



## Studies on the Compressive Behaviour of Aluminum – Zircon composites

Oluwaseyi Omotayo Taiwo<sup>1\*</sup>, Abraham Kehinde Aworinde<sup>2</sup>, Kenechukwu ThankGod Onyena<sup>3</sup>, Darlington Chinaza Amadi<sup>4</sup>, Binah Somtochukwu Ojiyi<sup>5</sup>

<sup>1,3,4,5</sup>Department of Metallurgical and Materials Engineering, Nnamdi Azikwe University, Awka, Nigeria.

<sup>2</sup>Department of Electrical and Biomedical Engineering, First Technical University, Ibadan, Nigeria.

Article Info	ABSTRACT
<p><b>Corresponding Author:</b> Oluwaseyi Omotayo Taiwo E-mail: taiwooluwaseyi2003@yahoo.com</p>	<p>The use of Zircon (ZrSiO<sub>4</sub>) as reinforcement for aluminum (Al) alloys is generating interest due to its attractive properties. This has therefore made zircon a promising reinforcement for Al composites in automobile, aerospace, packaging and structural applications. While investigations on the mechanical responses of aluminum reinforced with zircon composites (especially hybrid composites) developed via stir casting has been extensively considered, limited works have been done on the compressive behaviour of single reinforced zircon composites. Hence, this work evaluates the compressive strength, compressive modulus, hardness, density, and impact strength of Al-ZrSiO<sub>4</sub> composites produced by stir casting process. Compressive strength, hardness density increased with increasing zircon reinforcement while the compressive modulus and impact energy greatly reduced. Microstructural analysis confirms the presence and distribution of zircon particles.</p> <p><b>Keywords:</b> Aluminum composites, zircon, compressive strength, mechanical properties</p>

This is an open access article under the [CC BY-NC](#) license



### INTRODUCTION

The use of Stir cast technique in producing aluminum matrix composites have continued to attract interest due to its simplicity, applicability to mass production and cost-effectiveness (Inegbenebor et al., 2016). Reinforcing aluminum with ceramic materials has further increased the use of aluminum in various engineering applications where a combination of high strength to weight ratio, low density, stiffness, toughness and hardness are required. Hence, in addition to process parameters, the type of material used as reinforcement plays important role in enhancing mechanical properties of the aluminum as it also determines the area of application of the resulting composite Nturanabo et al., (2019). Ceramic materials used in AMCs have long been known to possess high hardness and modulus, as well as good thermal stability at the melting point of aluminum. Apart from popular reinforcement in AMCs such as silicon carbide (SiC), alumina (Al<sub>2</sub>O<sub>3</sub>), titanium carbide (TiC), titanium boride (TiB<sub>2</sub>), graphite (C), materials like Zircon (ZrSiO<sub>4</sub>) have also generated interest as a reinforcement of choice in AMCs (JohnyJames and Annamalai, 2017; Adeosun et al., 2014). With theoretical specific gravity of 4.60-4.71, Moh's hardness scale of 7.5 and fracture toughness of 5, zircon is well known to possess good wear resistance and thermal shock with low thermal conductivity

which is reported to be 20% of that of alumina (Raju and Ramamurthy, 2018; Okafor and Aigbodon, 2010; Pirkle and Podmeyer, 1993). Zircon has been therefore reported to improve successfully the mechanical properties of aluminum.

Girisha and Chittappa (2013) investigated aluminum matrix composites (AMCs) based on Al 356 reinforced with zircon using the stir casting technique. Their findings indicated that hardness increased nearly linearly with the weight fraction of zircon; however, excessive zircon content led to particle agglomeration in the composite. Jenix, et al., (2013) examined Al 6063 alloy composites with alumina and zircon sand as reinforcement, also produced via stir casting, and observed that properties such as strength and hardness improved significantly compared to the unreinforced alloy. Moreover, they noted an homogeneous dispersion of zircon particles in the matrix, minimal porosity, and the formation of intermetallic phases. Krishna et al., (2017) conducted a comparative investigation of Al 7075 composites reinforced with zircon sand and graphite, and another set with fly ash and graphite. Their results revealed that the Al-Gr-ZrSiO<sub>4</sub> composites had greater hardness and density, attributed to the presence of zircon. Yaday et al., (2015) explored the hardness, microstructure, and compressive properties of ADC-12 aluminum alloy reinforced with zircon and titanium carbide. They reported that a balanced ratio of both reinforcements yielded optimal mechanical performance, particularly in compressive strength and microhardness. Dhileepan et al., (2018) developed hybrid composites using an Al5083 matrix with 5 wt.% zircon sand and varying rice husk ash contents (5–20 wt.%) through stir casting. The enhancement in hardness was primarily attributed to the zircon addition. Similarly, Abdizadeh et al., (2008) studied Al-356 composites reinforced with zircon and titanium boride, and observed improvements in both hardness and tensile strength, which were linked to strain hardening effects..

