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DEVELOPMENT OF PERMANENT MOULD FOR THE PRODUCTION OF INTERNAL COMBUSTION ENGINE CONNECTING ROD

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ABSTRACT

The great demand for a Honda 125 motorbike for transportation has led to an increased demand for its critical parts production and maintenance. The connecting rod is an integral part of the engine that is responsible for transmitting motion. Aluminium-silicon alloy connecting rods were produced as replacements for imported Honda 125 motor-bike using old Honda 125 piston scraps as charge materials. The casting was done using permanent mould (gravity die-casting) techniques. The permanent mould was designed to accommodate the shrinkage and machining allowance along with a draft angle for easy removal of the cast with minimal damage. Microstructure analysis was carried out on the cast specimen with the result showing that there are sufficient homogenous grain distributions with dendrites within the matrices of the cast connecting rod. Hardness tests were also performed on the prepared samples from the as-cast connecting rod. The maximum brinell hardness number was 107 BHN which is capable of withstanding fatigue stresses generated during operation. The elemental composition of the prepared samples from the as-cast connecting rod showed that the cast connecting rod was made from a hypereutectic aluminium silicon alloy with 5% and 4.89% silicon.

KEYWORDS: Aluminium; Alloy; Honda; Mechanical Properties; Internal Combustion

INTRODUCTION

Automotive industry requirements for quality, productivity and cost efficiency are at a level where a study of the design and manufacturing of a product must occur in the earliest stages of conception (Adi et al., 2018). The connecting rod is an essential part of the compressor and engine which connect the piston to the crankshaft and converts the piston's reciprocating motion into the crankshaft's rotation. The connecting rod must be sufficiently strong to withstand the thrust from the piston during the combustion process as it faces a lot of tensile and compressive loads throughout its life span (Sriharsha & Rao, 2020). The connecting rod consists of a small end, a shank and a big end as shown in Figure 1. The piston is connected to the small end of the connecting rod by a gudgeon pin and the big end of the connecting rod connects to the crankpin on the crankshaft. The big end of some connecting rods is split into two halves so that it can be clamped around the crank journal (Sriharsha & Rao, 2020). The connecting rod's shank can have different cross sections such as circular section, I- section, H- section and rectangular section. With minimum weight, the connecting rod should have sufficient strength; the design of the connecting rod depends upon the speed of the engine. High-speed engines use connecting rod for I-Section and low-speed engines uses connecting rod for circular cross-section (Shubham & Ajay, 2015). Boga et al., (2018) designed and carried out the thermal analysis of the IC engine's connecting rod using different heat conditions. He compared the properties of Carbon Steel with Aluminium Alloy to ascertain the best materials for connecting rod production. The connecting rod is modelled in 3D modelling software known as Solid Works and the thermal analysis was done in a software called ANSYS. Sushil and Ashish (2018) reviewed the design and analysis of the IC engine connecting rod. He compared the strength with fatigue using Aluminium, Aluminium alloy, and Aluminium alloy with titanium coating. Kaliappan et al., (2018) carried out a modal and kinematic analysis of a connecting rod for different materials. They also performed a kinematics analysis and verified their motion characteristics that complied with the standard motion. Different materials and their alloys are being tested and compared to generate the final result to design connecting rods with upgraded material and enhance mechanical properties. Naman (2018) carried out a test on a modern optimized design analysis of the connecting rod of an engine connecting rod. He discussed how the connecting rod connects the reciprocating piston to the rotating crankshaft, transmitting the thrust of the piston to the crankshaft. The most commonly used materials for piston production are cast iron, cast aluminium, forged aluminium, cast steel, and forged steel. The wide usage of Al-Si alloys as piston materials has been attributed to their desirable characteristics such as good thermal conductivity, high strength over weight ratio, high strength at elevated temperatures, excellent castability, and improved wear resistance. Yamagata (2005) discussed “Materials used for connecting rods” The materials used for connecting rods widely vary, including carbon steel, ironbase sintered metal, micro-alloyed steel, spheroidized graphite cast iron. In mass-produced automotive engines, the connecting rods are usually made of steel. Presently, the foundry industry in Nigeria, despite its early start is still in its infancy.

