MATERIALS AND METHODS

The material used for the production of connecting rod for G-300 Honda generator was scrap of an Aluminum alloy of G-300 Honda generating set with percentage composition of the constituent element shown in Table 1.

Table 1 Percentage composition of G-300 aluminum alloy scrap

Al	Si	Cu	Zn
85-88	8-10	3-4	1

2.1 Specifications for Connecting Rod

Automobiles, tractors and generators engines employ a variety of connecting rods depending on the type of engine and arrangement of cylinders, Roy (2012) and Lilly (1986). Roy (2012), Demidove and Kolchin (1984), Pravardhan and Ali (2005) and Lilly (1986), the design elements of connecting rod are made up of three essential parts; namely:

i. The big end fitted over crank pin,
ii. The small end fitted over gudgeon pin and
iii. The shank.

The dimensional specifications of connecting rods vary with the type of engine, (Lilly 1986). Both the petrol and diesel engines design parameter are step-off from piston pin diameter which is approximately equal to the inside diameter of the small end of the connecting rod (Roy 2012 and Lilly 1986).

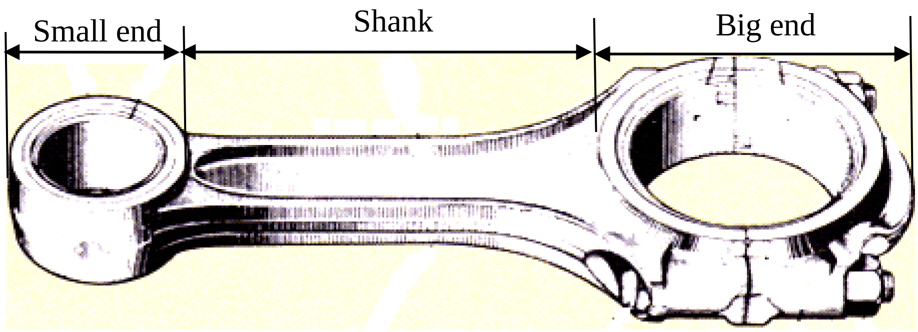


Fig. 1 Typical connecting rod (Demidov and Kolchin, 1984)

According to Demidov and Kolchin (1984), the basic design parameters of small end of connecting rod for petrol and diesel engines are as presented in Tables 2, 3 and 4

Table2: Basic design parameters for Small end of the connecting rod for diesel and petrol (Demidov and Kolchin 1984).

Description	Ratio	Petrol engine	Diesel engine
Piston pin diameter dp			
Small end inside: Diameter idse: without bushing		$id_{se} \approx dp$	$Id_{se} \approx dp$
Small end inside: Diameter idse (b): with bushing	$id_{se}(b)/dp$	0.95 – 1.03	0.95 – 1.03
Small end outside diameter OD_{se}	Od_{se}/dp	1.15 – 1.90	1.20 – 1.95
Length of small end L_{se}	$L_{se}/L_{sec}(max)$	0.66 – 1.07	0.66 – 1.07
Radial thickness of end wall rt_{ew}	rt_{ew}/dp	0.19 – 0.30	0.19 – 0.30

Table 3: Basic design parameters for the Big end of connecting rod (Demidov and Kolchin, 1984)

Description	Ratio	Variation limits
Crank pin diameter dep	$d_{cp}/L_{sec}(max)$	0.99-1.02
Shell wall thickness t_{sh}: Thin – wall	t_{sh}/ dcp	0.10 – 0.17
Shell wall thickness t_{sh}: Thick – walled	t_{sh}/ dcp	0.35
Length of big end L_{be}	L_{be}/dcp	0.82 – 0.99
Distance between connecting rod bolts D_{eb}	D_{cb}/dcp	1.25 – 1.45

Table 4 Basic design parameters for connecting rod shank (Demidov and Kolchin, 1984)