JohnyJames and Annamalai (2017) focused on Al 6061 composites containing 10 wt.% zircon, noting significant enhancements in both hardness and strength. Banerji et al. (1983) analyzed cast aluminum alloys (LM13: Al–11.8% Si–3% Mg) reinforced with zircon particles and found that the yield strength, elastic modulus, and ultimate tensile strength was enhanced with increasing zircon content. However, the percentage elongation decreased as the zircon volume fraction rose. Thandalam et al., (2015) reviewed the impact of zircon on the mechanical behaviour of aluminum-based composites, concluding that zircon has been effectively used to improve tensile strength, hardness, and overall microstructure. Similarly, Ramnath et al., (2014) highlighted the various reinforcements employed in aluminum composites and reported that zircon not only enhances compressive strength but also contributes to improved wear resistance, particularly in hybrid composite systems.

Furthermore, Kumar et al., (2016) investigated the age hardening behaviour and density of Al-Si-Mg alloy reinforced with alumina and zircon. The presence of the alumina and zircon was reported to enhance the age-hardening kinetics thus enabling the composites to achieve peak hardness at a faster rate than the unreinforced alloy. Also, the rate of achieving peak hardness was reported to be directly proportional to the hardness values obtained. Sharma and Das (2009) studied the precipitation hardening response of Al–4.5 wt.% Cu reinforced with zircon Composite in various quenching media. It was reported that the micro-hardness of the stir cast composites improves with the amount of solution heat treatment and reaches a maximum after which it progressively drops with more heat treatment cycles.

The addition of zircon to aluminum through different casting technique has been looked into over the years (Thandalam et al., 2015). zircon has been reportedly used mostly as hybrid

reinforcement and significant improvement in hardness, tensile strength, and wear resistance of aluminum alloy through its addition reported (Iqbal and Nuruzzaman, 2016). While its contribution to improvement on the compressive strength of aluminum as secondary reinforcement produced by stir casting have been evaluated, research has been limited on its effect as a single reinforcement Raju and Ramamurthy (2018). Therefore, this present study seeks to investigate the effect of zircon on the compressive behaviour of aluminum as a single reinforcement.

## METHODOLOGY

### Materials and Processing

The matrix aluminum alloy used in this study is Al 6011 series. The ingot was initially sectioned into pieces approximately 10 cm long and 20 cm thick using a power hacksaw. These were further reduced into smaller, irregularly shaped fragments using a shear cutter to facilitate precise determination of the weights in smaller quantities. Zircon sand, serving as reinforcement, along with magnesium as the wetting agent, were procured and milled to a particle size of 100 microns using a hammer mill. Reinforcement contents were measured in weight percentages ranging from 2wt.% to 10wt.% at 2wt.% intervals using an electronic balance.

Composite production was carried out through stir casting, using a custom-built electric resistance furnace. Prior to the casting process, the reinforcements, wetting agent, and mould were preheated to 300°C to eliminate moisture, which could otherwise lead to rapid cooling and affect the quality of the final product. The melting furnace, constructed from low-density refractory bricks and Nichrome 80 resistance wire, measured 35 cm × 35 cm × 36 cm. Aluminum was melted at 750°C in the electric furnace, after which the reinforcement and wetting agent were introduced into the melt and stirred for about 30 seconds. The molten mixture was then poured into a finger mould consisting of five cavities, each with a depth of 135 mm and a diameter of 15 mm. Once solidified, the castings were removed and subjected to T6 heat treatment to reduce casting defects, improve particle homogeneity, and enhance hardness. The heat treatment involved homogenizing the samples at 530°C for 3 hours in a LabScience box-type resistance furnace (Model DFW-7000), followed by water quenching to preserve the high-temperature microstructure. After quenching, the samples underwent artificial ageing at 180°C for 5 hours in an electric resistance furnace. The treated samples were then machined to the required dimensions for subsequent mechanical testing.

### Composite Density Determination

The density of the samples (dimension of 15 mm diameter and 30 mm height) was obtained using Archimedes principle. The volume of water displaced was measured by immersing samples into a cylindrical flask. Before then, an electronic weighing balance was used in measuring the masses. The density of the composites was determined by dividing the mass of the samples by the volume of water displaced as seen in equation 1.

$$\text{Density} = \frac{\text{mass of sample}}{\text{volume of water displaced}} \quad (1)$$

### Mechanical Tests

Compression tests were performed on cylindrical specimens measuring 25 mm in height and 15 mm in diameter using an Universal Testing Machine (Instron Model 3369). Hardness measurements were obtained using a Vickers hardness tester made by SLOMM (Model HVD-10001S). Prior to testing, sample surfaces were prepared by sequential grinding

using emery papers of grit sizes 60, 150, 220, 320, and 400 to ensure uniformity and suitability for microhardness indentation. Indentations were made using a 200 g load applied for 10 seconds dwell time, and measurements were taken at three different locations on each sample, with the average value recorded. Impact testing was conducted to assess the energy absorption capacity of the composites prior to fracture. Tests were carried out using a Charpy Impact Testing Machine (Avery Model E67424/4), operating with a velocity of a velocity of 5 m/s and at a striking force of 298 Nm. The impact specimens were machined to dimensions of 10 mm in diameter and 55 mm in height, featuring a central notch 2 mm deep at a 30° angle.

