DEVELOPMENT OF A PERMANENT MOULD FOR CASTING ALUMINUM PISTON USED IN SUMEC FIRMAN 2.5KVA GENERATOR

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ABSTRACT

There is a huge demand for imported generators due to irregular power supply in Nigeria. This has caused a high demand for generators spare parts especially, piston which soon gets worn out after a reasonable service life. Aluminum is the ideal material for producing internal combustion engine components because of its high strength to weight ratio, good formability, good resistance to corrosion and recycling potential. Aluminum-silicon alloy pistons for Sumec firman 2.5kVA generators were cast using Aluminum scraps as charge materials. The casting was carried out using permanent mould (gravity die-casting) technique. A permanent mold was designed for the piston casting. This implied that the material selected (mild steel) for the mould permitted good thermal dissipation from the molten metal to the core mould. The piston core also facilitated heat transfer from the molten metal to the core as the time increased from 0 sec to 10.5 secs. The surface area of the piston core received the maximum thermal energy (temperature) when the molten Al-Si alloy was poured into the mould at about 1 sec. The piston core also effectively transferred heat. Microstructure analysis showed good homogeneous grain distributions, and chemical analysis confirmed a hypoeutectic Al-Si alloy (13% Si). The cast pistons had a Brinell hardness of 198BHN matching expected value for LM13 alloy and 111 pistons were produced. The process successfully demonstrated the feasibility of recycling aluminum generator pistons for reuse.

Keywords: Generator, Piston, Thermal, Microstructure, casting

1 INTRODUCTION

Hydropower and thermal power plants are Nigeria's principal sources of electricity. According to studies, the majority of Nigerians do not have access to electricity, and those who are linked to the national grid endure frequent power outages [1]. It is self-evident that the country's lack of efficient and effective electricity supply is impeding its development. In reality, there is a strong link between the amount of energy used per person and the style of living [2]. Human development is directly linked to energy access, of which electricity is an important component. One of the United Nations' Sustainable Development Goals (SDGs) is to provide universal access to clean, affordable energy by 2030. The higher a country's per capita energy consumption is the higher its population's standard of living. The country's human development index (HDI) is also affected by this, Nigeria's HDI is currently 0.532, which is low in comparison to developed countries like the United States, Norway, Japan, Spain, and India [3]. Due to Nigeria's inconsistent power supply, imported generators are in high demand. As a result, there is a greater demand for generator spare parts, particularly pistons, which wear out quickly after a respectable service life [4]. A piston is a mechanical device that moves upward to compress gas and downward due to an explosion in a cylinder in order to transform heat energy into mechanical work [5]. A piston follows a cyclical process for the continuation of the heat converting process, this process is achieved in three ways which includes providing heat to the gas inside the cylinder for the useful work; removing heat from the cylinder in order to decrease the pressure, so that the gas can easily be compressed; and applying work to the piston when it's in its initial state, ready to perform the cycle again. Consequently, it operates at high speed to ensure the proper compression of the air-fuel mixture in the combustion chamber, as such must be strong and resistant to heat. So, the continuous use of piston beyond their recommended service life affects their thermal bearing capacity and reduces their abrasive wear resistance. Piston particularly wears out quickly after a respectable service life [6].