Casting, Forging and powder metallurgy are manufacturing processes used for producing connecting rods. Material used in the production of connecting rods depends on the engine manufacturer and its capacity. The importance of the foundry industry to the economy cannot be overestimated. Several works have been carried out on aluminium alloy sand, die and other casting methods (Li et al., 2004; Karl, 2005; Timelli & Bonollo, 2010; Oji & Pamtoks, 2007; Ejiko et. al., 2009; Ejiko et. al., 2015).

In industrial engines medium carbon steel is used for making connecting rods. Automobile engines use alloy steel connecting rods. Reducing the weight of the connecting rod is one way to reduce the inertia forces on a connecting rod for that aluminium material is being employed. Bending and axial stresses are induced in the connecting rod during engine operation. Fatigue, pin failure, over-revolving, less lubrication, and hydrostatic lock cause the failure of a connecting rod. The big end of the rod is produced as a unit and divided to establish a precision fit around the big end-bearing shell. The connecting rod is under tremendous stress from the reciprocating load represented by the piston, actually stretching and being compressed with every rotation & load increases with the third power with increasing engine speed. Connecting rods, automotive should be lighter and should consume less fuel and at the same time, they should provide comfort & safety to passengers, which unfortunately leads to an increase in the weight of the vehicle. This tendency in vehicle construction led to the invention and implementation of quite new materials which are light and meet design requirements. Lighter connecting rods help to decrease lead caused by inertia force in the engine as it does not require a big balancing weight on the crankshaft. Geometrically it can be seen that a longer connecting rod will reduce the amount of sideway force and therefore lead to longer engine life. Honda Company had already started the manufacturing of aluminium connecting rods reinforced with steel continuous fibres. The connecting rod's weight and design affect the performance of a vehicle. Changing the connecting rod material and changing the connecting rod design can result in variations in weight and stresses induced in it. Lauwagie (2008) stated that automotive industry requirements for quality, productivity and cost efficiency are at a level where the study of the design and manufacturing of a product must occur in the earliest stages of conception. The time spent in trial and error analysis in the design process needs to be eliminated for a manufacturer to remain competitive in a global market. Therefore, a computational method has been used in the early stage of the design. Modal analysis is the process of determining the inherent dynamic characteristics of a system in the form of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behaviour. Best mesh size determination is fundamental in carrying out the analysis of stability and convergence to improve the quality of the mesh (Taubin, 1995). Jacob et al., (2023) carried out a comparative analysis of four different connecting rod materials for an internal combustion engine using the finite element method. Zhang (2013) compared the high-pressure die casting and permanent mould casting of the Al-Si-Cu-Ni-Mg alloy. It was revealed that the cast from the high-pressure die-casting process produced a higher tensile strength after thermal exposure. The improvement of the design and modal updating can be run to determine the effect of the material properties on the dynamic characteristic of the design, this improvement process is called mesh optimization. Experimental Modal Analysis (EMA) for the experiment setup to locate the accelerometer usually correlates with the result of the computational modal analysis (Hoppe, 1993). The work aims to develop a permanent mould for casting an internal combustion engine connecting rods by designing the mould using Ansys & Solid Works, producing the designed mould, producing the connecting rods from the mould, and carrying out mechanical tests on the cast specimen**.** Strain measurement is an important parameter in low-cycle fatigue testing that is used to determine the durability of materials subjected to alternating strains during service, examples include parts of an engine (Ejiko & Olakolegan, 2018; Ejiko et al., 2020). The mould of connecting rod was developed using a lathe, drilling, turning and milling machine. The study is designed to produce a Honda 125 Motorcycle internal combustion engine connecting rod.

MATERIALS AND METHOD

Aluminium steel was selected as the material for the connecting rods. Aluminium steel has a melting of approximately 1220 °F and has a pouring temperature of 1250 °F to 1400 °F, automotive application is typically manufactured by forging from either wrought steel or powdered metal. They could also be cast. However, castings could have blow-holes which are detrimental from durability and fatigue points of view. The fact that forgings produce blow-hole-free and better rods gives them an advantage over cast rods. Between the forging processes, powder forged or drop forged, each process has its pros and cons. Powder metal manufactured blanks have the advantage of being near net shape, reducing material waste. However, the cost of the blank is high due to the high material cost and sophisticated manufacturing techniques. With aluminium alloys, the material is inexpensive and the rough part manufacturing process is cost effective.