Dimension of section	Ratio	Petrol engine	Diesel engine
L_{sec}	$Lsec/Ods$	0.62 – 1.07	0.62 – 1.07
$L_{sc\ (max)}$	$L_{sec}(max) / Lsec$	1.01 - 2.03	1.01 – 2.03
b_{sec}	$b_{sec} / L_{sec}\ (max)$	0.64 – 0.83	0.69 – 0.98
$t_h \approx t_{F1}$		3.5 – 5.0	5.0 - 9.0

2.2 Specification of Mould Cavity Dimension for Connecting Rod

The design element of a connecting rod is made up of three parts viz; big end, small end and the shank, (Roy (2012), Demidov and Kolchin (1984)).

Tables 2, 3 and 4 show the relative values of the basic design parameters of the three parts of the connecting rod used to establish the mould cavity. It can be seen (Table 2, 3, and 4) that most of the parameters depend on the piston pin diameter (d_p) and the crank pin diameter (d_{cp}) which are the basis of the connecting rod design (Roy (2012), Demidov and Kolchin (1984)). The piston pin diameter (d_p) which is equivalent to the small end inside diameter (id_{se}) of the connecting rod (G-300 Honda Generator) is 16mm. Hence the basis of the design for this connecting rod is 16 mm diameter.

In other to avoid the problem of exceeding or falling below the specified limits, all dimensions are taken as average of relative values in the column for petrol engine (Tables 2 and 4), since G-300 Honda generator uses petrol. Casting allowances such as shrinkage, machining and draft allowances were added to the mould cavity required for the connecting rod. For shrinkage allowance, 6.6 percent of all dimensions were used. The machining allowance provided in the big hole was 3mm and a 1.5^0 draft allowance was used for the mould (Choudhari et al (2013)).

2.3 Estimation of the Small End of the Connecting Rod

From Table 2, piston pin diameter (d_p) ≈ is approximately equal to the small end inside diameter without bushing (id_{se})

$$d_p \approx id_{se} = 16\text{mm}$$

2.3.1 Outside Diameter of the Small End (Od_{se})

(To avoid exceeding or falling below the specified limits, all dimensions are taken as average of relative values).

$$\frac{Od_{se}}{d_p} = \frac{1.15 + 1.90}{2} = 1.525$$

(d_p = 16 mm)

$$Od_{se} = 16 \times 1.15 = 24.4mm$$

2.3.2 Length of Small End (L_{se})

$$\frac{L_{se}}{L_{sec}\,(\max)} = \frac{0.66 + 1.07}{2} = 0.865$$

$L_{se} = 30 \times 0.865 = 25.95mm$ ($L_{sec(max)}$ = 30 mm)

2.3.3 Radial Thickness of End Wall (rt_{ew})

$$\frac{rt_{ew}}{d_p} = \frac{0.19 + 0.30}{2} = 0.245$$

$$rt_{ew} = 16 \times 0.245 = 3.92mm$$

2.3.4 Calculation for the Big End of the Connecting Rod

2.3.4.1 Crank pin diameter (d_{cp})

$$\frac{d_{cp}}{L_{sec}\,(max)} = \frac{0.99+1.02}{2} = 1.005 \qquad \text{(see Table 3)}$$

$$d_{cp} = 30 \times 1.005 = 30.15mm$$

2.3.4.2 Shell wall thickness (t_{sh})

$$\frac{t_{sh}}{d_{cp}} = \frac{0.10+0.17}{2} = 0.135 \qquad \text{(Table 3) } (d_{cp} = 30.15\text{mm})$$

$$t_{sh} = 30.15 \times 0.135 = 4.07mm$$

2.3.4.3 Length of the big end (L_{be})

$$\frac{L_{be}}{d_{cp}} = \frac{0.82+0.99}{2} = 0.905$$

(Table 3)

$$L_{be} = 30 \times 0.905 = 27.15mm$$

2.3.4.4 Distance between connecting rod bolts (D_{cb})

$$\frac{D_{cb}}{d_{cp}} = \frac{1.25+1.45}{2} = 1.35 \text{ (see Table 3)}$$

$$D_{cb} = 30 \times 1.35 = 40.7mm$$

2.3.5 Connecting Rod Shank

The cross-sectional view of the connecting rod (Fig. 2) was used to estimate the shank parameters (see Table 4).