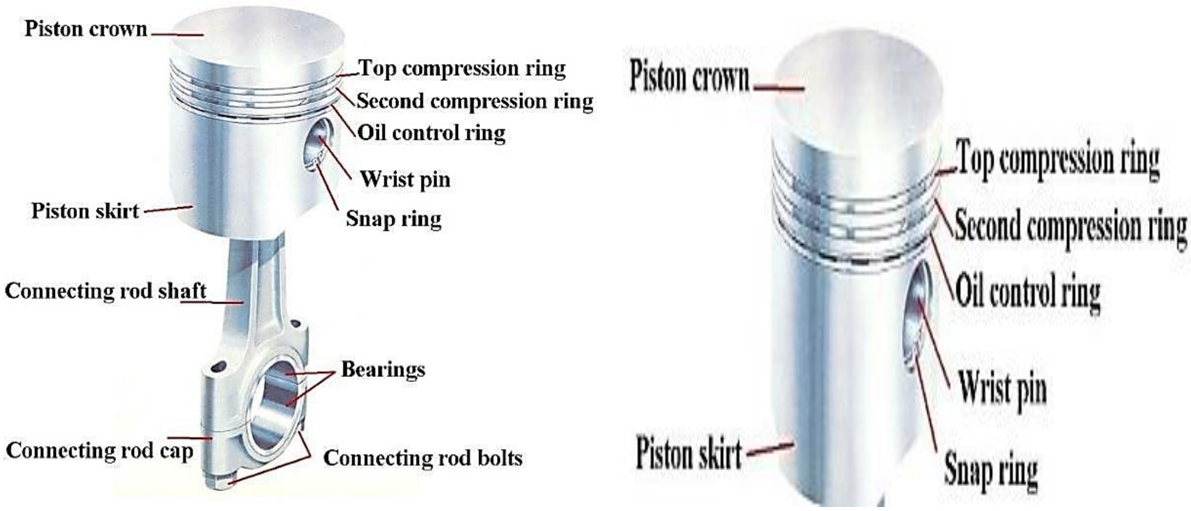


Figure 1. The pistons of an internal combustion engine [6]

Due to the geometric increase in the demand for electric power generators for household and industrial use to commensurate the unbalanced power supply in Nigeria has increased the need and demand for generators spare parts especially piston which soon gets damaged after a reasonable life span as observed by Dahunsi *et al.,* [6]. Therefore, this research addresses the development of a permanent mould for casting aluminum pistons used in generators to enhance the production and availability of aluminum pistons. The developed mould will be compared with existing moulds for casting pistons and test its performance in industrial application and piston manufacturing industries.

2 METHODOLOGY

2.1 Materials Description / Selection

In the fabrication of moulds for casting applications, the selection of suitable mould material is a crucial consideration that depends on factors such as production volume, material cost, thermal performance, and machinability. For medium to high production volumes, the mould material must possess specific properties such as low thermal expansion (for dimensional stability), high yield strength (to resist deformation), high temperature resistance, and good thermal conductivity (for effective heat transfer). Mild steel, classified under standards such as ASTM A36/A36M for carbon structural steel and ISO 630-1:2021 for general structural steel requirements, offers a balance of these properties. It provides adequate strength (≥250 MPa), stability under moderate thermal conditions, and is machinable and weldable, making it ideal for mould applications involving non-ferrous, low melting point alloys like aluminum and zinc. Moreover, mild steel conforms to DIN EN 10025-2:2019, which covers hot-rolled structural steels like S235 and S275, offering both reliability and formability for complex mould geometries. Its thermal expansion coefficient (~11–13 x 10^{-6} /°C) remains within the acceptable range for dimensional control during repeated heating cycles, as referenced in ISO/TR 15608. While it lacks intrinsic corrosion resistance, surface treatments or alloy modifications can enhance its performance, aligning with durability expectations highlighted in ISO 9223. For machinability and fabrication efficiency, ASTM A29/A29M and ISO 683-1:2016 endorse the use of mild and low-alloy steels due to their ease of forming, cutting, and heat treatment response. Hence, the use of mild steel in permanent mould construction is supported by international material standards for achieving durability, process efficiency, and extended mould life in casting operations.

2.2 Fabrication of the Permanent Mould

The fabrication process of the permanent mould involved machining different sections using various machine tools, including the center lathe machine, milling machine, power saw, and drilling machine. The subsequent assembly of the parts was achieved through the use of mechanical fasteners and welding processes. Plate 1 shows the assembly of the different parts of the permanent mould model.

S/N	Part	Description
1	1	Spure
2	1	Core handle
3	2	Mould half
4	5	Rod
5	2	Mould Half
6	1	Clamping Rod

Plate 1. The Permanent Mould Model Assembled

2.2.1 The Sliding Rod

In the fabrication of each of the four sliding rods (Figure 2), a mild steel material with a circular cross-section was utilized. The manufacturing process involved the following steps [4,9]: Mild steel, known for its versatility and durability, was chosen as the material for the sliding rods. The initial rod, having a 20 mm diameter, underwent a stepped turning process to achieve a reduced diameter of 16 mm. This transition occurred over a length of 206 mm, creating a stepped profile on the rod. One end of the rod, extending to a length of 105 mm, was threaded. This involved the creation of helical ridges on the external surface of the rod, providing a threaded section for attachment purposes. The opposite end of the rod underwent milling to form a hexagonal shape. This process involved removing material to create a structure with six flat sides. The across flat (A/F) dimension of the resulting hexagonal shape was specified as 17 mm.