The material used for the permanent mould

Mild steel was selected as the material for the mould, Mild steel has a melting point of 1350 ℃ – 1530℃ (2462 °F – 2786 °F) and has a pouring temperature of 2850 °F to 2950 °F. Plate 1: shows the permanent mould for the connecting rod.

In achieving this work, the following processes were carried out which include the design of the connecting rod through dimensioning of the cross-section, in which the cross-section of the shank may be rectangular, circular, tubular, I-section or H-section. A circular section is seldom used while an I-section is preferred for high-speed engines.

Design of the permanent mould

The mould was designed using solid works (AutoCAD), The finishing design of the mould is shown in Figure 2.

Design calculation of the connecting rod

Dimension for mould (70 x 180 x 18)

X + Y + Z

X= dimension of the connecting rod

Y= machining allowance

Z= shrinkage allowance

During the calculation of the connecting rod, Shrinkage and machining allowance for aluminium was added to the length, breadth and diameter of the big and small end bearing, shrinkage allowance for aluminium is 0.0103 while the machining allowance for aluminium is 0.200 as shown in Table 1 to 5.

Determination of the Diameter of the Big End Bearing

The diameter of the big end bearing is calculated using the relation as given;

D_b =D+M+S

where: D_b is the diameter of the big end diameter

M is the machining allowance

S is the shrinkage allowance

L is the overall length

D = 32.00, M = 0.200, S = 0.0103

= 32.5 + 0.200 +0.0103

= 32.71

Determination of the Diameter of the Small End Bearing

The diameter of the big end bearing is calculated using the relation as given;

$$D_S = D + M + S$$

where: D_s is the diameter of the small end diameter

M is the machining allowance

S is the shrinkage allowance

D=12.00, M=0.200, S=0.0103

Ds = 12.00 + 0.200 + 0.0103

=12.2103

Determination of the Volume of the Big End Core

The volume of the core is calculated to determine the amount of molten metals required to form the big end

$$V = \frac{\pi D^2 L}{4} = \frac{3.142 \times 40.5^2 \times 13.71}{4}$$

= 872.32 cm^3

Determination of the Volume of the Small End Core

The volume of the core is calculated to determine the amount of molten metals required to form the small end.

$$V = \frac{\pi D^2 L}{4} = \frac{3.142 \times 18^2 \times 13.71}{4}$$

= 387.69 cm^3

Length of the Connecting Rod

the length of the whole core was calculated using

L = l + M + S

= 13.5 + 0.200 + 0.0103

= 13.7103 cm^3

The production process of the permanent mould

Cutting Operation

This was done by using a cutting machine to cut the mild steel (workpiece) into the desired length and size.

Milling Operation

Mild steel cut into desired length and size was assembled and mounted on lathe machining for milling, where rotary cutters remove materials by advancing a cutter into a workpiece. Plate 2 shows the milling of the mould

Drilling Operation

The mild steel component was held in a lathe machine chuck and several holes were drilled into the mild steel block to produce the cavity for the big end and small end of the connecting rod. Plate 3 shows the half mould with the cavities for the small end of the connecting rod.

Turning Operation

The mild steel of diameter 40 mm was mounted on a lathe machine and the excess metal was parted off; this circular mild steel was meant for the core of the big end core of the rectangular mould used for the connecting rod.

Casting process of the connecting rod

Cleaning of the Scrap

After scrap was gathered it was separated from dirt and impurities that affect the composition during melting using cleaning.

Charging of the Scrap Metal into the Crucible Furnace

Different types of aluminium and steel scrap were selected and put into the crucible furnace and were heated to a maximum temperature of 710 ℃

Slag Removal

The dispersing natural granular perlite on top of the molten metal was removed by slag removal, used to remove impurities in molten aluminium steel in casting.

