Hardness and Elastic Modulus of Al-Based Composite Developed from Aluminium Piston Scaps Using Alumina and Snail Shell as Reinforcements

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Abstract- This paper presents the relationship between Young’s modulus and hardness of composites developed from recycled aluminium pistons reinforced with alumina and snails. The percentages of alumina and snailshells were kept within the range of 0-30 and 0-10 wt.%, respectively. Experiments were designed using response surface methodology (RSM) to evaluate the influence of the reinforcements on the tensile, hardness and Young’s modulus of the composites. The theoretical hardness was analysed from the ratio of indentation hardness to indentation modulus while the Young’s modulus was evaluated from the composite equations. The results indicate that an increased fraction of the hybrid reinforcement does not necessarily translate to higher hardness value and Young’s modulus. The sample with the best characteristics has a tensile strength of 172.5 MPa, modulus of resilience of 28.28 GPa and hardness value of 44.9 RH. The average experimental Young’s modulus of the samples is about 30% of the theoretical value of 86.5 GPa while experimental hardness value of 44.90 is about twice that of the theoretical value. The discrepancy between the experimental and theoretical modulus is due to the assumption of a perfect crystal for the former as against polycrystalline crystals. The two samples with highest modulus of resilience were chosen and further characterized. Scanning Electron Microscope images showed that fillers in the two samples were well bonded with the aluminium matrix.

Keywords- Mechanical Properties, Casting, Aluminium composite, Alumina and Snailshells

1 INTRODUCTION

Aluminium alloy composites have been extensively studied because of their excellent combination of mechanical properties including high specific strength, stiffness and thermal conductivities. The unique combination of these properties makes them versatile, economically attractive for a broad range of applications including automobile and aerospace industries (Das, 2004; Kainer, 2006; Davies, 2001; Totten & Mackenzie, 2003; Veeresh et al., 2011) among others. Aluminium composites belong to metal-matrix composite (MMC) materials in which properties of metals such as ductility, toughness, electrical and thermal conductivity are combined with high strength and high modulus of ceramic to produce superior materials for varieties of industrial applications (Das, 2004). The properties of the resulting MMC strongly depend on the matrix material and the fraction of the added reinforcements (Kainer, 2006; Davies, 2001; Totten & Mackenzie, 2003; Veeresh et al., 2011; Dipti et al., 2014; Yu & Lee, 2000).

Alumina (Al2O3) is a ceramic material used as a reinforcement in aluminium due to its high strength, stiffness, good thermal conductivity, and good wear resistance. Alumina is an oxide of aluminium alloy with 99.96% of alumina, 0.01% of iron, 0.01% of silicon, 0.005% of zinc, and 0.003% of magnesium (Dipti et al., 2014; Yu & Lee, 2000). Snailshells, being a non-biodegradable and non-consumable animal by-product, have been listed as one of the worst environmental problems. Snailshells can be used as a low-cost reinforcement in metal matrix composites due to the significant presence of biomaterial containing 97.5 wt% of calcium carbonate in the form of aragonite, calcite and 2.5 wt% of other elements including calcium phosphate, calcium silicate, magnesium oxide, iron oxide, manganese oxide, sodium and potassium. It can also be used for different application like treatment of wastewater from food industries, production of activated carbon for water filter and manufacturing of button, jewel and art collection (Atuanya et al., 2015; Udeozor & Evbuomwan, 2014; Gumus & Okpeku, 2015; Srinivaskannan & Abu-Baker, 2004; Brunt et al., 1999; Jato et al., 2010). Among several mechanical properties of composites, hardness and modulus of elasticity are usually considered as of top priority. While hardness is associated with resistance of material to surface penetration, elastic modulus is a measure of resistance to deformation. This implies that Young’s modulus and hardness deal with elasticity and plasticity of material, respectively (Tabor, 2000; Sakai, 1993; Sakai, 1999). The ratio of these properties is a measure of material toughness, an important consideration in engineering material. Hardness is a pointer to strength and in combination with toughness of brittle material (Tabor, 2000; Sakai, 1993; Sakai, 1999; Sakai et al., 1999; Cheng & Cheng 1998; Labonte et al., 2017). Furthermore, the relationship between hardness and elastic modulus of composites can be modelled for predictive purposes. This can significantly reduce number of required experiments and ultimately lowers cost. Olawuni et al., (2020) modelled the relationship between experimental and theoretical hardness and elastic modulus of aluminium reinforced with zirconium diboride and snailshells. It was found that theoretical Young’s moduli were higher than experimental Young’s moduli by a factor of 2.4 - 3.9. This is attributed to the fact that theoretical moduli were calculated from single crystals while experimental samples are largely polycrystalline with unknown number of crystal defects. Currently, no study has been reported on the relationship between experimental and theoretical hardness and elastic modulus of materials developed from aluminium reinforced with alumina and snailshells. Alumina and snailshells are used as composite to improve mechanical properties of piston (Dipti et al., 2014; Yu & Lee, 2000; Gumus & Okpeku, 2015). This paper therefore presents

