Investigation of Functionally Graded Aluminium A356 Alloy and A356-10%SiC\textsubscript{p} Composite for Hydro Turbine Bucket Application

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**Keywords:** Functionally graded materials; centrifugal casting; A356 alloy; A356-10%SiC\textsubscript{p} composite; Pelton bucket; turbine blade

**Abstract.** The study investigates the application of centrifugal casting process in the production of a complex shape component, Pelton turbine bucket. The bucket materials examined were functionally graded aluminium A356 alloy and A356-10%SiC\textsubscript{p} composite. A permanent mould for the casting of the bucket was designed with a Solidworks software and fabricated by the combination of CNC machining and welding. Oil hardening non-shrinking die steel (OHNS) was chosen for the mould material. The OHNS was heat treated and a hardness of 432 BHN was obtained. The mould was put into use, the buckets of A356 Alloy and A356-10%SiC\textsubscript{p} composite were cast, cut and machined into specimens. Some of the specimens were given T6 heat treatment and the specimens were prepared according to the designed investigations. The micrographs of A356-10%SiC\textsubscript{p} composite shows more concentration of SiC\textsubscript{p} particles at the inner periphery of the bucket. The maximum hardness of As-Cast A356 and A356-10%SiC\textsubscript{p} composite were 60 BRN and 95 BRN respectively, recorded at the inner periphery of the bucket. And these values appreciated to 98BRN and 122BRN for A356 alloy and A356-10%SiC\textsubscript{p} composite respectively after heat treatment. The prediction curves of the ultimate tensile stress and yield tensile stress show the same trend as the hardness curves.

**Introduction**

The study focuses on the wear and strength properties enhancement of A356 aluminium alloy and A356-10%SiC\textsubscript{p} composite, exploring manufacturing process (casting) and heat treatment process for Pelton bucket production. The use of locally sourced materials for SHP hydro turbine components and their manufacturing technologies, is very crucial to energy provision and sustainability in sub-Saharan Africa (SSA). Domestication of SHP technology, is the key to the perennial rural electrification problems in the region. To effectively tackle the perennial power in Sub Sahara Africa (SSA), the electricity generation and distribution technologies should be domesticated in the region. This will ensure that challenges as regards to high cost of power project, duration of project execution, installation, operation, maintenance and repair and downtime will be tackled and sustained. Several authors and energy research organisations see small and micro power system of renewable energy are the best option for rural and off grid areas in SSA [1, 2]. It therefore, imperative for countries of SSA to develop small and micro renewable energy system for her economic gains.

Technical capacities building for hydro turbine components and system; design, material selection and manufacturing should be promoted through regional joint effort, academic research, exchange programme with the developed countries, etc. [3]. The capacity building, should be such that will increase local participation in SHP technology domestication in the region. SSA with a lot of untapped SHP potentials as presented in Table 1, needs to explore merits of SHP for greater access to power [4].
Table 1: SHP potential in SSA [4]

<table>
<thead>
<tr>
<th>Regions in SSA</th>
<th>Available SHP potential (MW)</th>
<th>Installed capacity (MW)</th>
<th>Installed capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Africa</td>
<td>6,262</td>
<td>209</td>
<td>3.3</td>
</tr>
<tr>
<td>Middle Africa</td>
<td>328</td>
<td>76</td>
<td>23.1</td>
</tr>
<tr>
<td>South Africa</td>
<td>384.5</td>
<td>43</td>
<td>11.2</td>
</tr>
<tr>
<td>West Africa</td>
<td>742.5</td>
<td>82</td>
<td>11.1</td>
</tr>
</tbody>
</table>

**Review**

Loice and Ignatio investigated the effects of material, surface texture and fabrication methods on efficiency of hydro power plant within an acceptable cost range. The study concluded that manufacturing of more efficient financially viable Pelton turbines for SHP is possible. In their project, more electricity was generated at a reduced cost per unit kW [5]. A theoretical micro-hydroelectric plant design for off grid applications was carried out to produce a green power for remote farms or cottage. A prototype of the system was built to test the design [6].