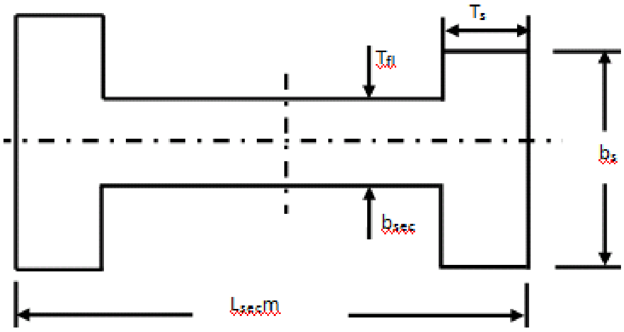


Fig. 2 Sectional view of connecting rod shank

$L_{sec\,(max)}$ = maximum sectional length
b_{sec} = sectional breadth
t_{sh} = shell thickness
t_{fl} = flange thickness
$t_{sh} \approx t_{fl}$ (kolchin and Demidov 1984)

2.3.5.1 Sectional length (L_{sec})

$$\frac{L_{sec}}{Odse} = \frac{0.62+1.07}{2} = 0.845 \quad \text{(see Table 4)}$$

$L_{sec} =$ $24 \times 0.845 = 20.28mm$

2.3.5.2 Maximum sectional length L_{sec} (max)

$$\frac{L_{sec(max)}}{L_{sec}} = \frac{1.01+2.03}{2} = 1.52 \quad \text{(see Table 4)}$$

$L_{sec\,(max)} =$ $20 \times 1.52 = 30.8mm$

2.3.5.3 Sectional breadth (b_{sec})

$$\frac{b_{sec}}{L_{sec(max)}} = \frac{0.64+0.83}{2} = 0.735 \quad \text{(see Table 4)}$$

$b_{sec} =$ $30 \times 0.735 = 22.16mm$

2.3.5.4 Shell thickness (t_{sh})

$$t_{sh} = \frac{3.5+5.0}{2} = 4.25mm \quad \text{(see Table 4)}$$

Shell thickness t_{sh} ≈ Flange thickness t_{fl} (Demidov and Kolchin (1984))

Table 5: Estimation of the small end parameters of the connecting rod

Outside diameter of the small end (Od_{se}) mm	Length of small end (L_{se}) mm	Radial thickness of end wall (rt_{ew}) mm
24.40	30.00	3.92

Table 6: Estimation of the big end parameters of the connecting rod

Crank pin diameter (d_{cp}) mm	Shell wall thickness (t_{sh}) mm	Length of the big end (L_{be}) mm	Distance between connecting rod bolts (D_{cb}) mm
30.15	4.07	27.15	40.70

Table 7: Estimation of connecting rod shank parameters

Sectional length (L_{sec}) mm	Maximum sectional length L_{sec} (max) mm	Sectional breadth (b_{sec}) mm	Shell thickness (t_{sh}) mm
20.28	30.80	22.16	4.25

After the estimation of the design and constructional parameters of the connecting rod and addition of the necessary allowances, the designed and illustration (plan and elevation) of the connecting rod and detailed specification are shown in Figs. 3 and 4 respectively.