### Microstructural Test

The XRD (X-ray diffraction) analysis of the samples was carried out using a Philips PW1710 diffractometer equipped with Cu K $\alpha$  radiation ( $\lambda = 1.5406 \text{ \AA}$ ), operating at 40 kV and 40 mA. The diffraction patterns were processed and analyzed using a software (PANalytical X'Pert HighScore) for phase identification through search-match functionality. To minimize background interference, the samples were mounted on zero-background holders. The data collected was performed in the  $2\theta$  range of 5° to 90° using a step scan interval of 0.0170° and a scan time of 1.00 second per step. The crystallite size and lattice strain of the samples were determined using the Scherrer calculator integrated within the X'Pert HighScore analysis software. The Scherrer formula for calculating crystallite size is based on the equations 2;

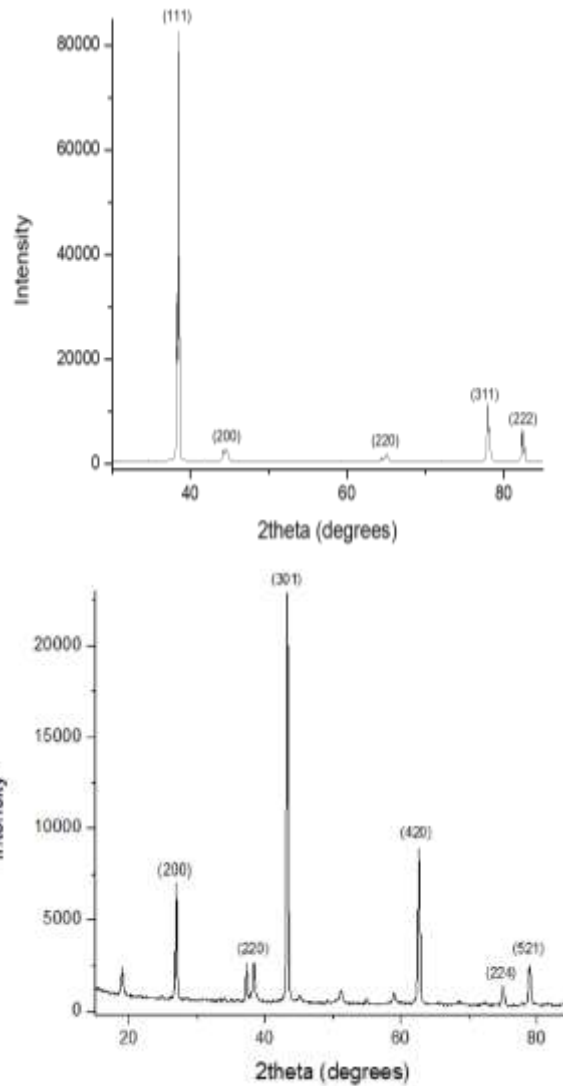
$$\text{Crystallite size (average)} = K \lambda / (B \cos \theta) \quad (2)$$

Where K is the constant of the order of about unity (0.94) for usual crystals,  $\lambda$  is the X – ray wavelength,  $\theta$  is the diffraction angle and B is the difference in integral profile width between a standard and the unknown sample which is referred to as the structural broadening.

## DISCUSSIONS

### XRD

Figure 1a shows the XRD of aluminum alloy. The observed peak positions correspond well to FCC aluminum, which is the dominant phase in aluminum alloys. The presence of minor peaks could indicate the presence of secondary phases, such as intermetallic compounds (e.g., Al<sub>2</sub>Cu, Al<sub>3</sub>Fe) depending on the alloying elements. Broadening of peaks can provide information about crystallite size and microstrain using Scherrer's equation. A sharper peak indicates larger crystallite sizes, while broader peaks suggest smaller grains or defects. The XRD of zircon is presented in Figure 1b. The most intense peak is at (301), indicating the preferred crystallographic orientation. Zircon typically exhibits a tetragonal crystal structure. The presence of well-defined, sharp peaks suggests a highly crystalline nature with minimal amorphous content. The positions of these peaks align with the standard JCPDS (Joint Committee on Powder Diffraction Standards) card for zircon. The absence of additional unidentified peaks suggests a single-phase material with minimal impurities.



a. b.