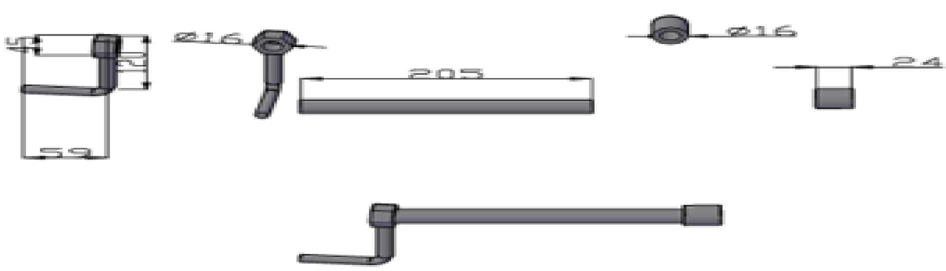


Figure 2. Slide Rod

2.3 The Production of the Piston

The production of the piston involved several crucial casting processes to ensure precision and quality. The following steps were undertaken (Plate 2):

2.3.1 Permanent Mould Coupling

For the production of the piston, Permanent mould coupling was a critical step in bringing together all the components of the Permanent mould. This process involved the strategic use of sliding rods and a clamping bolt [9]: The various members of the permanent mould, including the fixed and movable mould (dies), which were coupled together using sliding rods and a clamping bolt. The clamping bolt, when screwed, facilitated the movement of the movable mould, bringing it into contact with the fixed mould. This coupling mechanism allowed for the precise alignment and closure of the mould, forming the complete cavity necessary for the casting process.

2.3.2 Permanent Mould Preheating

Permanent mould preheating was a crucial preparatory step to optimize the casting process and minimize defects: The assembled mould was subjected to preheating using the heat generated from a crucible furnace. The mould was preheated to a temperature of 200°C. This controlled preheating ensured that the mould reached an optimal temperature for casting. The elevated temperature facilitated the easy flow of molten metal within the mould cavity during the casting process.

2.3.3 Casting of Piston

The charge of molten metal from the furnace was poured into the mould cavity through the sprue and allowed to solidify and ejected after solidification. With the thermocouple, the pouring temperature of the aluminum alloy was measured in the pouring ladle. The means of temperatures at the beginning of the pouring and immediately the pouring was completed were recorded and used as the pouring temperature at 700 -800^{0}C. Solidification of the molten metal was at an average of 30 seconds. The cast product was ejected from the mould by turning the handle of the clamping bolt in an anti- clockwise direction which in turn separated the moveable mould from the fixed mould.

2.3.4 Fettling

The gating system of the cast piston was removed by cutting using hack saw and smoothened with file. The parting line flash formed on the piston was removed through lathe machine. Various holes on the piston such as the gudgeon pin hole, gudgeon pin bosses and the oil ring grooves were drilled with a drilling and grinding machine. The excess metal on the piston was machined on a center machine.

2.4 Methods

2.4.1 Permanent Mould

In addressing the inherent challenges associated with solid shrinkage during the casting's solidification process, meticulous design considerations have been implemented. Solid shrinkage arises from the natural contractions of the casting as the metal cools to room temperature of 200^{0}C. The design acknowledges the solid shrinkage effects in the casting process, particularly in the cooling phase. A shrinkage allowance for 88mm lengths of aluminum-silicon alloy using the shrinkage rate are 0.6% to 0.9% (0.6mm to 0.9mm) while in this design 0.7mm has been adopted. This allowance is strategically incorporated into the dimensions of the mould to compensate for the anticipated shrinkage during the solidification of the molten metal. In addition to addressing solid shrinkage, the design incorporates machining draft allowance to facilitate effective performance during the post-casting machining operations. A machining allowance for 2.0mm, has been integrated into the mould design. This allowance provides the necessary material for subsequent machining processes, ensuring that the final piston can be precisely machined to meet the required dimensional accuracy. Figure 3 shows the dimensions of a standard piston after machining.