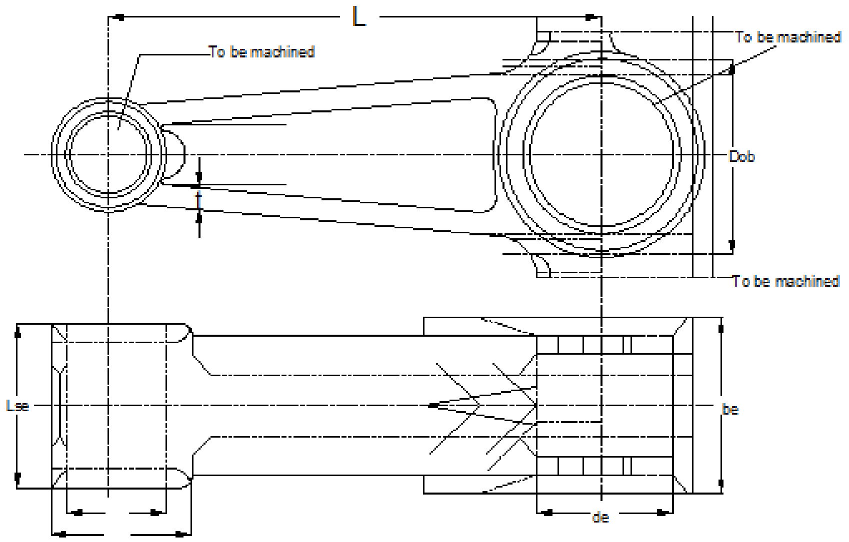


Fig. 3 Design diagram of the connecting rod

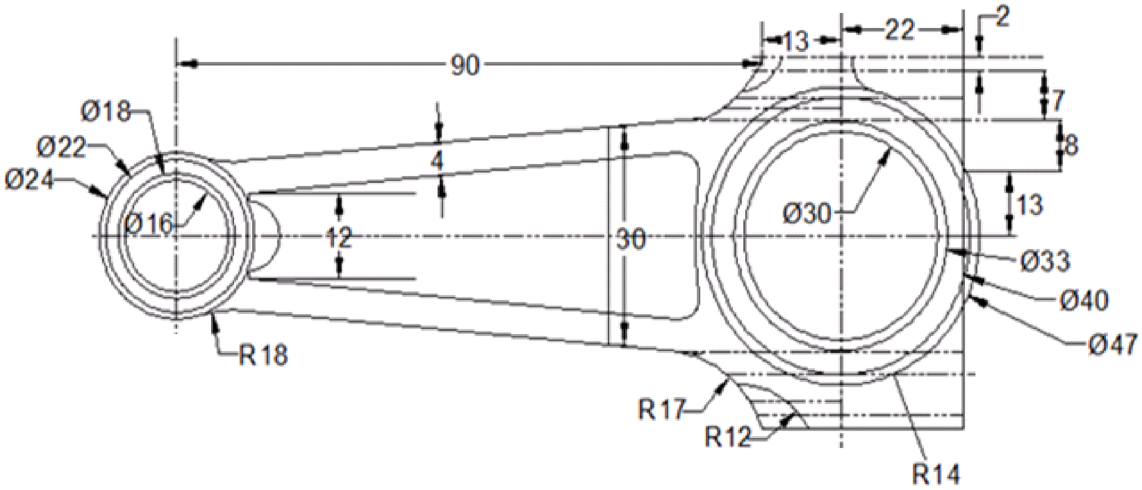


Fig. 4 Connecting rod detailed dimensions specification (mm)

2.4 CASTING PROCEDURE FOR CONNECTING ROD

The mould was preheated to 200^0C by heating it alongside the crucible in the furnance to prevent thermal shock and premature solidification as a result of very fast solidification time which may result in residual stress increase. This heating was maintained until the molten metal was ready for pouring. Just before pouring the molten metal, the mould was closed and the core rod inserted and preheating continues for about 10 minutes. Al-alloy scraps were melted in a pit type coke fired crucible furnace in a foundry shop established for melting aluminum scraps for the production of cooking pot at Panteka market in Kaduna, Kaduna State. The dross was skimmed off the surface of the melt and pouring was done at a temperature of 600^0C using type K thermocouple as quickly as possible. The pouring lip of the pot was held as close as possible to the gate so that the free fall of molten metal is at minimum in order to prevent gas absorption, cascading of the metal and entrapment of air in the metal flowing down the sprue. The metal was allowed to remain in the mould until solidification is completed. Ejections were achieved first by removing the core rod, then the mould de-clamped and die opened. Casting was removed by gently tapping sideways of the upper part of the gating system with hammer. After the trial attempts, three samples of connecting rods were cast alongside with three other similar rods under the same condition to determine the mechanical properties of the cast connecting rods.

