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Mechanical Properties of ZrO_2 Particles Reinforced Al2219 Alloy Metal Composites Prepared by Stir Casting Process

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Abstract

The current research focuses on the preparation of Al2219 with micron-sized ZrO_2 composite using a liquid metallurgy technique. Al2219 alloy was used to make composites with ZrO_2 particles. Microstructural analysis was performed on the created composites using SEM. Hardness, tensile strength and ductility were measured as per ASTM norms. Graphs taken using a scanning electron microscope showed that the boron carbide particles were evenly dispersed throughout the Al2219 alloy. The hardness, ultimate and yield properties of Al alloy were increased by adding ZrO_2 particles. Further, Al2219 with 3 and 6 wt.% of ZrO_2 composites showed lesser ductility than Al2219 material.

Keywords: *Al2219 Alloy, Hardness, Microstructure, Tensile Behavior, ZrO_2 Particles*

1.0 Introduction

There is a wide range of composite materials currently available, and their quantity is increasing because of continuous advancements and enhanced characteristics. The demand for high-performance materials has resulted in a renewed interest in utilising combinations of several materials to attain exceptional performance that cannot be attained by anyone component[1,2]. This methodology enables the development of adaptable, personalised materials that fulfil precise user needs[3]. Currently, the development of technology greatly depends on the progress made in the field of materials. The key to achieving this objective is making considerable progress in the effective utilisation of constantly developing materials, such as the composite[4,5].

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Composite materials consist of a continuous matrix phase that binds and moulds a stronger and more rigid reinforcing phase[6,7]. The combination of these materials produces a material that exhibits exceptional structural characteristics that exceed the attributes of each element[8]. Composites surpass other building materials due to their exceptional characteristics, including their ability to flex and bend without fracturing, their high specific strength and specific modulus, their resistance to fatigue and wear, and their capacity to withstand thermal cycling and a certain degree of thermal expansion[9,10].

The possessions of composites are influenced by the proportion and qualities of the several phases present, as well as the arrangement of the dispersed phase, which includes aspects like particle size and orientation within the matrix[11,12]. There are several methods available for manufacturing composites[13,14]. The composites that have been produced are evaluated for improved possessions by the execution of experiments such as hardness, tensile, and tribological tests, by the criteria established by the ASTM standards[15,16].

A stronger reinforcing component and a dominating matrix (binder) make up the composite material[17,18]. To assess their properties, the resulting samples are subjected to analysis after having their reinforcement weight percentages adjusted in proportion to the matrix alloy weight percentages[19]. The chemical composition of the matrix phase of a composite determines its classification as either a polymer composite a Metal Matrix Composite (MMC), or a ceramic composite[20,21].

Ceramic reinforced MMCs have under significant popularity in recent times due to their numerous advantageous characteristics[22]. MMC is highly favoured in the automobile, aerospace, and biomedical industries[23,24] due to its exceptional rigidity, superior strength-to-weight relation, and remarkable resistance to wear and tear. Materials such as SiC, boron carbide, titanium carbide, alumina, and graphite are commonly utilised as reinforcements in these materials[25-28].

Aluminium, titanium, and magnesium are commonly used as matrix resources. Aluminium composites have attracted significant interest over the last thirty years because of their superior specific strength, stiffness, and better wear resistance[29,30]. Aluminium alloys that consist of zinc, copper, and silicon as their primary alloying elements are a notable category of materials that undergo shaping processes and possess a remarkable blend of mechanical properties, castability, wear resistance, and good corrosion resistance[31,32]. These alloys and others have been used in the fabrication of composite materials[33-38].

AMMCs can be produced using various well-established methods, however there is no universally defined process. The production procedure depends on the matrix material and the exact types of reinforcement used[39]. The stir casting technique is widely acknowledged as a viable approach for producing short-fibre metal matrix composites. This is because of its straightforward nature, adaptability, and capacity to generate significant quantities for various applications[40,41].