Melting process of Aluminum   Fabricated Mould   Pouring of melted Aluminum

Casting process   Cast aluminum Piston   Machined Piston

Drilled Cast Piston

Plate 2. Stages involved in the Casting Process

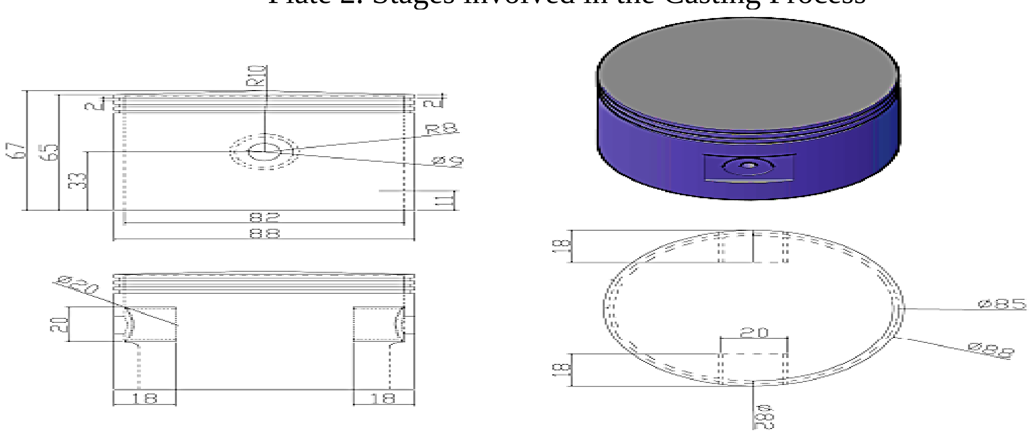


Figure 3. Piston design and dimensions

2.4.2 Calculation for Diameter of the Cavity of the Mould

The external diameter of the 2.5 KVA generator piston is 88mm and the height is 67mm.

$$D_2 = D_1 + M_a + S_a \tag{1}$$

Where; $D_2 =$ is the diameter of the mould cavity, D_1 = is the external diameter of the 2.5 KVA generator piston (given as 88 mm), M_a = is the machining allowance, S_a is the shrinkage allowance.

2.4.3 Calculation for Depth of the Mould Cavity

The depth of the mould cavity was calculated as equation 2.

$$H_2 = H_1 + M_a + S_a \quad (2)$$

Where; $H_2 =$ is the depth of the mould cavity, H_1 = is the is the height of the 2.5 KVA generator piston, M_a = is the machining allowance, $S_a =$ is the shrinkage allowance, $H_2 =$

2.4.4 Determination for Design of the Cavity for the Hardness Test Piece

The solid runner risers in the cast are used as hardness specimens. The length and the diameter for the hardness test piece are 125 mm and 10 mm respectively. The diameter of the test pieces is designed as using equation 3.

$$d_c = d_t + M_a + S_a \quad (3)$$

Where; $d_c =$ is the diameter of the Hardness test piece, d_t = is the specified diameter of the test piece, M_a = is the machining allowance, S_a is the shrinkage allowance.

The length of the test piece is calculated as equation 4.

$$h_c = h_1 + M_a + S_a \quad (4)$$

Where, $h_c =$ is the length of the hardness test piece, h_1 = is the specified length of the test piece, M_a = is the machining allowance, S_a is the shrinkage allowance.

2.5 Piston Core

The diameter of the piston core is 78.0mm and its depth is 66.0mm. Easy removal of the piston core from the cast piston is achieved by the addition of the draft allowance into the design. The draft angle for metal with height between 50.8 – 101.6 to be1ow and for a metal with a length of 66.0mm having a diameter of 78.0mm, the draft allowance was calculated using equation 5.

$$D_a = 2(L * Tan\emptyset) \quad (5)$$

Where, $D_a =$ is the draft allowance, $L =$ is the length of the metal (specified as 66.0 mm), $\emptyset =$ is the draft angle (specified as 1o).

2.5.1 Diameter of the Tapered end of the Piston Core

The diameter of the tapered end of the piston core was calculated as equation 6.

$$D = D_i - D_a \quad (6)$$

Where, $D =$ is the diameter of the tapered end of the piston core, D_i = is the initial diameter of the piston core, $D_a =$ is the draft allowance.

2.5.2 Calculation for Volume of the Cast

The volume of the cast which depends on the size of the product and was calculated using equation 7.

$$V_c = V_{mc} - V_{cc} + V_{rl} + V_{rs} \quad (7)$$

The volume of the sprue V_{rl} is equal to the volume riser V_{rs}. Where: $V_c =$ is the total cast volume, $= V_c \frac{\pi {d_1}^2 l_1}{4}$, $mV_c =$ is the volume of the mould cavity = $\frac{\pi {d_1}^2 l_1}{4}$, V_{cc}= is the volume of the core = $\frac{\pi {d_2}^2 l_2}{4}$, V_{r1}

= is the volume of the sprue = $\frac{\pi {d_3}^2 l_3}{4}$, V_{r2}= is the volume of the riser = $\frac{\pi {d_3}^2 l_3}{4}$, The total volume of cast was determined using equation 8.

$$V_c = \frac{\pi {d_1}^2 l_1}{4} - \frac{\pi {d_2}^2 l_2}{4} + \frac{2(\pi {d_3}^2 l_3)}{4} \quad (8)$$

Where: d_1= is the outside diameter of the piston (91.60mm), l_1= is the height of the piston (70.60 mm), d_2 = is the outside diameter of the core (78mm), l_2 = height of the core (66mm), d_3 = is the diameter of the runner (13.60mm), l_3 = height of the runner (129 mm).