A study on the modelling and validation of results empirically, using locally available materials was carried out in Kenyan [7]. In the study, 14.2 % stress reduction was achieved by modifying the profile of the Pelton bucket. A recycled A356 aluminium alloy, was found to withstand stress of 150Mpa, produced by the generated 5 kW power [7]. A Pelton turbine was designed and manufactured for Pico Pelton turbine, using chopped glass fibres reinforced epoxy matrix composite as the bucket material [8]. A 50,000 litres capacity storage tank in a 10 storey tower was used as a water source to operate the turbine. In the study, 1.5 kW was generated out the 2.793 kW that was theoretically designed for. In the design study of Nava and Siva, CATIA V5 design and modelling software was used to designed and optimised Pelton turbine considering three materials in the analysis [9]. Efficient and stress in relation with the number of buckets were studied in the work. In the three bucket materials selected (steel, cast iron and fibre glass reinforced plastic matrix), the study concluded that fibre glass reinforced plastic matrix shows exceptional performance compared to cast iron. However, there are striking limitation in that are associated with the use fibre reinforced composite. It requires depth expertise, most of the material constituents are imported, and forms solid waste it is damage as most cases recycling and decomposition are not possible. A lot of theoretical design work of hydro turbine have been studied. However, only few is known of the use of aluminium alloys and their composites for the fabrication of Pelton turbine bucket. Present applications of aluminium alloys and their composites, hypothetically suggest that aluminium alloys and composites are promising materials for Pelton turbine bucket and turbine blade fabrication.

**Application of A356 alloy and A356-SiCp composite suitability for Pelton turbine bucket**

Previous studies of hydro turbine plants, revealed that silt erosion affects the underwater components greatly which include turbine blade [10-12]. In some cases, water is stored in a reservoir or in a settling basin to be used when the need arises. Over a period of time, sediments that includes silts and hard abrasive sand settle at the bottom of the reservoir or basin. This problem must be taken care of by sediment settling systems in power plants. However, a lot of unsettled sediment still pass through the turbine every year and the turbine runner is therefore, exposed to severe erosion wear. This sediments are often prevented from go through the turbine by incorporating sediment settling systems in the power plant. However, there are still possibilities of unsettled sediment passing through the turbine and this occurrence causes serious erosion to the nozzle system and the turbine runner. The parts that are vulnerable to silt erosion are bucket/blade, faceplates and seal rings. Studies have shown that, silt erosion menace is more severe during the raining season [12, 13].
The effects of erosion on turbine depends on certain water and turbine material factors. The factors include water flow velocity and discharge, water salt concentration, silt quantity and size, and wear and corrosion resistance, hardness and strength of the turbine material. To effectively guide against turbine failure and to enhance its life span, the design consideration of these features is vital. However, wear and corrosion resistance enhancement of the turbine blade can be achieved through manufacturing method. This attribute improvement helps the blade to withstand the effect of the water salt concentration, and the moving unsettled silt and hard abrasive sand.

**Metal Reaction in Environment**

Presently, hydro turbine blades are made from metals and they show three types of behaviour when immersed in the environment: Immune behaviour, active behaviour and passive behaviour as shown in Fig 1 [14]. The noble metals like gold, silver and platinum show immune behaviour as they do not react with the environment and therefore, no corrosion. A metal is said to have an active behaviour when it corrodes in a solution and forms soluble, non-protective corrosion product. This active behaviour is associated with higher weight loss of the metal and example is mild steel immersion in NaCl solution (seawater). In the third behaviour, the metal corrodes in a solution, but forms an insoluble protective film that makes it to have a passive state. Passive films are different from paints for coating as some people hold. Sodium, potassium, and magnesium are active in almost all aqueous media. Titanium and tantalum are passive nearly in all aqueous environments. Aluminium and zinc are passive in some media, but are very active metals and show active character in many environments.

![Fig 1: Three metal characters in an environment [14]](image)

Seawater is the most corrodent natural medium where metals are commonly used and its composition has corrosive reagents, halides (NaCl and MgCl₂). The compositional content of seawater depends on geographical location and varies over a wide range, however, the salt content of World Ocean is approximately constant, about 3.1% [15, 16]. The world seas salt compositions are shown in table 2.