Preheating of Assembled Mould

The assembled mould was preheated through the evolving heat from the crucible furnace to a temperature of 200 ℃ for easy flow of the molten metal in the die cavity as shown in Plate 5. The pre-heating of the mould helps in reducing casting defects.

Melting of Aluminium Scrap

This is done by changing solid scraps into liquid when heat is applied.

Pouring of molten metals into the assembled mould

The charged molten metal from the crucible furnace was poured into the mould cavity through the sprue and allowed to solidify and ejection of the mould followed immediately after solidification of the molten metal.

Ejection of the cast connecting rod

The cast connecting rod was ejected from the assembled mould after the solidification and cooling of molten metal in the mould. The clamped was unscrewed and the half moulds were separated then the half mould with the connecting rod was placed on a hydraulic press and the cast connecting rod was forced out of the mould.

Fettling of the cast connecting rod

The gating system of the cast connecting rod was removed by cutting with a hack saw and smoothened with a file. The parting line formed on the piston was removed through grinding. After the removal of the excess metal on the connecting rod, it was machined on a lathe machine and the gudgeon pinhole was drilled on the small end of the connecting rod. The finished standard connecting rod is shown in Plate 9.

Mechanical test carried out on the specimen

The mechanical test which includes hardness, microstructure and composite composition was carried out on the specimens through the following tests:

Hardness test

The hardness test was done using the Monsanto Testing Machine. The sample was fixed into the tensiometer where it was subjected to compression of a load of 250 kg for about 15 seconds after which the indented diameter was measured by eye scope. A conversion table was used to know the hardness number of the material, using the following equation 1.

$$BHN = \frac{W}{(\pi D/2)\left(D - \sqrt{D^2 - d^2}\right)} \qquad (1)$$

Where BHN is the Brinell hardness number,
W is a load on indenter in kg,
D is the diameter of the steel ball in mm,
d is the average measured diameter of indentation in mm.

Microstructural test

Metallographic examination

Visual examination is good enough for macro-examination but on the micro-level, there is the need for aided media. The samples under consideration were prepared for micro-examination.

Sample Preparation

This is the primary stage involved in metallographic examination processes. These include grinding, polishing, and etching before final examination under the metallurgical microscope.

Grinding

This operation aims at producing a perfectly flat and smooth surface Silicon carbide papers of different grades placed on the grinding machine were used in the order of 220,320,400 and 600, i.e. from coarse grade to fine grade. The grinding process was done under running water to wash away the grits and also to avoid overheating. The samples were turned through 900 while changing from one grit size to another in the materials laboratory at Afe Babalola University. This is to neutralize the scratching effect of the previous grinding of the former grit size.

Polishing

A universal polishing machine was employed. A polishing cloth (emery cloth) was placed on the polisher for the initial polishing swamped with a solution of one micron of silicon carbide solution, then, followed by the final polishing stage with emery cloth swamped with a solution of 0.5µm Silicon carbide until a mirror-like surface is attainable. It is then washed and dried.

Etching

This is done to reveal the microstructure of the polished surface. Etching is the selective attack on the grain boundaries being a region of high energy and dislocation density. The mirror-like surface was etched in 2% NITAL (2% NITRIC ACID and 98% Ethyl Alcohol) while Sodium hydroxide is for non-ferrous materials Again, it was washed, dried, and later viewed under the metallurgical microscope with magnification 400x and 800x respectively.

RESULTS AND DISCUSSION

The result of hardness is shown in Table 5, which shows Vickers hardness number equivalent to 104 and 89 for Sample A and B respectively, Sample A had the greatest hardness properties. This implies that it can maximally withstand wear better than sample B.

Microstructure test

The microstructure of the test samples for A and B at the magnification of 400x and 800x respectively and the dendritic grain structure and size of the aluminium alloy matrix are shown in Plate 12 and 13. The microstructures of the aluminium silicon alloy cast connecting rod show interdendritic regions in the matrix of the as-cast aluminium silicon alloy. The composite composition of the test samples for A and B were captured in Table 6.