The Al-ZrO_2 composites are essential in meeting the growing demand for lightweight materials in many applications. Conventional Al2219 alloy has moderate strength, this can be improved with the addition of oxide or ceramic particles. According to the previously described observations, the plan is to produce composites of Al2219-ZrO_2 with varying weight proportions of ZrO_2 particles. The objective of this study is to examine the hardness and tensile parameters of Al2219-ZrO_2 composites that were produced using the stir cast process.

2.0 Experimental Details

2.1 Materials Used and Preparation of Composites

Table 1 shows the various elements in the Al2219 alloy. Table 2 and Table 3 represent the various properties of Al2219 alloy and ZrO_2 respectively.

Table 1. Chemistry of Al2219 alloy

Elements	Si	Fe	Cu	Mn	Mg	Zn	Zn	Ti	Al
Weight (%)	0.20	0.30	6.80	0.40	0.02	0.10	0.20	0.05	Bal

Table 2. Properties of Al2219 alloy

Density (g/cc)	**2.8**
Melting point (˚C)	660
Poisson's Ratio	0.33
Modulus of Elasticity (GPa)	70-80
Hardness (HV)	65
Tensile Strength (MPa)	180-190
Co-efficient of Thermal Expansion µm/m˚C	24.3
Thermal Conductivity W/mK	190

Table 3. Typical properties of zirconium oxide (ZrO_2)

Properties	**ZrO_2**
Melting point (˚C)	2715
Hardness (BHN)	1300
Density (g/cm^3)	5.68
CTE (10^{-6} ºC)	11.6
Fracture toughness (MPa-m$^{1/2}$)	2.9-3.7
Poisson's ratio	0.32
Colour	White

The manufacturing process for Al2219 alloy with ZrO_2 composites utilises the liquid metallurgy technology as in Figure 1 (a-c). The Al2219 metal ingots are placed into the electric furnace and heated until they melt into a liquid condition. The molten metal is exposed to a significantly high temperature of 750ºC. Thermocouples that are appropriate for the given temperature range are utilised to measure both the melting temperature and the superheated temperature, and subsequently, these values are recorded.