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the comparison of experimental and theoretical modulus and hardness of aluminium reinforced with alumina and snailshells.

2 MATERIALS AND METHODS

2.1 MATERIAL PREPARATION

Scraps of aluminium pistons made by BAJAJ extra NIKKO (Japan standard technology model BAJAJ 100 size standard) were collected from different auto-mechanic workshops in Ogbomoso, South-West Nigeria. Only BAJAJ pistons were used to ensure uniformity of properties. The pistons were cleaned of dirt/impurities by means of organic solvent and liquid detergent. They were melted in a local hearth oil-fired furnace and prepared as melt (molten alloy) (Olawuni et al., 2020; Olawuni et al., 2018; Olawuni, Durowoju, Asafa, & Mudashiru, 2018). Elemental composition was conducted with Energy Dispersive X-ray fluorescence (EDXRF, Malvern Pan Analytical, Netherlands). African giant snailshells (Achatina achatina) were collected from a dump site in Ogbomoso, and were grounded to 150 µm particle sizes after sun-drying (Jato et al., 2010; Olawuni et al., 2020; Olawuni et al., 2018; Olawuni, Durowoju, Asafa, & Mudashiru, 2018). Alumina (Al2O3) was purchased from local markets, and was used as ceramic material due to its ability to retain mechanical strength at high temperature (Dipti et al., 2014; Yu & Lee, 2000; Olawuni, Durowoju, Asafa, & Mudashiru, 2018).

The piston melts between 660°C and 700°C. Based on D-optimal technique (DOT), which is a component of mixture design of experiment (Olawuni et al., 2018), different fractions of alumina and snailshells (reinforcements) were added to the molten aluminium at temperature of 700±5°C according to the experimental design (Table 1) and stirred rigorously for almost 5 min and then poured into pre-heated moulds (Olawuni et al., 2018). To ensure uniform mixing of the melt and reinforcements, the furnace temperature was later raised to 1200°C while dross was later removed prior to pouring. Since the furnace was tightly covered, evaporation of samples was minimized. These procedures were repeated for all the samples with varying fraction of aluminium, alumina and snailshells. Stir cast technique was used because it is cost effective. The mould was preheated to avoid sudden solidification of the cast samples (Olawuni et al., 2020; Olawuni et al., 2018; Olawuni, Durowoju, Asafa, & Mudashiru, 2018).

2.2 EXPERIMENTAL DESIGN AND OPTIMIZATION

The D-optimal technique of response surface methodology (RSM) (Olawuni et al., 2020; Olawuni et al., 2018; Olawuni, Durowoju, Asafa, & Mudashiru, 2018; Asafa et al., 2015) was deployed for experimental and optimization purpose. It enables a designer to determine both individual and interaction effect of several factors that could affect design output. Response surface methodology is used to reduce the number of experimental runs needed to provide enough information for statistically acceptable result (Asafa et al., 2015). The modified samples contained aluminium, alumina and snailshell arranged in 11 experimental runs in addition to the control sample which is the molten aluminium (Table 1). The fractions of alumina were varied between 0-30 wt.% while snailshells compositions ranged from 0-20 wt.%.