Composite composition test

The chemical analysis was carried out using EDX3600B X-ray fluorescence at Material Science in Obafemi Awolowo University, Ile-Ife, Osun state. The spectrometer applied XRF technology to conduct a fast and accurate analysis of complex composition. The result shown in Table 6 from the machined samples A and B was made from a hypereutectic aluminium silicon alloy with 5 % and 4.89 % silicon respectively. The output of the tested samples was sent to Excel.

CONCLUSIONS AND RECOMMENDATIONS

The Honda 125 motorcycle connecting rod was cast from aluminium silicon alloy connecting rod scraps through permanent mould casting techniques. A mechanical test was conducted on the cast samples to determine the strength of the cast connecting rod. The micro-structural analysis was carried out on the cast specimen. The results from the various tests were analysed. The cast connecting rod from the recycled aluminium scraps has close properties to the original connecting rod hence; connecting scraps can be recycled and used for engineering applications.

It is recommended that pure Al (90.2 % wt) and Ni (0.042 % wt.) should be added to the Al-Si connecting rod scraps (during melting at 730ºC) to bring the nominal composition of the as-cast connecting rod relatively close to that of aluminium alloy and to equally improve the mechanical properties of the piston.

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Table 1: Types of Materials and their Shrinkage Allowance.

Material	**Shrinkage allowance (mm)**
Grey cast iron	0.0105
White cast iron	0.0160 - 0.0230
Plain carbon steel	0.0201
Chromium steel	0.0200
Aluminium	0.0130
Aluminium bronze	0.0200 – 0.0230
Brass	0.0155
Bronze	0.0155 – 0.0220
Copper	0.0160
Lead	0.0260
Magnesium	0.0130

Table 2: Drafting Angles for Different Materials

	Draft angle(deg.)	
Pattern material	**Outer**	**Inner**
Wood	0.25 to 3.00	0.50 to 3.00
Metal	0.35 to 1.50	0.50 to 3.00
Plastic	0.25 to 1.00	0.35 to 2.25

Table 3: Machining Allowance for Different Materials

	Allowance(mm)		
Dimension	Bore	Surface	Cope slide
Cast Iron			
Up to 300	3.0	3.0	5.5
300 to 500	5.0	4.0	6.0
500 to 900	6.0	5.0	6.0
Cast Steel			
Up to 150	3.0	3.0	5.5
150 – 500	6.0	5.5	7.0
500 to 900	7.0	6.0	9.0
Non Ferrous			
Up to 200	2.0	1.5	2.0
200 to 300	2.5	1.5	3.0
300 to 900	3.0	2.5	3.0

Table 4: Dimensions for the connecting rod

Small End	
Parts	**Size (mm)**
Inner diameter	12
Outer diameter	18
Thickness	0.3
Big end	
Inner diameter	32.5
Outer diameter	40.5
Thickness	10
Overall Length	13.5

Table 5: Hardness result of specimen A and B

SAMPLE	TEST 1 HARDNESS(BHN)	TEST 2 HARDNESS (BHN)	AVERAGE (BHN)
A	104	107	105.5
B	86	89	87.5

Table 6: Composite Composition test result

Elements	Sample A (%)	Sample B (%)
Si	5.07	4.89
Fe	1.12	1.95
Cu	1.15	1.08
Mn	0.501	0.590
Mg	0.326	0.288
Cr	0.0307	0.0384
Ni	0.0425	0.0408
Zn	1.12	1.06
Ti	0.0422	0.0485
Ag	0.00069	0.0010
B	0.0016	0.0018
Ba	0.00010	0.00010
Be	0.0011	0.0021
Bi	0.0031	0.0042
Ca	0.00058	0.00073

Cd	0.00059	0.00068
Ce	0.0015	0.0015
Co	0.00050	0.0019
Ga	0.0130	0.0133
Hg	0.00100	0.00100
La	0.00030	0.00030
Li	0.00010	0.0242
Na	0.00010	0.00014
P	0.0039	0.0049
Pb	0.0299	0.0267
Sb	0.0030	0.0030
Sn	0.0105	0.0087
Sr	0.00010	0.00010
V	0.0068	0.0095
Zr	0.0023	0.0120
Al	90.5	89.9