2.5.3 Calculation for Weight of Cast

The weight of the cast which depends on the volume of the cast product was calculated as equation 9.

$$M = p^V \quad (9)$$

Where; M = Mass of the cast; V = Volume of the cast (0.00001865m^3), p = is the density of aluminum alloy (2500kg/ m^3),

2.5.4 Calculation for Feeding and Gating System

To minimize the rate of metal consumption, the modulus of casting was calculated using equation 10 as adopted from Dolar, [7].

$$M_c = \frac{V_c}{A_{cc}} = \left|\frac{A_c \times l_c}{P_c \times l_c}\right| \quad (10)$$

Where: M_c = Modulus of casting; V_c = Volume of casting, A_{cc} = Cooling surface area of casting, A_c = Area of casting, P_c = Perimeter of the cross section of the casting, l_c = Length of casting, P_r = Perimeter of runner, l_r = Height of the runner. The cast cooling surface area is determined using equation 11 adopted from Dolar [7].

$$P_c \times l_c = (\pi d_1 l_1 - \pi d_2 l_2 + 2\pi d_3 \times l_1) \quad (11)$$

$$M_c = \frac{volume\ of\ the\ cast}{cooling\ surface\ area\ of\ the\ cast} \quad (12)$$

2.5.5 Determination of Pouring Time

The pouring time was calculated using equation 13 as adopted from Santhi [8].

$$t = \frac{M_c}{E} \quad (13)$$

Where t = Pouring time (s), M_c = Modulus of casting, $E = Constant = 0.015\ to\ 0.035$

2.5.6 Sprue Diameter for ensuring Flow of Metal

The sprue which direct the molten metal from the pouring basin to the sprue well was calculated using equation 14.

$$A = \frac{G}{c \times p_a \times t\sqrt{2gh}} \quad (14)$$

Where: A = is the choke area (sprue exit area); G = is the casting gross weight = (piston + runner) = 0.0466 kg, c = discharge coefficient =0.4 (for thin wall casting), p_a = density of molten aluminum base alloy = 200 km/m^3, t = time of pouring (1.0s), h = effective height of metal head (128.60mm), g = 9.81m/s^2

2.5.7 The In-Gate Diameter

The in-gate diameter from which the molten moves into the mould cavity was calculated from the relation as given in equation 15 adopted from Anjo and Khan [9].

$$A_{sprue-inlet} = \frac{A_{sprue-exit}\sqrt{H_{sprue-exit}}}{\sqrt{H_{sprue-inlet}}} \quad (15)$$

Where: $A_{sprue-exit}$ = sprue inlet cross-sectional area (7.16mm^2), $A_{sprue-inlet}$ = sprue exit cross-sectional area, $H_{sprue-exit}$ = distance between the ladle and sprue exit (130mm), $H_{sprue-inlet}$ = distance between laden and sprue (20mm). Diameter, of the sprue inlet, D_{inlet} was calculated from the relation.

$$D_{inlet} = \frac{\sqrt{4 \times A_{sprue-inlet}}}{\pi} \quad (16)$$

2.6 Design of the Clamping Bolt

The force required to turn the clamping screw was calculated as equation 17.

$$F = \mu W \quad (17)$$

Where: F = the force required to turn the clamping screw, μ = the coefficient of friction (0.15), W = the weight of mould = 37.28N.

2.6.1 The Bolt Screw Efficiency

The lead screw efficiency was calculated using equation 18.

$$e = \frac{tan\lambda(1-f\ tan\lambda)}{tan\lambda+f} \quad (18)$$

Where: e = lead screw efficiency, λ = helix inclination =30^0, f = coefficient of friction.

2.6.2 Torque required for clapping bolt

The torque required for the clapping of the mould was calculated using equation 19.

$$T_t = T_f + T_a \quad (19)$$

Where: T_t = the total torque required for clamping the bolt, T_t = the frictional torque, T_a = the acceleration torque.

$$T_t = \frac{F}{2\pi Pe} \quad (20)$$

Where F_t = is the force applied, P = the pitch of the thread = 2 mm, e = the lead screw efficiency.