2.3 SAMPLE PREPARATION

Rods (15 mm diameter and 300 mm long) were cast from the melt, cleaned, and checked for casting defects. They were then machined into different specifications required for tensile and hardness tests as well as composition and microstructure analyses (Olawuni et al., 2018; Olawuni, Durowoju, Asafa, & Mudashiru, 2018).

2.4 MECHANICAL TESTING

Eleven rods were machined for hardness and tensile tests. The hardness test was conducted on Rockwell hardness machine of HR15N with diamond indenter (West port corporation) following ASTM E18 standard. The samples were placed under a preliminary load by load selector with a diamond indenter of 1.58 mm diameter. The hardness results were estimated from the mean value of the four closest measurements. Tensile test was performed on universal testing machine (Shanghai Hualong Cooperation) following ASTM E8 standard.

2.5 THEORETICAL YOUNG’S MODULUS CALCULATION

The theoretical Young’s modulus was calculated based on the rule of mixture (Cheng & Cheng, 1998) which accounts for the lower (L) and upper limit (u).

\[
E_C(u) = E_m V_m + E_{Al} V_{Al} + E_s V_s 
\]

(1)

\[
E_C(L) = \frac{E_m E_{Al} E_s}{V_m E_s + V_{Al} E_m + V_s E_m E_{Al}} 
\]

(2)

Where E, V, C, M, and S denote elastic modulus, weight fraction of the components, composite, matrix, alumina and snailshell, respectively (Olawuni et al., 2020; Callister, 2007). The elastic modulus of snailshells, aluminium, and alumina are 50, 69 and 215 GPa, respectively (Prakash & Arun, 2013; Gumus & Okpeku, 2015).

2.6 CORRELATION BETWEEN THEORETICAL HARDNESS AND THEORETICAL YOUNG’S MODULUS

According to Labonte et al. (2017), true resistance to plastic deformation, H, depends on the ratio of indentation hardness to indentation modulus. Indentation hardness is proportional to indentation modulus with a proportionality constant of 0.05. True hardness or theoretical hardness is estimated from equation 3.

\[
H_i = 0.046E_i^{1.05} H_i
\]

(3)

\[
H = \frac{H_i}{\left(1-H_i^2/2\tan(\beta)^2\right)}
\]

(4)

Where H, H, E, and ß represent indentation hardness, true hardness, indentation modulus, equivalent cone angle of indenter (usually 19.7°), respectively (Sakai 1999; Labonte et al., 2017; Olawuni et al., 2020).
2.7 Further Characterization

To obtain more information about the samples with best combination of mechanical properties, microstructural analyses were conducted using scanning electron microscopy (Phenom Prox Phenom World, Netherland) while crystalline information was obtained from PAN analytical BV X-ray Diffraction machine (Netherland). Spectral were matched with the mineral phases using XPert Highscore Plus.

Table 1. Experimental Runs obtained from D-optimal Technique

| Run   | Sample code | Al wt.% | Alumina wt.% | SS wt.% |
|-------|-------------|---------|--------------|---------|
| 1     | Sample 1    | 80.00   | 10.00        | 10.00   |
| 2     | Sample 2    | 72.50   | 22.50        | 5.00    |
| 3     | Sample 3    | 75.00   | 15.00        | 10.00   |
| 4     | Sample 4    | 70.00   | 10.00        | 20.00   |
| 5     | Sample 5    | 80.00   | 0.00         | 20.00   |
| 6     | Sample 6    | 80.00   | 20.00        | 0.00    |
| 7     | Sample 7    | 75.00   | 20.00        | 5.00    |
| 8     | Sample 8    | 75.00   | 5.00         | 20.00   |
| 9     | Sample 9    | 70.00   | 30.00        | 0.00    |
| 10    | Sample 10   | 70.00   | 20.00        | 10.00   |
| 11    | Sample 11   | 75.00   | 10.00        | 15.00   |
| 12    | Control     | 100.0   | 0.00         | 0.00    |