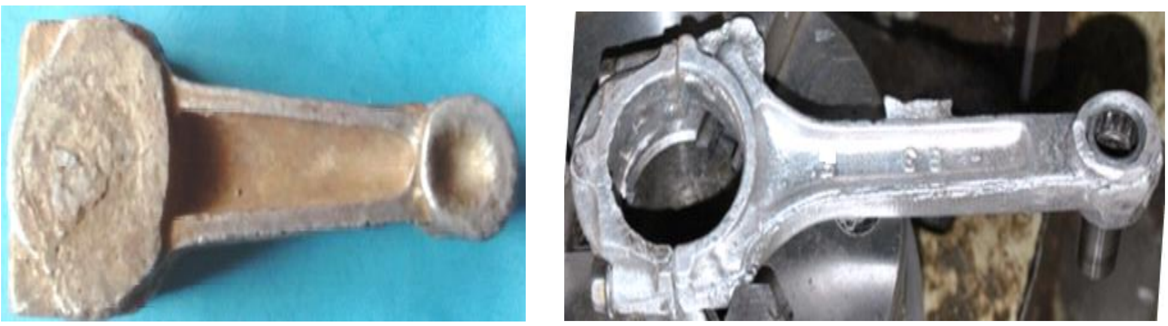
3.0 RESULTS AND DISCUSSIONS

3.1 Production of Connecting Rod

Production of defect free connecting rod was not just at first trial, but sound after series of trials before an accepted product was obtained due to some experimental challenges encounter during production. Four attempts were made with different experimental challenges before the fifth one which produced acceptable connecting rod. However, problem encountered at each attempt prior to the production of accepted product was solved before repeating the production cycle.

The problem faced in the first attempt ranged from difficulty in both core and casting removal from the mould cavity to mould not properly filled and uneven edges of the casting at the parting line. It was noticed that, there was delay in removing the core after pouring the molten metal which made it difficult in removing the core. The problem of inadequate filling of the mould and uneven edges of the sample produced were found to be as a result of improper alignment in the mould components (mould split-halves and the core) and the delay experienced between the removal of the crucible from the furnace and pouring. However these odds were eliminated by positioning the mould components in proper alignment, avoiding unnecessary delay in pouring and ensuring good fluidity by superheating the melt to 700 ^{0}C

In the second attempt, the temperature was monitored and pouring was done at a temperature of 650^0 C. The filling of the mould cavity was satisfactory with the removal of core rod about a minute after pouring. After a while, the mould was opened, unevenness was eliminated but the casting was difficult to remove. It was found that the casting after solidification had clung to some part of the die. It is therefore suggested that the mould should be lubricated and to remove the casting soon after the removal of the core to prevent the contracting casting from clinging to the die cavity. In the third attempt, efforts were made and the problem of the first and the second attempt were eliminated. Ejection of the core followed immediately but unfortunately the casting was still difficult to remove. It was noticed that, the draft provided was not sufficient for easy removal of the casting. However, the draft was further increased before the fourth attempt was carried out. In the fourth attempt, increasing the draft allowance +0.5 ensured smooth ejection of the casting without any challenges. The final stage of connecting rod production is satisfactory. Samples were produced and finishing operations were carried out on lathe and milling machines using end mill cutter, turning and boring tools respectively (see Fig.5). The cleaning was done using grinding machine together with file and emery cloth after which the samples cast for mechanical test were machined to specification and subjected to mechanical properties test.