<table>
<thead>
<tr>
<th>Oceans</th>
<th>salt content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic Ocean</td>
<td>3.5–3.8</td>
</tr>
<tr>
<td>Pacific Ocean</td>
<td>3.4–3.7</td>
</tr>
<tr>
<td>Mediterranean Sea</td>
<td>3.7–3.9</td>
</tr>
<tr>
<td>Red Sea</td>
<td>4.1</td>
</tr>
<tr>
<td>Sea of Azov</td>
<td>0.9–1.2</td>
</tr>
<tr>
<td>Baltic Sea</td>
<td>0.2–0.45</td>
</tr>
<tr>
<td>White Sea</td>
<td>1.9–3.3</td>
</tr>
<tr>
<td>Caspian Sea</td>
<td>1.0–1.5</td>
</tr>
<tr>
<td>Black Sea</td>
<td>1.7–1.85</td>
</tr>
<tr>
<td>Rivers</td>
<td>0.01–0.05</td>
</tr>
</tbody>
</table>

Aluminum alloys susceptibility to corrosion are reasonably differ, as a result, aluminum alloys can be categorised into two groups, according to their seawater corrosion resistance:
i. High corrosion resistance alloys but vulnerable to pitting corrosion
ii. Alloys vulnerable to intergranular corrosion (IGC) exfoliation corrosion (EC) and corrosion cracking (CC) the structural corrosion types.

Empirically, conducting laboratory corrosion test with traditional seawater is not always accurate due to the effects of other impurities apart from chlorides in seawater. Table 3 presents other impurities in seawater. The impurities affect structural corrosion types (EC, IGC and CC) susceptibility of metal.

Table 3: The standard seawater composition [17-19]

<table>
<thead>
<tr>
<th>Salts</th>
<th>g/l water</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>27.2</td>
<td>77.8</td>
</tr>
<tr>
<td>MgCl$_2$</td>
<td>3.8</td>
<td>10.9</td>
</tr>
<tr>
<td>MgSO$_4$</td>
<td>1.7</td>
<td>4.7</td>
</tr>
<tr>
<td>CaSO$_4$</td>
<td>1.2</td>
<td>3.6</td>
</tr>
<tr>
<td>K$_2$SO$_4$</td>
<td>0.9</td>
<td>2.5</td>
</tr>
<tr>
<td>CaCO$_3$</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>MgBr$_2$</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Totally</strong></td>
<td><strong>35</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

The Al-Si cast alloys and their composites, are known for superior properties like corrosion and wear resistance, high strength, low thermal coefficient, excellent castability, etc. This has make them relevant materials for number of applications in airspace and other engineering industries. Various methods are used to develop and improve the properties of Al-Si cast alloys and composites. These properties are depended on microstructure of the matrix, and the size, shape, type and volume of reinforcement in the matrix. Wear resistance and other mechanical properties are function of the hardness of the second phase particles in the matrix [20, 21].

**Functionally graded manufacturing technique: Centrifugal casting technique**

Centrifugal casting technique was chosen due to its mechanical and microstructural enhancing advantages. The process aids microstructure gradient and improve hardness of alloys even without reinforcement and therefore, gives the material a better wear and corrosion resistance [22]. The mechanical properties of aluminium–silicon alloys are often improved by casting technology [23]. Quite often, hypoeutectic and near eutectic Al-Si alloys are applied when corrosion resistance and good castability are needed and with little quantity of Mg and Cu for heat treatment enhancement. It has been revealed that centrifugal can increase: rupture strain by 160% and rupture strength by 35%; young modulus by18% and; fatigue life by 1.5% [24].

**Methodology of the Study**

The study is divided into two parts: manufacturing of Pelton turbine bucket by centrifugal casting technique and; characterisation of Pelton turbine bucket materials.

**Manufacturing of Pelton turbine bucket**

The fabrication of Pelton turbine bucket has two stages: Production of permenat mould and; centrifugal casting of the Pelton bucket. The 3D model of the bucket is shown in Fig 2. In this study, the bucket was designed for a capacity of 18.45kW turbine power.
Production of Mould. The mould was designed with Solidworks software where the IGES files of the mould components were generated. Computer numerical control (CNC) machining centre was used to machine the components of the permanent mould. The computer aided design (CAD) drawing of the mould as designed and as produced are shown in Fig 3(a) and (b) respectively.

Fig 3: a) Exploded diagram of the Pelton bucket mould as designed; b) Exploded diagram of the Pelton bucket mould as fabricated
Mould Material. Oil Hardening Non Shrinking Die Steel (OHNS) was used as the mould material and the components were heated treated before they were put to use. The chemical composition is shown in Table 4. OHNS steel is a reliable material for gauging, blanking and cutting tools as well as for hardness and elevated temperature performance [25]. The hardening temperature used was 800 °C and had a hardness of about 432 of Brinell 3000Kgf standard. The fabricated Pelton bucket mould components are shown in Fig 4.