3 Results and Discussion

3.1 Tensile Strength and Rockwell Hardness Value for Aluminium Reinforced with Alumina and Snailshells

Figure 1a displays the stress and strain curves of the aluminium melt reinforced with alumina and snailshells while the summary of the mechanical properties is provided in Table 2. Accordingly, samples 7 and 9 have the highest modulus of resilience (52.6 and 56.1 GPa, respectively) which is probably due to the high composition of alumina (20 and 30 wt.%, respectively) and low fraction of snailshells (5 and 0 wt.%, respectively). The respective results of sample 7 and 9 are significantly greater than unreinforced sample (20.08 GPa). However, in relation to sample 2 and 10 that have 22.5 wt.% alumina with 5 wt.% snailshells and 20 wt.% alumina with 10 wt.% snailshells could be associated with the variation in stress and strain of samples made with the same material in which the deformation is not strictly elastic (Sakai 1993; Sakai, 1999).

More so, increase in strain rate results in an increase in Young’s modulus. The defect such as porosity and microcracks in samples can also be responsible for the variation in their modulus. Sample 9 has ultimate tensile strength of 172.52 MPa and strain of 0.61% making it less ductile than sample 7 which has ultimate tensile strength of 165.51 MPa and 0.68% strain. The ultimate tensile strength and strain rate of both sample 7 and 9 are also higher than unreinforced sample (103.49 MPa and 0.388%). This indicates that addition of 5 wt.% snailshells enhanced resilience and ductility while higher alumina content improved interfacial strength (Shen et al., 2001; Olawumi et al., 2020). In addition, incorporating 10 wt.% snailshells into sample 10 raised the tensile strength from 128.22 MPa for sample 6 (with the same alumina fraction but zero snailshells) to 159.56 MPa. This compliments the fact that addition of two fillers/reinforcements improve mechanical properties more than a single filler. This is largely due to the synergy between alumina which offers high strength (Dipti et al., 2014; Yu & Lee, 2000) and snailshells of high modulus (Genevive et al., 2011; Asafa et al., 2015). The maximum tensile strength of 172.5 MPa obtained from sample 9 is higher than 161.1 MPa reported for aluminium based composite reinforced with zirconium diboride and snailshells (Olawumi et al., 2020).

The average Rockwell hardness values are also shown in Table 2. As indicated, sample 7 which was reinforced with 5 wt.% snailshells has hardness value of 41.2 RHN and modulus of resilience of 56.1 GPa while sample 2 with similar fraction of snailshells has higher hardness value of 51.2 RHN but a lower modulus of resilience of 25.8 GPa. This implies that the higher value of alumina in sample 2 enhances hardness of the composite because the hardness of Al₂O₃ is significantly higher than pure aluminium thereby hinders the movement of dislocation during deformation (Parvin & Rahimian, 2012). The hardening property of snailshells is attributed to its elemental composition which are CaCO₃, C and SiO₂ (Patricio et al., 2007). The optimal hardness value of 51.2 RHN is lower than the highest value of 56.2 RHN reported for aluminium based composite reinforced with zirconium diboride and snailshells (Olawumi et al., 2020).

3.2. Theoretical and Experimental Hardness with Elastic Modulus of Alumina Reinforced with Alumina and Snailshells

According to Table 2, sample 2 has the highest experimental and theoretical hardness. These values vary with the composition of the composites even at similar value of piston fraction. For instance, sample 3 and 11 have 75 wt.% pistons scraps but varied proportions of aluminium and snail shells. The experimental and theoretical hardness values of sample 3 (45.50 RHN and 18.28 GPa) are greater than for sample 11 (39.42 RHN and 17.24 GPa) indicating that alumina contributes to the hardness more than the snailshells (Parvin & Rahimian, 2012). This trend however differs for sample 7 and 8 where experimental hardness value reduced with increased Al composition.