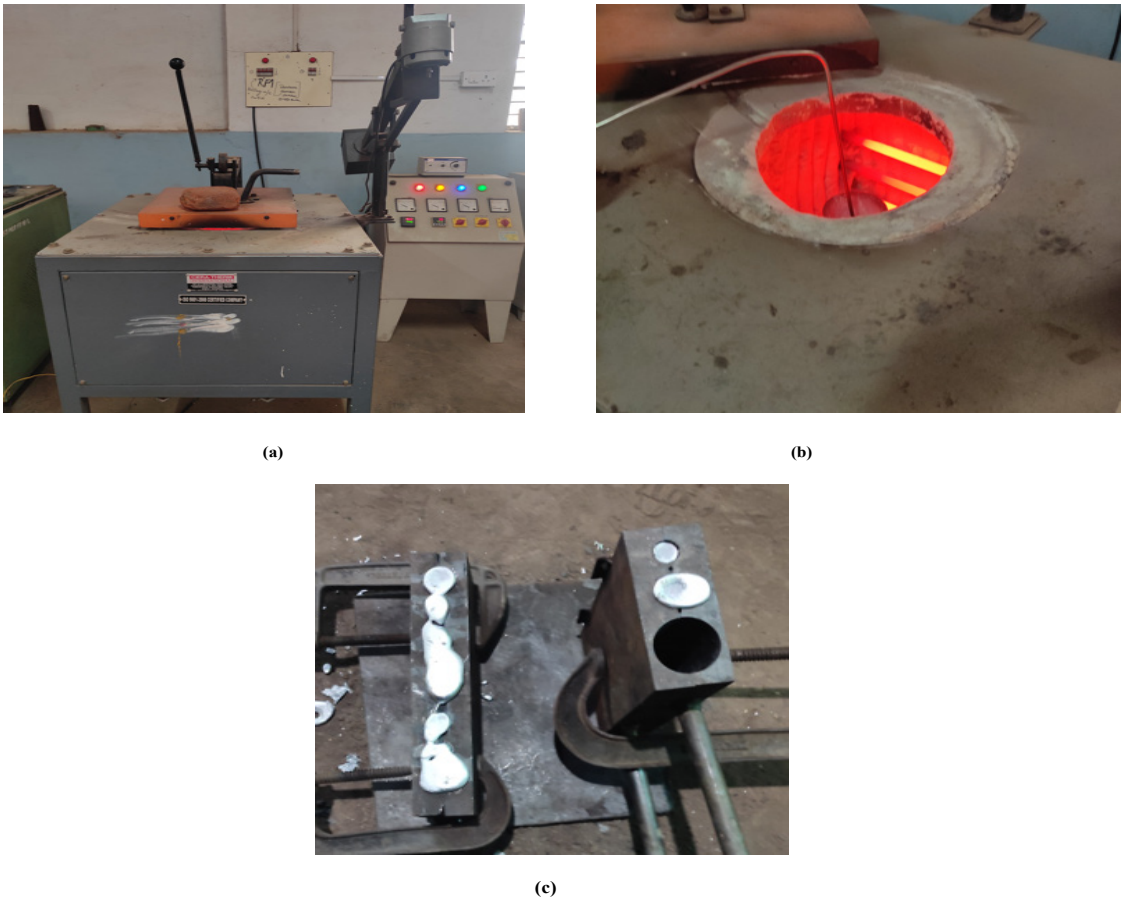
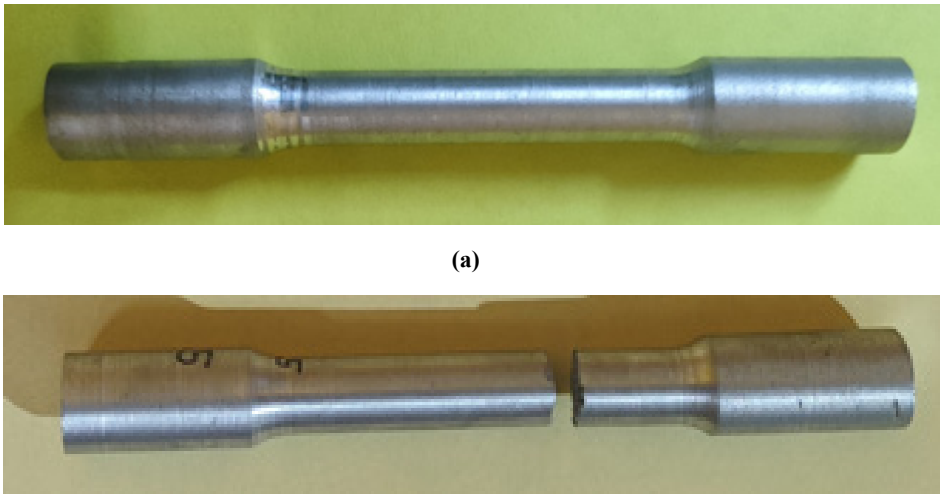


Figure 1. **(a)** Stir casting set up **(b)** Molten metal in crucible **(c)** Molten metal in a cast iron die.



(a)

(b)

Figure 2. **(a)** Tensile test specimen before test **(b)** Tensile specimen after test.

The molten metal is de-gassed by employing solid hexachloroethane (C_2Cl_6)[42,43] for approximately three minutes. A steel rotor, designed like a fan, is attached to a shaft and utilised as a stirrer to agitate the liquid metal. To achieve this objective, the rotor is coated with zirconium ceramic material. The stirrer is completely submerged in the molten metal, reaching a depth of approximately 65% within the crucible. The molten metal undergoes vigorous agitation at 300 rpm, leading to the creation of a whirling vortex. During the process of stirring the liquid metal, the ZrO_2 particles, which make up 3% of the weight of the Al2219 alloy, are heated individually in a heater until they reach a temperature of 500°C. These heated particles are then systematically injected into the swirling flow of the liquid metal in a controlled manner, done in phases. The stirring is continued until the Al2219 and ZrO_2 reinforcement achieve optimal wettability, resulting in the enhancement of interfacial shear strength. The liquid metal blend, consisting of an Al2219 and ZrO_2, is poured into moulds of different dimensions, resulting in the formation of the Al2219- ZrO_2 6 wt. % composite. Figure 2 (a-b) illustrates the tensile specimen utilised in the investigation before and after testing.