2.6.3 Calculation of Torque for Acceleration

The torque calculation for acceleration is calculated using equation 21.

$$Ta = \frac{1}{g}\left(\frac{J_{total}}{e} + Jleadscrew\right)\frac{\omega}{t} \quad (21)$$

The angular velocity (radian/sec) was calculated using equation 22.

$$\omega = 2\pi PV \quad (22)$$

Where T_a - is the acceleration Torque, ω – is the angular velocity (radian/sec), t – is the time (5 secs), g – is the gravity constant, p – is the pitch of the screw (2mm), v – is the linear velocity (5.5mm/sec).

$$J\,leadscrew = \frac{\pi L\rho R^4}{2} \quad (23)$$

$$J\,Load = \frac{W}{(2\pi P)^2} \quad (24)$$

2.7 The Complete Piston Die to be fabricated

Figure 4 shows the fixed and the movable die with the runner and the riser at both sides. The fixed die is an essential component of the piston die. It is typically the stationary part that provides the shape and structure for the piston during the casting process. This die is designed to withstand high pressures and temperatures associated with the casting of piston components. The movable die complements the fixed die [10]. It is the part of the die that moves or closes onto the fixed die during the casting process. The runner is a channel or passage that connects the pouring basin or sprue to the actual cavity in the die. It serves as a conduit for molten metal to flow from the pouring basin to the mold cavity. The design of the runner is crucial for facilitating the smooth and controlled flow of metal, ensuring that the entire mold cavity is filled uniformly.

3 RESULTS AND DISCUSSION

3.1 Chemical Composition of the Piston

The chemical composition of aluminum alloys used for casting pistons in 2.5 kVA generators is essential in achieving the desired mechanical and thermal properties required for efficient performance. Table 1 outlines the key compositional elements of three common aluminum alloys: Al-Si (hypoeutectic), Al-Si-Cu-Mg, and Al-Si-Cu-Ni alloys. The aluminum (Al) content serves as the base metal, ensuring lightweight properties and excellent thermal conductivity. Silicon (Si), present in varying percentages (7–13%), contributes to the alloy's wear resistance, thermal stability, and castability. Copper (Cu), ranging from <1% to 5%, enhances strength and fatigue resistance, while magnesium (Mg) (0.3–1.2%) improves hardness and corrosion resistance. Nickel (Ni), unique to the Al-Si-Cu-Ni alloy (1–2%), provides high-temperature strength and stability, essential for pistons operating in extreme environments. Trace elements like iron (Fe), manganese (Mn), and zinc (Zn) are kept below 1% to prevent brittleness and maintain ductility. This balanced composition ensures that the pistons exhibit durability, resistance to thermal stresses, and optimal performance in generator engines.

Table 1. Chemical Composition of the piston

Element	Al-Si Alloy (Hypoeutectic)	Al-Si-Cu-Mg Alloy	Al-Si-Cu-Ni Alloy
Aluminum (Al)	Balance	Balance	Balance
Silicon (Si)	10–13%	7–9%	10–12%
Copper (Cu)	<1%	3–5%	1–3%
Magnesium (Mg)	<1%	0.3–0.6%	0.5–1.2%
Nickel (Ni)	-	-	1–2%
Iron (Fe)	<1%	<1%	<1%
Manganese (Mn)	<0.5%	<0.5%	<0.5%
Zinc (Zn)	<0.1%	<0.1%	<0.1%

Table 2. The nominal chemical compositions of cast piston alloys [11]

Alloys	Chemical composition (w/%)									
	Si	Cu	Ni	Mg	Fe	Mn	Cr	Ti	Zr	V	Al
A	13.12	1.11	0.89	0.85	0.59	0.18	0.09	0.07	≈0.03	≈0.01	residue
B	13.05	3.58	1.01	0.90	0.52	0.19	0.09	0.07			
C	12.95	3.91	1.91	1.02	0.42	0.18	0.09	0.07			
D	11.20	5.41	1.90	0.53	0.37	0.25	0.09	0.07			

Table 3 presents the comparison between the experimental Al-Si piston alloy compositions and the nominal chemical compositions reported by Manasijevic [11]. The chemical composition reported by Manasijevic [11] in Table 2 aligns closely with the Al-Si-Cu-Ni alloy group. Both highlight a eutectic or near-eutectic Si content (11-13%), comparable Cu (1-5%), and Ni presence (0.89–1.91%). Manasijevic alloys include more detailed specifications for Fe (0.37–0.59%) and Mg (0.53–1.02%), which influence the mechanical properties and phase distribution critical for high-performance cast pistons.