According to Table 2, theoretical Young’s moduli are higher than those of experimental moduli. The correlation between theoretical modulus to theoretical hardness from Table 2 (Figure 1b) is approximately 1 (R² = 0.999) which is similar to a recent study on aluminium melt reinforced with zirconium diboride and snailshells (Olawumi et al., 2020). The theoretical hardness increases with increased theoretical modulus with a constant ratio of hardness to elastic modulus (H/E) of 0.25 as similarly reported elsewhere (Olawumi et al., 2020; Gibb et al., 2008).
Table 2. Mechanical Test of Aluminium Based Composite Reinforced with Alumina and Snailshells

| Specimen | Wt. % DP | Wt. % Al | Wt. % SS | Wt. % Stress (MPa) | Strain Yield Strength (MPa) | Exp Young's Modulus (GPa) | Theoretical Modulus of Resilience (GPa) | Exp Brandts Hardness (GPa) | Theoretical Hardness (GPa) | Ratio of Brandts Hardness to Young’s Modulus (H/E) | Ratio of Theoretical Hardness to Young’s Modulus (H/E) |
|----------|---------|---------|---------|-------------------|--------------------------|--------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------------------|---------------------------------|
| Sample 1 | 80      | 10      | 10      | 139.004           | 0.62                     | 78                       | 22.420                        | 71.127                        | 43.091                        | 48.204                          | 17.002                          |
| Sample 2 | 72.5    | 22.5    | 5       | 112.361           | 0.46                     | 62                       | 24.426                        | 66.552                        | 25.843                        | 51.290                          | 21.700                          |
| Sample 3 | 75      | 15      | 10      | 112.266           | 0.44                     | 84                       | 25.315                        | 73.707                        | 24.608                        | 45.496                          | 18.283                          |
| Sample 4 | 70      | 10      | 20      | 153.477           | 0.56                     | 105                      | 27.407                        | 68.446                        | 42.973                        | 39.664                          | 16.896                          |
| Sample 5 | 80      | 0       | 20      | 156.400           | 0.57                     | 140                      | 27.438                        | 64.126                        | 44.574                        | 43.060                          | 15.763                          |
| Sample 6 | 80      | 20      | 0       | 128.217           | 0.47                     | 70                       | 27.280                        | 79.844                        | 30.131                        | 47.842                          | 19.909                          |
| Sample 7 | 75      | 20      | 5       | 165.509           | 0.68                     | 118                      | 24.414                        | 78.126                        | 56.108                        | 41.194                          | 19.453                          |
| Sample 8 | 75      | 5       | 20      | 30.941            | 0.77                     | 55                       | 4.020                         | 66.216                        | 11.881                        | 47.250                          | 16.310                          |
| Sample 9 | 70      | 30      | 0       | 172.521           | 0.61                     | 140                      | 28.282                        | 66.653                        | 52.619                        | 44.900                          | 21.722                          |
| Sample 10 | 70    | 20     | 10      | 159.559          | 0.63                     | 130                      | 25.407                        | 76.481                        | 59.101                        | 40.760                          | 19.017                          |
| Sample 11 | 75   | 10     | 15      | 49.706           | 0.35                     | 8                        | 14.202                        | 69.761                        | 8.699                         | 39.422                          | 17.342                          |
| Unreinforced | 100 | 0      | 0       | 103.497          | 0.388                    | 00                      | 26.675                        | 60.000                        | 20.078                        | 31.122                          | 17.042                          |

Fig. 1: (a) Stress-strain curves (b) theoretical modulus and theoretical hardness curves for the reinforced Samples

Fig. 2: SEM Micrograph of Aluminium Reinforced with (a) 20wt% Al + 5wt% Snailshells (sample 7) (b) 30wt% Al + 0% Snailshells (sample 9) (c) SEM of Unreinforced Sample (100 wt.%Al)