For characterisation, the synthesized micro composites were machined to ASTM standards. After confirming the presence of Zr and O components and the consistent distribution of elements in the matrix using SEM, the mechanical behaviour of Al2219 and its composites is evaluated using ASTM standards. Figure 2 (a) shows the tensile specimen as per ASTM E8 standard[44,45].

3.0 Results and Discussion

3.1 Microstructural Studies

This investigation involved cutting parts of a composite casting into several pieces obtained from different locations. These pieces were subsequently polished using polishing products that contained abrasive particles less than 3 microns in size. The polishing procedure was conducted at a significantly slow rate utilising a polishing apparatus. Polishing effectively eradicates surface scratches on composite materials, yielding a sleek and flawless surface. The polishing process utilised films containing SiC and ZrO_2 abrasives. The paramount importance of utilising both high-grade abrasive films and polishing cloth cannot be overstated when aiming to attain a sophisticated microstructure. The refined substance was subjected to etching using Kellar's reagent[46,47], a solution consisting of hydrochloric acid, hydrofluoric acid, nitric acid, and water. This etchant was used to enhance the clarity of microstructural attributes, such as phase properties and grain size. Once it was verified that the polished surface was devoid of any dirt, grease, or oil, Kellar's reagent was administered to the surface using cotton swabs soaked in etchant. The reagent