**Figure 1:** XRD of (a) Aluminum (b) Zircon.

Figure 2 a - e shows the XRD of the composites (aluminum reinforced with 2, 4,6,8,10 wt.% Zircon composites). The peaks shows highly crystalline structures and presence of other phases such as quartz, alumina, sillimanite, aluminum - zirconium - silicon are identified. These phases exist as intermetallic due to the interaction between aluminum and zircon. Quartz, alumina and sillimanite is identified in all the composites while aluminum - zirconium - silicon is observed to be absent in 2wt.% of zircon in aluminum. This might be due to insufficient amount of zircon to react with aluminum since the formation of aluminum - zirconium - silicon phase is attributed to reaction kinetics between aluminum and zircon, formation of Al-Si eutectics from silicon release or addition, zircon acting as a grain refiner forming precipates, and processing effects Kumar et al., (2019). The presence of the phases identified also contribute significantly to the improved compressive strength of aluminum.

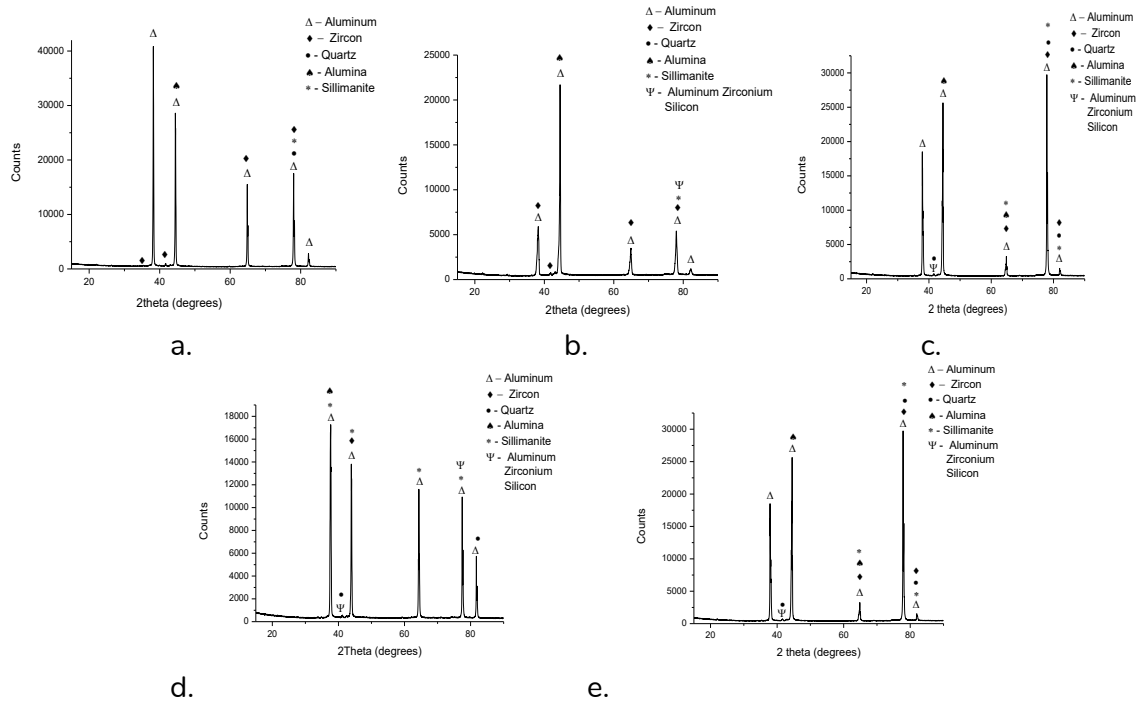


Figure 2: XRD of Aluminum - Zircon composites.