Table 4: Chemical composition of the OHNS material used for the Pelton bucket mould.

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Mn</th>
<th>Cr</th>
<th>W</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>0.95</td>
<td>1.1</td>
<td>0.6</td>
<td>0.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Fig 4: The fabricated Pelton bucket mould components

Centrifugal Casting of Pelton Bucket. The functionally graded materials (FGMs), A356 alloy and A356-10%SiC_p are under investigation. The chemical composition of A356 used is shown in Table 5.

Table 5: A356 alloy chemical composition

<table>
<thead>
<tr>
<th>Elements</th>
<th>Cu</th>
<th>Mg</th>
<th>Mn</th>
<th>Si</th>
<th>Fe</th>
<th>Ti</th>
<th>Zn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
<td>7.5</td>
<td>0.35</td>
<td>0.05</td>
<td>0.10</td>
<td>91.10</td>
</tr>
</tbody>
</table>

Casting of A356 Alloy. Clay graphite crucible was used to process the alloy. Hexachloroethane was applied at 720 °C for degassing of the molten metal to prevent hydrogen entrapment. The molten metal was superheated to 750 °C, above its Liquidus temperature. The liquid metal was then poured into a spinning Pelton bucket mould (centrifugal casting) and a stationary rectangular mould (gravity casting). The moulds were preheated to 300 °C and the Pelton bucket mould was rotated at 1500 RPM during pouring and solidification. The rotation was stopped 5 minutes after pouring.

Casting of A356-10%SiC_p Composite. The same melting conditions for A356 alloy as stated above, were followed for the casting of A356-10%SiC_p composite. The 25 µm SiC particle was preheated to 600 °C before inserting it into the A356 molten and the mixture was stirred with electric motor driven impeller at a speed of 300 RPM. The particle feed rate to the molten metal is about 1gm/s and the mixture was stirred 15 minutes more after the particle addition.

In the mould configuration, it is designed to produce castings in one operation. The arrangement is such that the faces are in the same direction as depicted in Fig 5.
Preparation of test specimen

Microstructure Examination. The cast bucket of both materials under investigation were sliced at the middle (plan X-X, see Fig 6a) into two parts and both halves were prepared for microstructural examination and hardness test. The samples for the microstructural view were polished using the following grades of grit emery papers of 80, 100, 320, 400, 600 and 1000 consecutively. The emery paper polishing was followed by cloth polishing with 6 μm, 3 μm and 1 μm SiC_p particle pastes. The prepared samples for microstructural examination are shown in Fig 6. The polished sample was subjected to Leica optical microscopy for transverse viewing as shown by the arrow in Fig 6d and capturing.

Hardness Test. The second half of the sample was prepared for Brinell hardness test and was only subjected to polishing using grades of grit emery papers of 80, 100, 320, 400, 600 and 1000 respectively. The specimens for hardness test are shown in Fig 7. The polished sample was subjected to 62.5Kgf load of Tinus Olsen hardness test machine transversely as shown by the dots in Fig 7b.
Heat Treatment. The solution heat treatment (T6), is the most widely used for the improvement of the combination of strength and ductility. A356 alloy test sample was treated according to T6 heat treatment standard for A356 alloy for hardness, strength and ductility enhancement. The specimen was heated to 540 °C and held for 4 hours and quenching in a water of 65 °C temperature according to earlier studies [26, 27]. Artificial aging was carried out at 165 °C for 6 hours and the process profile is shown in Fig 8. A356-10%SiCp composite specimen was heated to 520 °C, held for 8 hours and quenching in a water of 80 °C temperature. The artificial aging was done at 160 °C and held for 20 hours [28]. The heat treatment process for A356-10%SiCp is represented in Fig 9. Quenching was done in accordance with the B-917 ASTM standard, with the cooling from 400 °C to 260 °C and the quenching delay time was less than 10 seconds. These precaution measures were necessary to prevent the formation of premature precipitate.

Results and Discussion

Casting of Pelton bucket by centrifugal process

The first few castings shown the same defect as the one shown in Fig 10a. The defect was caused by the centrifugal force effect on the cast bucket. This was a major challenge in this study. Several attempts were made by changing the process variables before a good cast was made. In centrifugal casting, there is the tendency of the surface of the cast, towards the centre of rotation, to form a parabola of revolution as depicted in the schematic in Fig 10b.
Fig 10: a) a defected cast caused by centrifuge; b) schematic of the effect of centrifuge cast

The curve formed is a function of these parameters: the rotational speed; the cast geometry and; pouring and mould temperatures. In this work, the defect was corrected significantly by geometry and Fig 11 shows the defect free Pelton bucket cast.