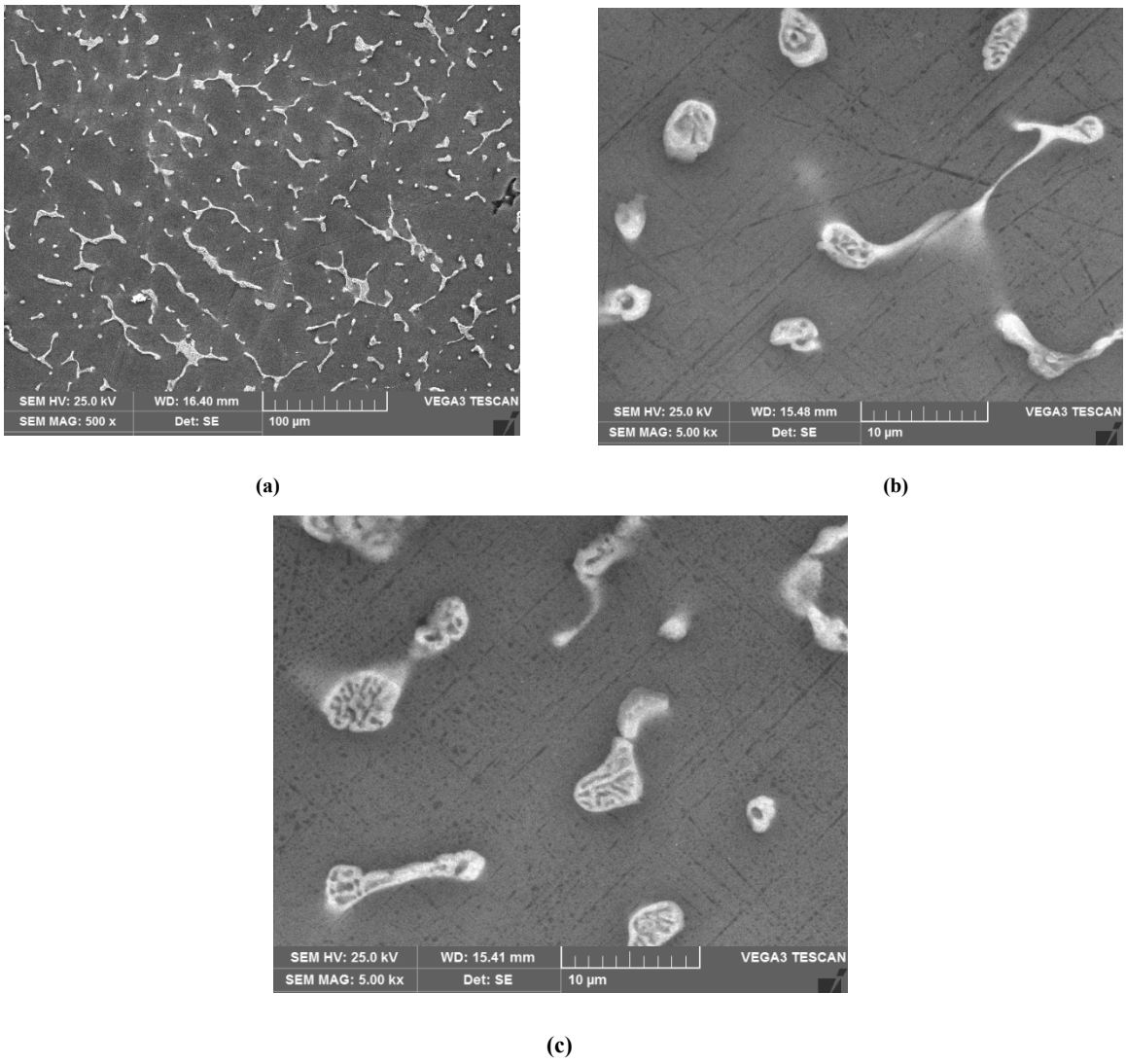


Figure 3. **Figure 3.** Scanning electron microphotographs of **(a)** Al2219 alloy **(b)** Al2219-3% ZrO_2 **(c)** Al2219-6% ZrO_2 composites.

was administered using delicate rotational motions. Afterwards, the surface that had undergone etching was purified using alcohol and subsequently dried.

The specimens undergo analysis for microstructural features via SEM. Figure 3 (a-c) exhibits the micrographs of the Al2219 and the composites strengthened with micro ZrO_2. Figure 3 (a) shows the SEM image of the Al2219 in its unadulterated state. The micrographs of the Al2219-3wt. % ZrO_2 and Al2219-6 wt. % micro ZrO_2 composites are shown in Figure 3 (b-c). The study reveals that a substantial proportion of the micro ZrO_2 particles are uniformly dispersed throughout the Al2219 alloy. Moreover, these data illustrate the consistency of the composites that were formed. The microphotographs clearly show the increased amounts of reinforcement in the Al2219 composites.

3.2 Hardness Measurements

Figure 4 demonstrates a clear correlation between the wt.% of ZrO_2 and the hardness of Al2219 alloy. Specifically, as the wt.% of ZrO_2 increases from 3 to 6 wt. %, there is a noticeable increase in hardness. The Al2219 in its as-cast state has a hardness of 68.52 BHN. The alloy's hardness increases to 27.4% by adding 6 wt. % of ZrO_2.

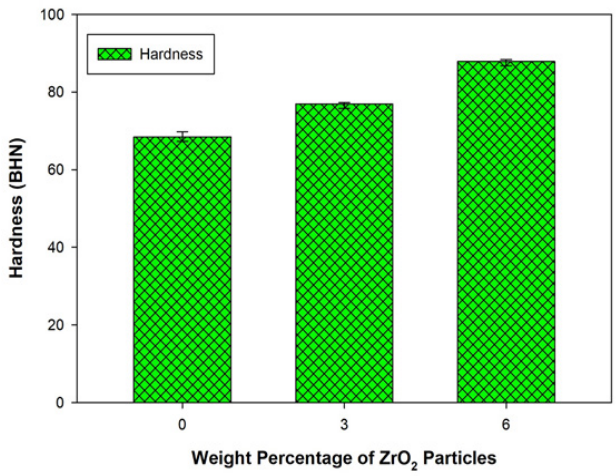


Figure 4. The hardness of Al2219-ZrO_2 composites.