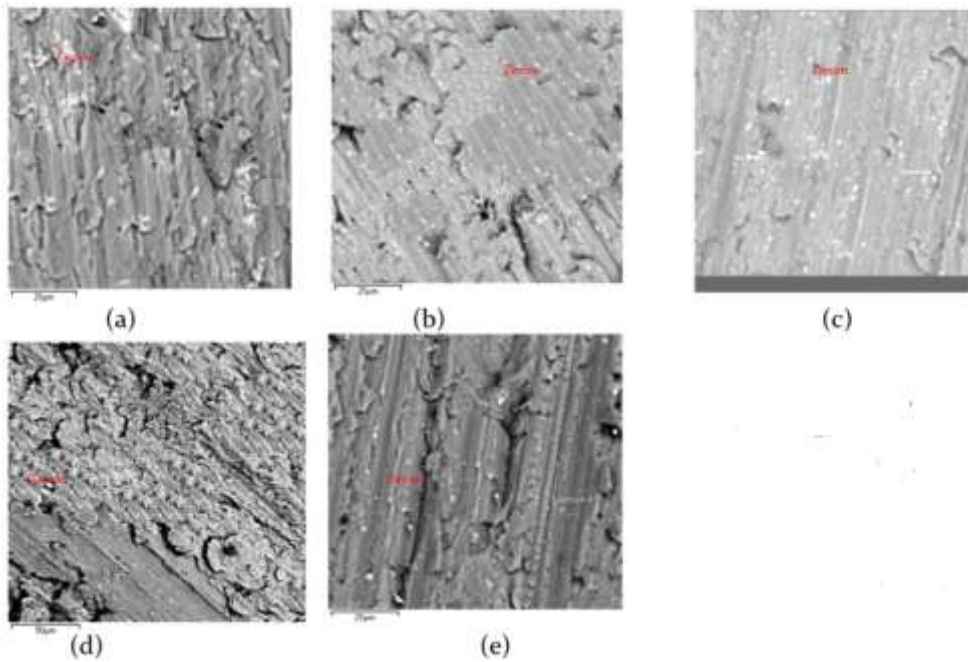
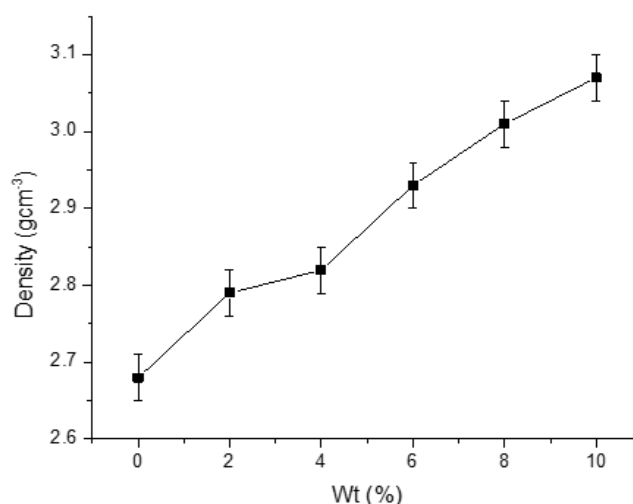


Figure 3 shows the SEM of Aluminum - Zircon composites. (a) Al/ 2wt.% Zircon (b) Al/ 4wt.% Zircon (c) Al/ 6wt.% Zircon (d) Al/ 8wt.% Zircon (e) Al/ 10wt.% Zircon.

**Density**

Figure 4 shows the effects of weight fractions of zircon on the density of aluminum respectively. In both cases, the density of aluminum increases with increasing weight fractions, however, for the experimental results, the increase was up to 8wt.% before a decline at 10wt.%. The general increase in density is because of the inherent higher density of zircon as the addition of denser ceramic reinforcement into the aluminum matrix will increase its density Saravanan et al., (2015). For the results as observed in Figure 4, the density of aluminum-zircon composites ranges from 2.8 (2wt.%) - 3.08gcm<sup>-3</sup> (8wt.%) as against unreinforced Al alloy's (2.680 gcm<sup>-3</sup>). Therefore, an increase in density of up to

14.68% maximum at 8wt.% and 4.21% minimum at (2wt.%) over the unreinforced matrix was obtained from the incorporation of zircon in the aluminum alloy. Increase in density will occur when the reinforcing phase is denser than the matrix however, presence of pores and other casting defects may cause a reduction in density of the composites which might be responsible for the decline in density at 10wt.% compared with 6 and 8wt.% Das et al., (2014).



**Figure 4:** Density of Aluminum - Zircon Composites

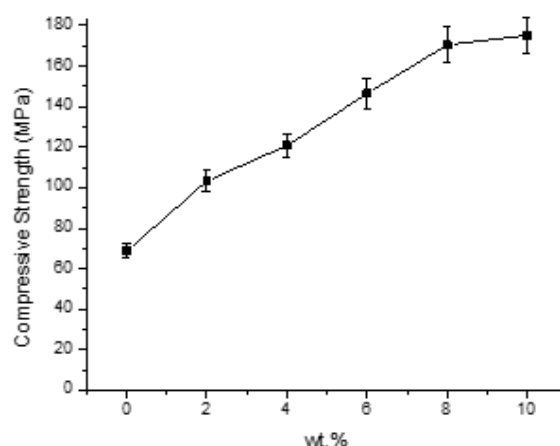
### Mechanical Properties

Mechanical properties of the composite depend on the behaviour of the reinforcement in its interaction with the matrix at micro-level. Factors like interface, solidification, microstructure, wettability, porosity and distribution of reinforcement in the matrix play an important role in tailoring the properties of the composites Casati et al., (2014). The mechanical behaviour of composite materials is largely influenced by how the reinforcement interacts with the matrix at the microscopic scale. Key factors such as the solidification behavior, interfacial bonding, microstructural features, porosity, wettability, and the uniformity of reinforcement distribution within the matrix significantly contribute to determining the overall properties of the composite Casati et al., (2014).