Fig 11: The defect free Pelton bucket cast

**Microstructural examination**

The micrograph of buckets 1 and 2 is shown in Fig 12. It was observed that the two buckets have the same gradient trend. However, the trend in 2 was in opposite direction of 1. For the purpose of the operational performance of the bucket, especially for wear resistance, bucket 1 arrange in Fig 5 is preferred. Figs 12 and 13 show the pattern of microstructure gradient of the alloy and composite respectively used in bucket 1.

Fig 12: The micrograph the gradient of cast bucket 1 of A356 alloy.
Effect of T6 heat treatment and centrifugal casting technique on hardness

A356 alloy, which has Al-7.5% Si-0.3Mg is widely used in engineering industries like automotive, aerospace and military applications for high strength parts. It offers good combination of mechanical properties such as castability, strength, corrosion resistance and pressure tightness in both the permanent mould and sand cast condition. Despite these attributes, in most cases, A356 alloy is not used as-cast, as the presence of eutectic silicon causes it to perform below optimal value. Generally, mechanical properties of aluminium alloys and composites are reduced by coarse grain, cavities and needle shape eutectic silicon. Modification and refinement improve the mechanical properties of alloy such as tensile strength, impact strength, wear resistance and hardness significantly [29, 30]. Rapid solidification, vibration, heat treatment and chemical treatment are the basic methods of manipulating the morphology of an alloy for properties enhancement. In chemical treatment, small amount of sodium is added to the melt and this changes the eutectic silicon phase morphology from coarse acicular to fine fibrous. The process results in enhancement of mechanical property. [31-33].

Centrifugal Casting. The large dendritic cells, large flakes of silicon and large inter-dendrite arm spacing of α-aluminum dendrites that are produced by low solidification rate. These morphological features need to be refined and modified for the alloy to possess better mechanical properties. High solidification rate gives small dendritic cells, small inter-dendrite arm spacing and small flakes of silicon and morphologically changed from acicular to fibrous [34]. Centrifugal casting influences the rate of solidification and consequently enhances the quality of casting.

The rate at which centrifuge affects the microstructure of an alloy is speed of rotation depended. Studies have shown that the optimum centrifugal is between 1200-1500 RPM [34, 35]. At the speed of 1500 RPM, the microstructure of the bucket experiences the following: transformation of large primary silicon into needle shaped eutectic silicon in the inner; long needle-shaped eutectic silicon are converted into fine primary silicon at the outer and; there is the formation of fine grain. The transformations and the high rate of solidification, enhanced the hardness value of both A356 alloy and A356-10%SiC\textsubscript{p} composite. This transformation is evidently pronounced in Fig 14: Long needle-shaped eutectic silicon are seen broken into fine primary silicon at the outer of the bucket; while at the inner, large primary silicon are being converted into needle-shaped eutectic silicon. The maximum hardness of 60 BRN was recorded at 5 mm from the surface of the inner part of the bucket and 55 BRN was recorded at the outer region as show in Fig 16.
Heat Treatment. The heat treatment of A356 can be classified into three, based on soaking temperatures: Soaking at high temperature of $560^\circ$C [26, 27]; soaking temperature slightly below the eutectic temperature, $540^\circ$C [36-38] and; soaking temperature at $500^\circ$C. Quite often, hypoeutectic and near eutectic Al-Si alloys are applied when corrosion resistance and good castability are needed and with little quantity of Mg and Cu for heat treatment enhancement. In certain heat treatment conditions, as in the case T6 treatment of A356, precipitation of Mg$_2$Si and that of silicon occur [31]. The micrograph of the microstructure examination of T6 treated A356 is shown in Fig 15.

The hardness of both alloy and composite samples increased appreciably after the heat treatment. Maximum hardness (98 BRN and 122 BRN for alloy and composite respectively) were recorded at about 5 mm from the inner face in both samples. Lower hardness values were recorded, at 3 mm from the inner surface in all the samples. This is due to the rapid solidification at the inner periphery caused by fast cooling facilitated by the mould rotation.