Table 3. Comparison of Chemical Compositions:

Element	Manasijevic 2013 (wt.%)	Al-Si Alloy (Hypoeutectic)	Al-Si-Cu-Mg Alloy	Al-Si-Cu-Ni Alloy
Silicon (Si)	11.20–13.12	10–13%	7–9%	10–12%
Copper (Cu)	1.11–5.41	<1%	3–5%	1–3%
Nickel (Ni)	0.89–1.91	-	-	1–2%
Magnesium (Mg)	0.53–1.02	<1%	0.3–0.6%	0.5–1.2%
Iron (Fe)	0.37–0.59	<1%	<1%	<1%
Manganese (Mn)	Not Reported	<0.5%	<0.5%	<0.5%
Zinc (Zn)	Not Reported	<0.1%	<0.1%	<0.1%

3.2 Cast Piston

The piston (Plate 4) was manufactured by casting aluminum alloy scrap into the desired shape, followed by precision machining on a lathe machine to achieve the final dimensions and functional features. This process results in a high-performance, sustainable product suitable for use in generator engines. Key features are states are (1) Material: The piston is made from recycled aluminum alloy scrap, emphasizing sustainability while retaining excellent properties such as lightweight, high thermal conductivity, and wear resistance. (2) Casting Process: The raw material was melted and cast using a permanent mold casting technique, which ensures a uniform microstructure and reduces defects such as porosity. (3) Machining on Lathe: Post-casting, the piston was machined on a lathe to achieve, precise dimensions for proper engine compatibility, and smooth surface finish on critical areas like the piston crown, skirt, ring grooves, and connecting pinhole. (4) Features and Quality: The piston demonstrates structural integrity, with a well-refined aluminum matrix and evenly distributed silicon particles and enhanced wear resistance, thermal stability, and durability under engine operating conditions. (5) Sustainability: The use of aluminum scrap reduces environmental waste, making the production eco-friendly while maintaining high-quality standards.

Plate 4. Machined Cast Piston

3.3 Hardness Test

The Hardness Test was conducted at various points on the piston (Table 4). The highest hardness values were found in the thicker sections of the piston, as these areas are more resistant to deformation due to greater material density and structural integrity (Figure 4). The testing was performed using the Leeb

Hardness Tester (Model LM500), a reliable instrument for measuring material hardness by rebound method. However, the hardness values range from 103 HB to 240 HB, reflecting some variation in material properties. This is normal in cast components due to factors such as microstructure, cooling rate, and silicon distribution. The average hardness of 198 HB is consistent with expectations for hypoeutectic Al-Si alloys used in pistons. This indicates good wear resistance and adequate strength for generator applications, while Implications for Application of Pistons with higher hardness values (e.g., 227 HB, 240 HB) may exhibit better wear resistance but could be more brittle and Lower hardness values (e.g., 103 HB) could indicate localized issues like porosity or segregation during casting, which may require process optimization.

Table 4. Hardness Test Results for Cast Aluminum Piston

Test Number	Hardness Value (HB)	Remark
1	228	High hardness
2	178	Moderate hardness
3	227	High hardness
4	240	Maximum observed value
5	199	Near average
6	103	Minimum observed value
7	211	Above average hardness
Average	198	Typical for the material