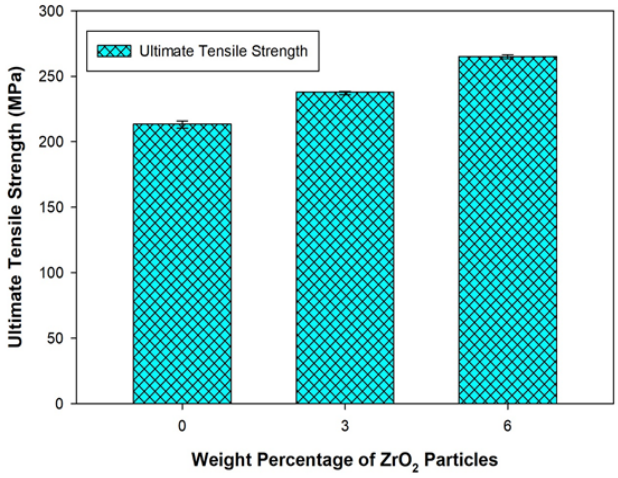


Figure 5. The ultimate strength of Al2219-ZrO_2 composites.

The increased hardness is due to the existence of inflexible ZrO_2 particles that hinder the movement of dislocations inside the Al2219. The inclusion of microparticles often enhances the strain energy at the outside edge of ZrO_2 particles, leading to an increase in hardness in composites. Other researchers have also discovered similar results[48,49].

3.3 Tensile Properties

Figure 5 exhibits the outcome of the tensile tests carried out at standard room temperature, showcasing the various wt. proportions of micro ZrO_2 particles. Figure 5 demonstrates that the average Ultimate Tensile Strength (UTS) values rise as the concentration of ZrO_2 in the Al2219 increases. ZrO_2 inclusion in the Al2219 matrix alloy acts as a protective measure for the more pliable matrix. The Al2219 has a strength of 213 MPa in its as-cast state. Furthermore, as the weight percentage of micro ZrO_2 increased from 3 to 6 wt. % in increments of 3 wt. %, there was a noticeable increase in the UTS values, as shown in Figure 5. The Al2219 alloy with a 3 wt. % of ZrO_2 composites has been determined to have a UTS of 237.2 MPa. The strength value of Al2219 with 6 wt. % of ZrO_2 composites is observed to be 264.8 MPa. The addition of 6 wt. % of micro ZrO_2 particles to the Al2219 alloy resulted in a 24.3% increase in its ultimate strength. The increase in the ultimate strength of the Al2219, resulting from the addition of 3 and 6 wt. % of ZrO_2 particles can be attributed to the difference in thermal coefficients between the Al2219 and the evenly dispersed micro ZrO_2 particles[50,51].

Figure 6 demonstrates an improvement in yield strength by adding ZrO_2 in Al2219. Raising the wt.% of ZrO_2 particles from 3 to 6 wt. % results in an elevated yield strength in the Al2219. The Al2219 has a Yield Strength (YS) of 175.3 MPa in its as-cast state. The strength of the alloy is increased to 201.9 MPa and 228.6 MPa, respectively, when it is reinforced with 3 and 6 weight % of ZrO_2 in composite form. Previous studies[52,53] have reported similar findings when including rigid particles in the aluminium alloy matrix. The strength of uncoated ZrO_2 reinforced composites with 6 wt. % Al2219 is

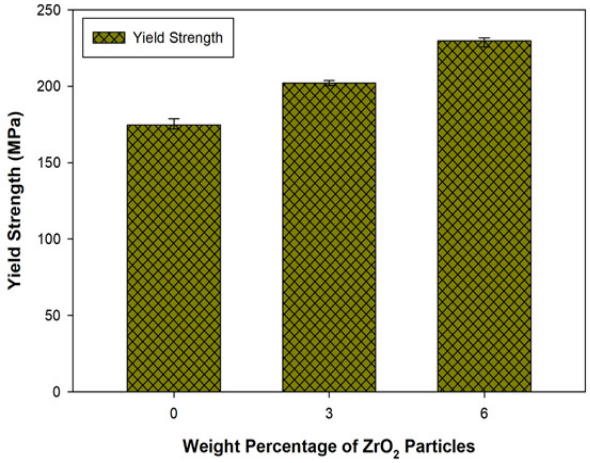


Figure 6. Yield strength of Al2219-ZrO_2 composites.