The increase the hardness observed is due to supersaturated solid solution production that occurred during the soaking of A356 alloy at $540^\circ$C for 4 hours. This process causes the dissolution of hardening elements (Mg$_2$Si) in the matrix into globular primary $\alpha$-Al, spheroidisation of eutectic silicon and casting homogenisation [10, 11, 39]. Fig 16 shows hardness trends in the samples.
Fig 16: Brinell micro-hardness plot for a) A356 alloy as-cast and heat treated and; b) A356-10%SiC as cast and heat treated.

Where AC = as-cast A356 alloy; A-HT = A356 alloy heat treated; AC-C = As-cast A356-10%SiC composite; C-HT = A356-10%SiC composite heat treated

The dissolution of Mg$_2$Si, Spheroidisation and homogenisation of eutectic silicon in A356, happen within 5 minutes of soaking at 540°C. The diagram of the Pseudo-binary of Al-Mg$_2$Si phase is shown in Fig 17.

Fig 17: Pseudo-binary of Al-Mg$_2$Si phase diagram

Yield strength (YS) and Ultimate tensile strength (UTS) predictions

The strength of A356-T6 and A356-SiC-T6 can be predicted using this relation in equation (1) [11]:

$$YS = 3.03 \times VHN \times (0.055)^n$$

Where YS - yield strength, VHN – Vickers hardness number and; n - strain hardening exponent (0.091). The YS and UTS prediction curves for the samples are shown in Figs 18, 19 and 20.
Fig 18: Yield strength prediction of a) A356 as cast (YS_AC-A) and heat treated (YS_AC-HT) and b) A356-SiCp as cast (YS_A-C) and heat treated (YS_C-HT)

Fig 19: Yield strength prediction of a) A356 as cast (YS_AC-A) and A356-SiCp as cast (YS_A-C) and b) A356 heat treated (YS_A-HT) and A356-SiCp heat treated (YS_C-HT)

Again, YS-UTS ratio, can be predicted in terms of n, using the expressions (2) and (3):

\[
\frac{YS_{0.2\%}}{UTS} = \left(\frac{(0.002)^n (exp \ n)}{(n)^n}\right)
\]

(2)

\[
UTS = \frac{YS_{0.2\%}}{(0.002)^n (exp \ n)}
\]

(3)
Fig 20: UTS prediction of heat treated a) A356 (UTS_A-HT) and A356-SiC_p (UTS_C-HT)

From Figs 18-20, it was observed that, the YS and UTS, appreciated greatly across the surface for both A356 alloy and A356-SiC_p composite after heat treatment.

Protective Coating of Pelton Bucket

Despite the wear and corrosion resistance of A356 alloy and A356-SiCp composite, they are still very much susceptible to seawater corrosion and silt erosion over time. For better operation performance and longer life span, coating the inner surface of the bucket with tougher and hardened material is recommendable. Coating Pelton bucket with ceramic is will be effective due to the provision of the following protective service to the surface of the bucket: Wear and corrosion protection; impingement protection, silt erosion protection and surface hardness improvement. This study recommends ceramic coating of Al_2O_3 implanted Fe micrograins, and microarc oxidation (MAO) or plasma electrolytic oxidation (PEO).

Conclusion

Domestication of SHP technologies was noted as a significant way of reliably tackling rural electrification problems in SSA and the use of FGMs production technique was considered vital. In engineering sectors, such as aerospace, automotive and energy, FGMs play a vital role in ensuring that the desired attributes of components as regards their functionality are achieved. The needed operational properties of parts have pushed the material engineers and scientists to develop different FGMs production methods. This study, therefore, exploits the FGMs production method to enhance locally sourced aluminium alloy for Pelton hydro turbine bucket production. However, the cost of production, complexity of technique, and mass production of parts are some of the major barriers to the application of these fabrication techniques. This notwithstanding, centrifugal casting technique was identified as a simple and cost-effective process that enhances the mechanical properties of aluminium alloys and composites. This study then concludes that:

i. To genuinely turn around the perennial power issues in SSA, power should be generated from the abundant small hydro potentials with the application of indigenous technology and made from locally sourced materials.

ii. Use of centrifugal casting method and heat treatment improved the mechanical properties of A356 alloy and A356-SiC_p composite, making them more suitable for Pelton bucket production.

iii. Heat treated A356 alloy and A356-SiC_p composite, will be suitable for turbine materials for water storage turbine system. This is due to minimal % of silt in the stored water and the enhanced corrosion and wear resistance property of the materials.

iv. To further improve the life span of bucket, hard surface coating should be applied.
Acknowledgement

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References