Table 3. Composition (wt.%) of Aluminium Reinforced Alumina and Snailshells

| Elements | Si   | Al   | Ca   | Ti   | Mn   | Fe   | Cu   | Zn   | V    | Cr   | Sb   | As   | Pb   |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Unreinforced sample | 0.28 | 98.32 | 0.036 | 0.031 | 0.108 | 0.297 | 0.643 | 0.13  | 0.0014 | 0.0035 | 0.038 | 0.001 | 0.014 |
| Sample 7  | 0.25 | 98.10 | 0.048 | 0.034 | 0.11  | 0.32  | 0.74  | 0.17  | 0.003  | 0.0087 | 0.095 | 0.001 | 0.016 |
| Sample 9  | 0.30 | 98.60 | 0.038 | 0.022 | 0.133 | 0.307 | 0.614 | 0.098 | 0.0038 | 0.0055 | 0.049 | 0.002 | 0.016 |
A discrepancy of 57.6% was also reported between experimental (38.1 GPa) and theoretical (68.9 GPa) value of Young’s modulus by Nikita et al., (2013) and AMS Material Data Sheet. This was associated with the fact that theoretical Young’s modulus was calculated based on the assumption of a single crystal while a realistic assumption is to consider polycrystalline grains. Most samples were polycrystalline with lot of grains thereby decreasing their strengths relative to pure single crystal metal or ceramics (Nikita et al., 2013; ASM Material Data Sheets).

It is also noticed in Table 2 that the combined fraction of the reinforcements (but different fraction of each of alumina and snailshells) produced different results as observed in sample 5 (0 wt.% AL, 20 wt.% SS) and sample 6 (20 wt.% AL, 0 wt.% SS). In this case, the experimental moduli are 27.44 and 27.28 GPa with respective experimental hardness of 43.06 and 47.84 RHN. These values indicated that experimental modulus does not increase with experimental hardness for equal combined fraction of reinforcements. Similar result is observed in sample 4 (10 wt.% AL, 20 wt.% SS) and sample 10 (20 wt.% AL, 10 wt.% SS) with experimental moduli of 27.41 and 25.41 GPa, and experimental hardness of 39.66 and 40.76 RHN, respectively. As observed in Figure 1b, the theoretical moduli of the samples increased with theoretical hardness (coefficient of correlation of 1). Furthermore, the mechanical behaviour of aluminium reinforced with alumina and snailshells depend on the ratio of hardness to elastic modulus (H/E) (Musil et al., 2000; Musil & Visek, 2001; Ragent & Musil, 2001).

However, the resistance to plastic deformation (H/E²) (Table 2) increases with hardness (H) because H/E is approximately constant (Olauwuni et al., 2020; Musil et al., 2002). It is evident in this study that the harder the piston material, the higher the modulus of elasticity (E) and the resistance to plastic deformation as corroborated in a recent study (Olauwuni et al., 2020). The H/E of 0.25 indicates that the deformation is inelastic (Williams, 1994). For the composite without snailshells such as sample 9, the highest values of resistance to plastic deformation of 1.4, theoretical modulus of 86.6 GPa and theoretical hardness of 21.7 GPa were obtained. Similarly, when the composite did not contain alumina as in sample 5, the lowest values of resistance to plastic deformation, theoretical modulus and theoretical hardness were obtained. In between these two, as in sample 1 (10 wt. % Al, 10 wt.% SS), the respective values of resistance to plastic deformation, theoretical modulus and theoretical hardness are 1.08, 71.1 and 17.6 GPa, respectively. It has been shown that alumina and snailshells have different mechanical properties that can be harnessed to enhance properties of composites.

### 3.3 Chemical Composition of the Aluminium Composite Reinforced with Alumina and Snailshells

The compositions of samples 7, 9 and unreinforced sample are shown in Table 3. As previously stated, samples 7 and 9 have the highest modulus of resilience (a measure of yield strength and elastic modulus). Alumina, being an oxide of aluminium, contributed to the increase in hardness in sample 9 (44.9 RHN) than that of sample 7.
(41.2 RHN) while sample without reinforcement has 31.1 RHN. Sample 7 has higher calcium (0.048 wt.%) and iron (0.32 wt.%) than sample 9 and unreinforced sample because it contained higher fraction of snailshells. EDX compositional analysis also complements the facts, as calcium (0.95 wt.%) in sample 7 is higher than that of sample 9 (0.28 wt.%). Snailshells contained minerals which are CaCO$_3$, CaO and SiO$_2$ (Brunt et al., 1999; Patricio et al., 2007) which is similar to eggsHELLS (Schoebel & Jaeger 2006; Hussein et al., 2011; Patricio et al., 2007). This is responsible for its hardening property.