### Compressive Strength

Compressive strength of aluminum - zircon composites is shown in Figure 5 below. The addition of zircon particles increases the compressive strength of the matrix with increasing weight fractions. Compressive strength increased from 103.25MPa (2wt.%) to 175.05MPa (10wt.%). The increase at 10wt.%, which is the maximum, is 155% increase over the unreinforced matrix (168.77MPa). The significant increase in the compressive strength is attributed to stability imparted into the matrix by hard zircon particles, which possess higher rigidity and crushing strength when compared to the matrix material Quadros et al., (2017). The increase in compressive strength with increasing weight fractions might be attributed to the homogenous distribution of zircon particles in the matrix. These enable the hard zircon particles in the matrix to effectively act as a barrier to the plastic flow generated in the composites when subjected to compressive loading Hashim et al., (2001). The decrease in average particle size from 2wt.% to higher weight fraction can also be responsible for the increasing compressive strength at higher weight fraction as particle size are inversely proportional to strength Ashok and Shanmughasundaram (2017). The compressive strength

observed can also be further attributed to the heat treatment that all the samples were subjected to. This is because reinforcing particles serves as a substrate for the formation of heterogeneous nucleation thus producing more grains which are needed to inhibit dislocation flow during load application Zhang et al., (2008). With increasing weight fraction, the difference between 8 and 10wt.% are smaller than the others which suggests that the compressive strength shows an approach to the peak value, hence for this work peak value might just be a few weight fractions above 10wt.%.



**Figure 5:** Compressive Strengths of Aluminum - Zircon composites

### Hardness

The hardness of aluminum - zircon composites is presented in Figure 6. The resistance to plastic deformation by indentation of the composites increases as the weight fraction of zircon particles increases until it reaches 8wt.% before a decline at 10wt.%. The Figure shows improvement of the hardness of Al (419.83HV) by 100% (838.93HV), 113% (892.40HV), 130%(966.33HV), 118%(915.30HV) at 2, 4, 6, 8wt.% respectively while a reduction of 15% (353.27HV) is observed at 10wt.%. The significant improvement is attributed to the addition of zircon as well as the T6 heat treatment carried out on the samples. This is because the presence of zircon being relatively homogenous will enhance the resistance of the composite to deformation by indentation or scratching Madhusudan et al., (2016). Also, good bonding between zircon and Al has been reported to be responsible for the improvement in hardness of aluminum – zircon composites over the unreinforced alloy Thandalam et al., (2015). Furthermore, the inherent hard nature of zircon like other hard ceramic will influence the hardness of their matrix alloy when used as reinforcement Kumar and Venkatesh (2018). Moreover, the hardness of the composites was further enhanced through a sequential heat treatment process consisting of solution heat treatment, water quenching, and subsequent age hardening. Increased hardness by heat treatment (solution treatment phase) was attributed to the formation of the second phase which dissolves in the matrix after solution treatment, resulting in lattice distortion of the matrix thus leading to solid-solution strengthening. Furthermore, the formation of ageing precipitation phases (as a result of the subsequent ageing phase in the heat treatment procedure) interact with dislocations and inhibit dislocation motion in the composites when subjected to deformation (Zhang et al., 2008). Hence, subjecting these composites to heat treatment improves strength and hardness and the results in Figures 5 and 6 exemplify the positive correlation between the properties with the exemption of 10wt.% where there was a decrease in hardness compared with the unreinforced. The decreased hardness might be attributed to high brittleness of the

reinforcements (enhanced by the heat treatment) which will impact negatively on the hardness of the matrix alloy at higher weight fractions (Verman and Khvan, 2019)

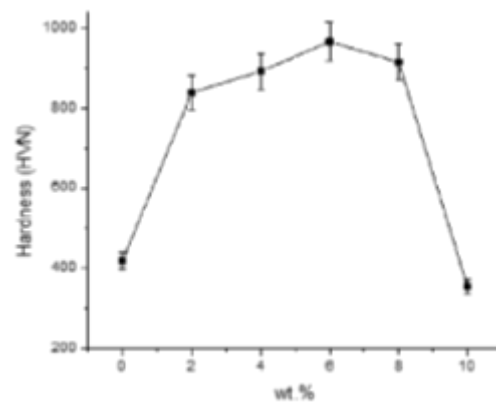


Figure 6: Micro hardness of Aluminum - Zircon Composites

### Impact Strength

The impact strength of the composites is shown in Figure 7. The impact energy shows the amount of energy absorbed before fracture. The addition of the zircon particles generally reduces the impact energy of the Al alloy (33.905 J/m<sup>2</sup>) by 76% (8.14 J/m<sup>2</sup>), 80% (6.78 J/m<sup>2</sup>), 84% (5.42 J/m<sup>2</sup>), 74% (8.82 J/m<sup>2</sup>) and 68% (10.85 J/m<sup>2</sup>), at 2wt.%, 4wt.%, 8wt.% and 10wt.% zircon respectively. This implies that the addition of zircon as reinforcement decreases the ability of aluminum alloy to resist failure due to sudden application of load. The reduction in impact strength might be attributed to poor cohesion at the matrix and reinforcement interface especially at the crack sites Verma and Khvan (2019). Reduction in impact energy of aluminum by introducing hard ceramics such as Alumina and Silicon Carbide as reinforcements have been reported in many works (Osoba et al., 2017; Okafor et al., 2010; Karvanis et al., 2016). Generally, factors such as particle agglomeration, particle cracking and weak matrix-filler bonding have been suggested as reasons for reduced impact strength in aluminum composites Iqbal and Nuruzzaman (2016) .