enhanced by 30.45%. The rise in yield strength is ascribed to the existence of rigid ceramic ZrO_2 particles, which strengthen the structural composition and consequently result in enhanced mechanical stiffness. The expansion of these inflexible micro-particles during the cementing process may have resulted in substantial and enduring compressive stress due to the disparity in expansion coefficients between the pliable matrix and fragile particles[54]. The improved quality is also attributed to the compact arrangement of the reinforcement, which leads to a minimal distance between particles in the lattice[55,56].

Figure 7 demonstrates the effect of including ZrO_2 particles on the ductility of the Al2219 and composites. When a specimen is subjected to a load in its axial route, the material exhibits a propensity to elongate[57,58]. The elongation of a test specimen in tensile testing is considered by measuring the ratio of the rise in its gauge length. Usually, the extension of a sample is quantified as a percentage. Increased elongation percentage corresponds to better material ductility[59,60]. Figure 6 illustrates the percentage growth in length of the Al2219 alloy in its original, unaltered condition. Tensile testing was conducted on the Al2219 alloy incorporating composite composites consisting of 3 and 6 weight per cent of ZrO_2 particles.

Incorporating ZrO_2 particles into the as-cast Al2219 alloy leads to a reduction in the percentage elongation. In addition, the percentage elongation decreases as the wt.% of particles increases in the Al2219. The initial tensile strain of the Al2219 alloy is 14.6%. Nevertheless, the inclusion of 6 wt. % of ZrO_2 particles leads to a reduction in the tensile strain, resulting in a fall to 11.91%. The decline in elongation is mostly ascribed to the incorporation of inflexible oxide particles inside the Al2219 matrix.

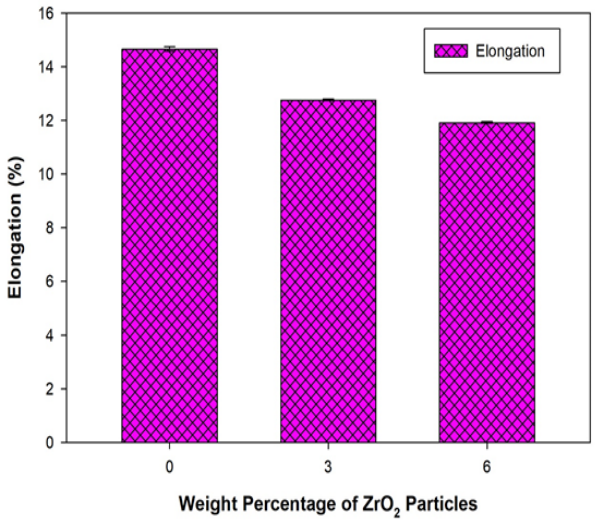


Figure 7. Elongation of Al2219-ZrO_2 composites.

4.0 Conclusions

This study examined the microstructure and mechanical properties of composites constructed of Al2219 alloy with ZrO_2 particles. The following findings arrived:

- Micro composites of Al2219 alloy with reinforcement of ZrO_2 were made using the stir cast technique.
- Micrographs of composites show the even dispersal of ZrO_2 in the Al2219 alloy.
- The hardness of Al2219 is improved by 27.73 % by adding 6 wt.% of ZrO_2 in the Al2219 matrix.
- The ultimate and yield strengths of Al2219 alloy were enhanced by the addition of ZrO_2. The UTS and YS of Al2219 have been improved by 24.31% and 30.45%, respectively, in the case of Al2219 with 6 wt.% of ZrO_2 composites.
- The ductility of Al2219 alloy has been reduced due to the inclusion of hard oxide particles in the soft Al2219 matrix.

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