### 3.4 SEM Results

Figure 2a, 2b and 2c show the respective SEM micrograph of sample 7, 9 and unreinforced sample. From the micrograph, alumina particles have a flake-like morphology and aluminium alloy particles are uniformly distributed with both irregular and round shape. The distribution of alumina is one of the most important requirements for achieving excellent mechanical and physical properties of the composites. It was clearly observed in the SEM micrographs that sample 7 with small proportion of snailshells have an obvious irregular shape with black images. Although, clusters of irregular shapes of alumina were observed in sample 7 and 9, this may be attributed to insufficient stirring speed and time (Agida et al., 2004). Literature reported that the higher the fraction of reinforcement, the higher the possibility of clusters and defects (Foganelo et al., 2004). A little pore was observed in samples 9 and unreinforced sample which can be associated with dissolved gases, air bubbles sucked into the melt, improper compaction or particles pull out during grinding and polishing. The fillers in samples 7 and 9 are well bonded in the aluminium matrix (Rana et al., 2012), whereas microcracks were observed sample where composite where absent.

### 3.5 XRD Analysis

Figure 3 depicts the XRD spectral of sample 7, 9 and unreinforced sample. While sample 7 and unreinforced sample contains calcium carbide, graphite, and aluminium, apart from sample 9 which has aluminium and calcium. Using Scherer’s equation, Al, CaC$_2$ and Ca have particle size of 5.6, 5.7 and 9.5 nm, respectively. However, piston scraps have particle size of 8.6, 8.7 and 6.3 nm, respectively. The calcium carbide (CaC$_2$) was a product obtained of Al-Al$_2$O$_3$ composite because of the extremely hard Al$_2$O$_3$ compared from snailshells of particle size 150 µm which dissolved in aluminium matrix. The strengthening mechanism of alumina is associated with its effect on aluminium matrix.

Alumina being a ceramic contributed to the hardness to the unreinforced sample (Gibb et al., 2008). More so, an increase in alumina (Al$_2$O$_3$) particle was reported to enhance yield strength due to the hobble effect which describes the role of Al$_2$O$_3$ particle against dislocation movement. In addition, different thermal expansion coefficient of Al$_2$O$_3$ and aluminium create stress which may increase dislocation density and then the composite strength (Gibb et al., 2008). In addition, snailshells particle can be effective in distributing the applied stress over a large volume at the base of the notch, and prevent propagation of cracks by carrying large part of the load (Atuanya et al., 2015; Asafa et al., 2015; Shen et al., 2001; Genevive et al., 2011; Patricio et al., 2007).

### 4 Conclusions

Response surface methodology (RSM) was used to determine the mixing ratio of the cast samples of aluminium composite produced from piston scraps and reinforced with alumina, and snailshells. Sample 7 (75 wt% aluminium, 15 wt% alumina and 5 wt% snailshell) gave the optimum tensile strength of 172.5 MPa, modulus of resilience of 28.28 GPa and hardness value of 44.9 RHN. The significant variations between the experimental and theoretical Young’s modulus as well as experimental and theoretical hardness are associated with the fact that theoretical values were calculated based on the assumption of a single crystal while a realistic assumption is to consider polycrystalline grains. The SEM micrographs show evenly distributed reinforcements with pockets of clusters while particle size, obtained from XRD spectra, ranges from 5.6 to 18 nm. It has been proven that alumina and snailshells used as composites have enhanced mechanical properties of aluminium having compared it with unreinforced sample.

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