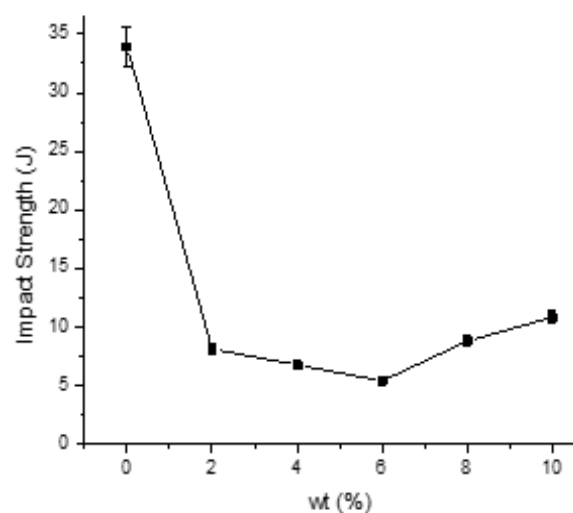


Figure 4: Impact Strengths of Al-Zircon Composites

### CONCLUSION

Aluminum – zircon composites were developed by stir casting and further subjected to heat treatment. The microstructure, physical and mechanical properties were studied. The presence of zircon is confirmed in the microstructure to be well distributed. The XRD shows

the presence of intermetallic phases which must have contributed to the compressive strength behaviour of the composites. Also the peaks observed in the XRD are sharp showing good crystalline properties also leading to improved strength properties. Conclusively, with the addition of zircon as the reinforcement, compressive strength, hardness, as well as density of aluminum alloy was increased while a reduction in the impact strength is observed.

## REFERENCES

- Abdizadeh, H., Baharvandi, H. R., & Moghaddam, K. S. (2008). Comparing the effect of processing temperature on microstructure and mechanical behavior of (ZrSiO<sub>4</sub> or TiB<sub>2</sub>)/aluminum composites. *Materials Science and Engineering A*, 498, 53–58.
- Adeosun, S. O., Osoba, L. O., & Taiwo, O. O. (2014). Characteristics of aluminum hybrid composites. *International Journal of Chemical, Nuclear, Materials and Metallurgical Engineering*, 8(7), 697–704.
- Ashok, N., & Shanmugasundaram, P. (2017). Effect of particles size on the mechanical properties of SiC-reinforced aluminium 8011 composites. *Materials and Technology*, 51(4), 667–672.
- Casati, R., & Vedani, M. (2014). Metal matrix composites reinforced by nano-particles: A review. *Metals*, 4(1), 65–83. <https://doi.org/10.3390/met4010065>
- Das, D. K., Mishra, P. C., Singh, S., & Thakur, R. K. (2014). Properties of ceramic-reinforced aluminium matrix composites: A review. *International Journal of Mechanical and Materials Engineering*, 1(12), 1–16.
- Dhileepan, S., Velu, D. L. S., Raj, I. J. A., & Joyal, J. S. (2018). Al5083 matrix hybrid composites reinforced with zircon sand (ZrSiO<sub>4</sub>) particles and rice husk (RHA) particles are synthesized by the stir casting method. *International Research Journal of Engineering and Technology*, 5(2), 1047–1051.
- Girisha, K. B., & Chittappa, H. C. (2013). Preparation, characterization and wear study of aluminium alloy (Al 356.1) reinforced with zirconium nano particles. *International Journal of Innovative Research in Science, Engineering and Technology*, 2, 3627–3637.
- Hashim, J. (2001). The production of cast metal matrix composite by a modified stir casting method. [Source title not provided], 35(A), 9–20.
- Inegbenebor, A. O., Bolu, C. A., Babalola, P. O., Inegbenebor, A. I., & Fayomi, O. S. I. (2016). Aluminum silicon carbide particulate metal matrix composite development via stir casting processing. *Silicon*, 9, 1–7.
- Iqbal, A., & Nuruzzaman, D. M. (2016). Effect of the reinforcement on the mechanical properties of aluminium matrix composite: A review. *International Journal of Applied Engineering Research*, 11(21), 10408–10413.
- Jenix, R., Sivalingappa, D., Halesh, K., & Daniel, J. (2013). Properties of Al6063 MMC reinforced with zircon sand and alumina. *IOSR Journal of Mechanical and Civil Engineering*, 5, 72–77.
- JohnyJames, S., & Annamalai, A. R. (2017). Fabrication of aluminium metal matrix composite and testing of its property. *Mechanics, Materials Science & Engineering Journal*, 9, 1–5.
- Karvanis, K., Fasnakis, D., Maropoulos, A., & Papanikolaou, S. (2016). Production and mechanical properties of Al-SiC metal matrix composites. *IOP Conference Series: Materials Science and Engineering*, 161, 1–9.