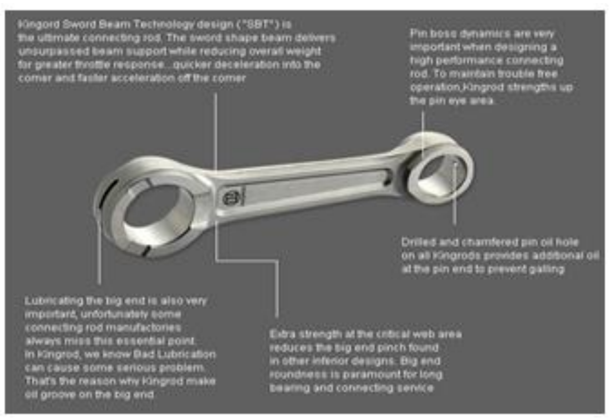

Figure 1. Diagram of Connecting Rod

Figure 2. Design of Permanent Mould Using AutoCAD Software

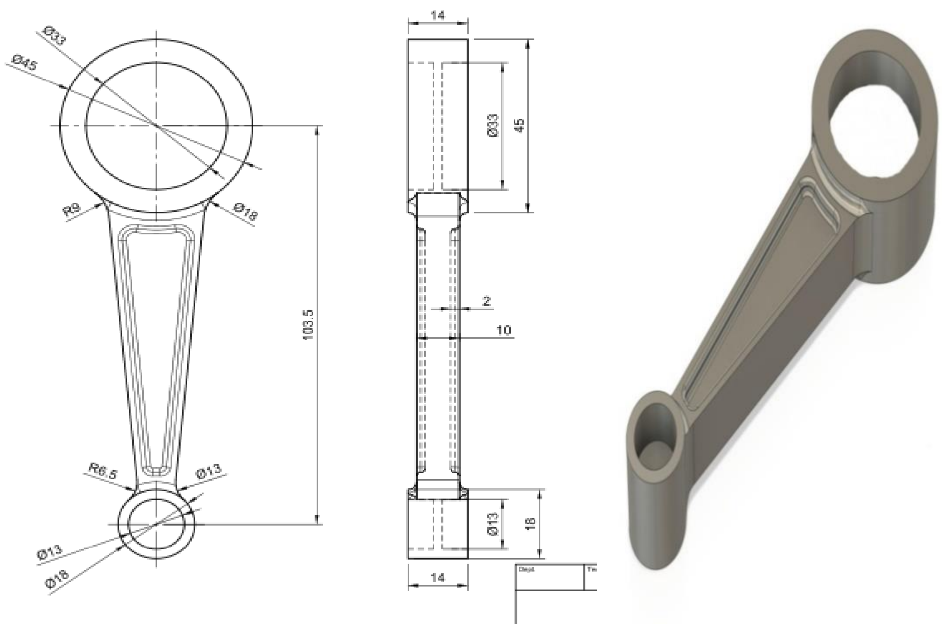

Figure 3. Design of Connecting Rod Using AutoCAD Software

Plate 1. Mould for connecting rod

Plate 2. Milling process

Plate 3. Drilling of holes on mild steel

Plate 4. Turning operation

Plate 5. Preheating of the mould

Plate 6. Scraps of Aluminium and Steel

Plate 7. Pouring of molten metals

Plate 8. Cast connecting rod

Plate 9. Casted specimen for samples A and B

Plate 10: Grinder Machine (Model 900)