(a) (b)

Fig. 5(a) and (b) Image of the produced connecting rod. (a) before machining and (b) after machining

(a) (b)

(b) gauge length – 35 mm, diameter – 10 mm, radius of fillet – 6 mm, total length–55 mm

Fig. 6 (a) and (b) Image of the rod samples for tensile test. (a) before machining and (b) after machining

3.2 Mechanical Properties of the Cast Connecting rod

The results of both hardness and tensile properties tests carried out on the cast connecting rod and compared with the original sample (imported) were as presented in the Tables 5 and 6. The hardness of both the cast product and the imported one were determined using Avery Universal Hardness testing machine (ASTM D789) by taking the depth of the indenter on the sample, while the tensile properties of both the imported and the produced connecting rod was carried out on a Monsanto Tensometer Tensile Testing machine with UTM 10584. The tensile properties evaluated are shown in table 9

Table 8 Comparison of Hardness value for produced connecting rod and the imported one

Sample	Hardness value (BHN)
Control Sample A	162.34
Control Sample B	160.51
Product Sample A	138.86
Product Sample B	134.24
Product Sample C	136.28

Table 9 Comparison of Tensile properties for produced connecting rod and the imported one

Tensile Properties	Control Sample		Product Sample		
	Imported A	Imported B	C	D	E
Tensile Strength (Nmm^{-2})	183.39	193.48	168.02	173.12	162.93
Percentage elongation (%)	5.8	5.4	3.9	3.1	4.2
Percentage reduction in area (%)	15.36	11.64	7.8	4.0	11.6
0.1 % Proof stress (Nmm^{-2})	178.21	183.30	162.93	152.75	122.20

Table 8 shows a typical experimental result of the hardness value for both imported and produced connecting rod. Two and three samples each of the imported and produced connecting rods respectively were evaluated for hardness value. The hardness values for imported one vary between 160.51 to 162.34 BHN Compare with the cast product that varies between 134.24, 136.28 to 138.86 BHN. Table 9 was the result of tensile properties of both the imported and locally produced connecting rod. The tensile strength of two imported samples was found to be 188.39 and 193.48 N/mm^2 as compared to three samples of locally produced connecting rod with tensile strength of 168.02, 173.12 and 162.93 N/mm^2. For the percentage elongations, imported sample has an average value of 5.6 % as compared with the locally produced one with average value of 4.55 %. The result of 0.1 % proof stress of two imported samples were found to be little more than that of the locally produced one. The difference in properties of locally produced connecting rod to that of the imported one is presume to be as a result of some factors ranging from the equipment used, impurities that might entrapped into the melt during production resulting into gas porosity which tends to reduce the material strength and difference the manufacturing route. Another factor might still be a result of allowance left on the mould (Ilia et al (2014) which affect the flow of melt into the cavity and as a result affect the solidification profile during solidifying to adversely affect the strength of the produced samples. However these results may be enhanced to compete favourably with imported connecting rod if further metallurgically heat treated via age-hardening, normalizing and solution heat treatment means as submitted by Ilia et al (2014), to compensate for the difference in the properties as observed in the present work to improving the strength of the alloy.

CONCLUSION

The development and performance evaluation of permanent mould for the production of Aluminum alloy connecting rod has been carried out. The analysis of the connecting rod produced was done by determining the hardness, tensile strength, percentage elongation, percentage reduction in area and 0.1 percent proof stress. From the results obtained, it can be concluded that;

1. Connecting rod aluminum scraps can be recycled and converted into useful components such as automobile parts
2. G-300 Honda connecting rod can be produced locally to match the imported ones with improved technical expertise and use of precision equipment couple with post production metallurgical heat treatment.
3. Indigenous foundry technologies can be used to produce some component parts of any sort of engine to serve as a foundation toward advanced technological development.

ACKNOWLEDGEMENT

The authors acknowledge the foundry laboratory technologist (Mr Muhammad Ndagi) for his contributions in ensuring the success of this work especially during casting of the connecting rod and Mr Ilori in strength of material laboratory Unit for samples properties testing.

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