- Krishna, B. N., Unnikrishnan, P., & Ilangovan, S. (2017). Synthesis and characterization of zircon/Gr and flyash/Gr reinforced aluminum 7075 alloy: A comparative study. *Journal of Materials and Environmental Science*, 9(1), 26–31.
- Kumar, A., Sahoo, R., & Mandal, A. (2019). Effect of zircon addition on the microstructure and mechanical properties of Al-based composites. *Journal of Alloys and Compounds*, 785, 247–258.
- Kumar, S. T., Subramanian, R., Shalimi, S., & Angelo, P. C. (2016). Age hardening behaviour of Al-Si-Mg alloy matrix/zircon and alumina hybrid composite. *Journal of Scientific and Industrial Research*, 75, 89–94.
- Kumar, V. M., & Venkatesh, C. V. (2018). Effect of ceramic reinforcement on mechanical properties of aluminum matrix composites produced by stir casting process. *Materials Today: Proceedings*, 5, 2466–2473.
- Madhusudan, S., Sarcar, M. M. M., & Rao, N. B. R. M. (2016). Mechanical properties of aluminum-copper(p) composite metallic materials. *Journal of Applied Research and Technology*, 14, 293–299.
- Nturanabo, F., Masu, L., & Kirabira, J. B. (2019). Novel applications of aluminum metal matrix composites. *IntechOpen*. <https://doi.org/10.5772/intechopen.86225>
- Okafor, E. G., & Aigbodion, V. S. (2010). Effect of zircon silicate reinforcements on the microstructure and properties of as-cast Al-4.5 Cu matrix particulate composites synthesized via squeeze cast route. *Tribology in Industry*, 32, 31–37.
- Pillai, U. T. S., & Pandey, R. K. (1999). Fracture characteristics of Al-zircon particulate composites. *Composites Science and Technology*, 40, 333–354.
- Pirkle, F. L., & Podmeyer, D. (1993). *Zircon: Origin and uses*. Society for Mining, Metallurgy, and Exploration, Inc.
- Quadros, J. D., Vaishak, N. L., & Suhas. (2017). Evaluation of mechanical properties of aluminium alloy 7075 reinforced with short coated carbon metal matrix composites. *American Journal of Materials Science*, 7(4), 102–107.
- Raju, H. T., & Ramamurthy, V. S. (2018). Fabrication and evaluation of properties of aluminum alloy-zirconium silicate particles reinforced metal matrix composites: A review. *International Journal of Innovative Research in Science, Engineering and Technology*, 7(11), 9284–9288.
- Ramnath, B. V., Elanchezian, C., Annamalai, R. M., Aravind, S., Atreya, T. S. A., Vignesh, V., & Subramanian, C. (2014). Aluminum metal composites: A review. *Reviews on Advanced Materials Science*, 38, 55–60.
- Saravanan, C., Subramanian, K., Krishnan, V. A., & Narayanan, R. S. (2015). Effect of particulate reinforced aluminium metal matrix composite: A review. *Mechanics and Mechanical Engineering*, 19(1), 23–30.
- Sharma, A., & Das, S. (2009). Study of age hardening behavior of Al-4.5 wt.% Cu/zircon sand composite in different quenching media: A comparative study. *Materials & Design*, 30, 3900–3903.
- Thandalam, S. K., Ramanathan, S., & Sundarrajan, S. (2015). Synthesis, microstructural and mechanical properties of ex situ zircon particles (ZrSiO<sub>4</sub>) reinforced metal matrix composites (MMCs): A review. *Journal of Materials Research and Technology*, 4(3), 333–347.

- Verma, V., & Khvan, A. (2019). A short review on Al MMC with reinforcement addition effect on their mechanical and wear behaviour. *IntechOpen*. <https://doi.org/10.5772/intechopen.83584>
- Yadav, S. K., Patel, S. K., & Nateriya, R. (2015). Microstructure, microhardness and compressive behaviour of dual reinforced particles aluminium alloy composites. *International Journal of Innovative Science, Engineering & Technology*, 2(4), 1154–1163.
- Zhang, L., He, X. B., Qu, X. H., Duan, B. H., Lu, X., & Qin, M. L. (2008). Dry sliding wear properties of high volume fraction SiCp/Cu composites produced by pressureless infiltration. *Wear*, 265(11–12), 1848–1856.
- Osaba, L., Taiwo, O., & Samson Adeosun. (2026). *The Dry Sliding Wear Behaviour of Aluminum Composites: A Review*. West Indian Journal of Engineering. <https://journals.sta.uwi.edu/ojs/index.php/wije/article/view/7739>.