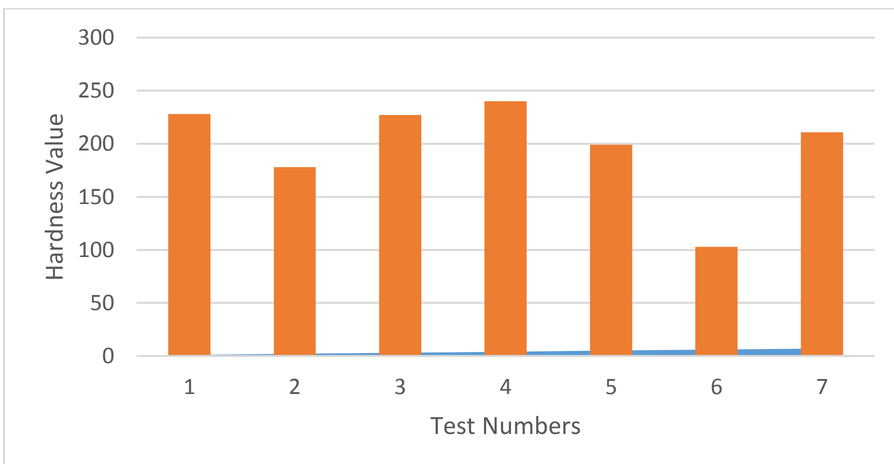


Figure 4. Hardness Test Graph

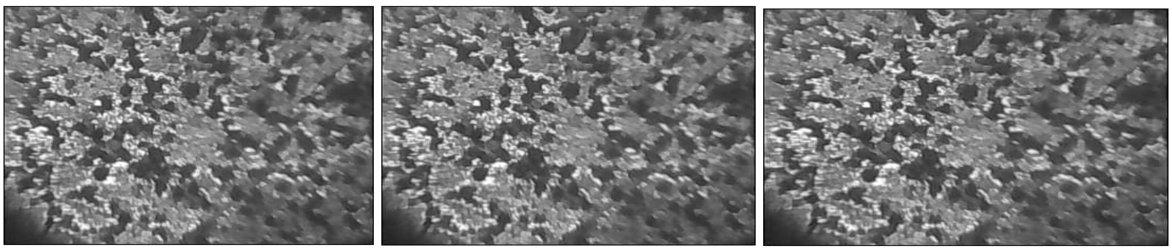
3.4 Microstructure Result of the Cast Piston

The microstructure of the cast specimen was observed under magnifications of A100, A200, and A400, as showed in Figure 2. The dendritic grain structure and grain size of the aluminum alloy are clearly visible. These dendritic formations are characteristic of cast alloys and play a significant role in determining the material's mechanical properties. At lower magnifications (A100), the broader grain structures are evident, while higher magnifications (A200 and A400) revealed finer details within the dendritic arms and the grain boundaries. The observed microstructure indicates uniform solidification, suggesting effective casting conditions. The dendritic structure enhances the strength and hardness of the material while maintaining some ductility, which is crucial for the specimen's performance in mechanical applications. To interpret the microstructure results observed under magnifications A100, A200, and A400 (Plate 5).

Table 5. Interpretation of Microstructure Observations Under Different Magnifications:

Magnification	Observation Focus	Details
A100	Broad view of the microstructure	Identifies primary phases such as the Aluminium maxtrix, large silicon particles, and intermetallic compounds. Detects porosity or inclusions.
A200	Refined view	Evaluates grain size, silicon particles, and distribution, and phase interactions for deeper structural understanding.
A400	Detailed analysis	Examines fine features like eutectic silicon morphology, intermetallic phases, and microsegregation for precise characterization.

Combine these observations to analyze the alloy's solidification behavior, mechanical properties, and suitability for the intended application.



(Specimen sample A100) (Specimen sample A 200) (Specimen sample A 400)

Plate 5. Showing Microstructure of the cast piston Specimen

3.5 Cost of the Study

This study’s expenditure was about 155,000.00 (One Hundred and Fifty-Five Thousand Naira Only) as indicated in the table 6 below;

Table 6. Bill of Engineering Material and Evaluation

S/N	Items	Materials	Size	Qty	Cost (N)
1	U’ Channel	Mild Steel	230x140x50x10mm	1	2,000
2	Round Rod	Mild Steel	θ 10 x 250mm	4	4,000
3	Round Rod	Mild Steel	θ 18 x 200mm	1	3,000
4	Plate Metal	Mild Steel	150 x150 x 10mm	2	3,000
5	Round Rod	Mild Steel	θ 100 x 200mm	1	10,000
6	Piston’s Scrap	Al-Si alloy	950 Watts gen. piston	100 pcs	12,000
7	CO_2 Gas	CO_2 Gas	10kg	10kg	5,000
8	Sodium Silicate	Sodium Silicate	10 Liters	10 Liters	16,000
9	Literature Search				25,000
10	Labour and Logistics				20,000
11	Laboratory Test				25,000
12	Preparation of Reports				10,000
13	Miscellaneous				20,000
	TOTAL				155,000

4 CONCLUSIONS

The following conclusion have been drawn from this research work: The design of the 2.5KVA generator piston was successfully achieved. The fabrication of the piston in (i) above was done. The casting of the piston in (ii) above was achieved and the hardness value obtained 198BHN compared favorably with the existing ones in literature

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