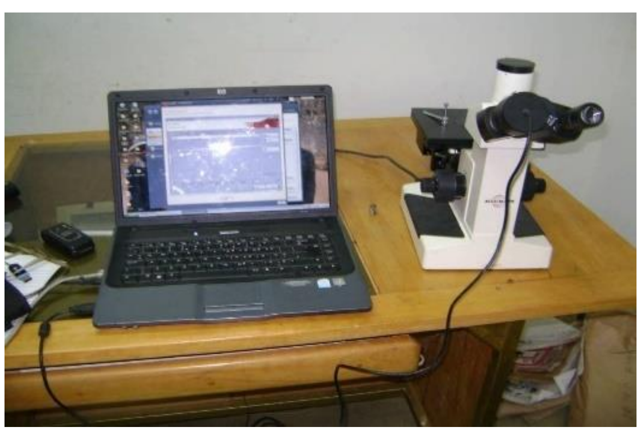

Plate 11. Accuscope miroscope with camera

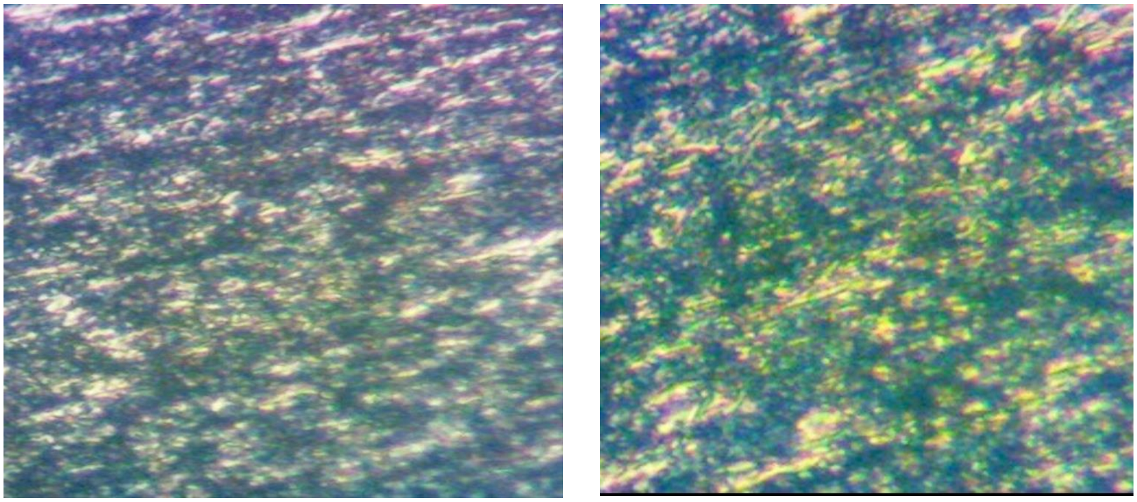

Plate 12. Microstructure result of the cast specimen A

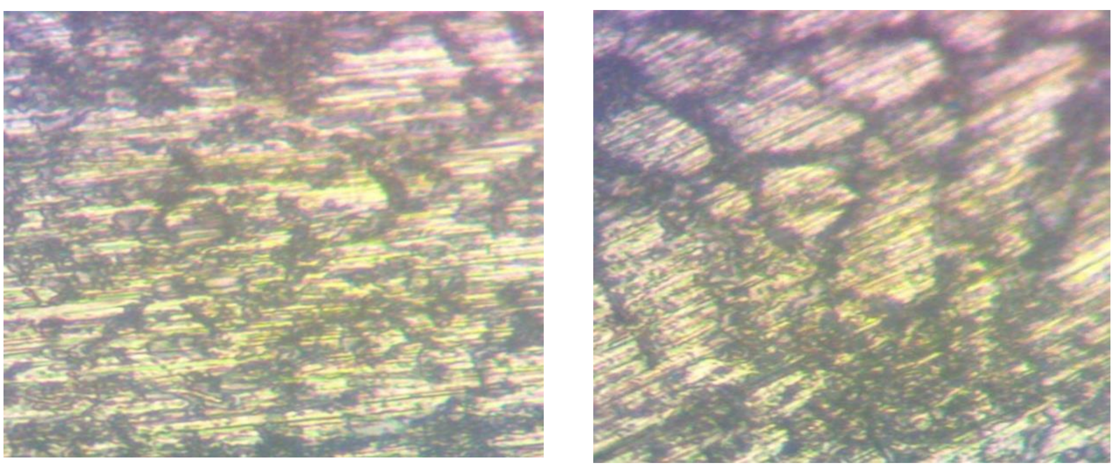

Plate 13. Microstructure result of the cast specimen