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COMPARATIVE STUDIES ON THE EFFECTS OF VARIOUS PARTICULATES REINFORCEMENTS ON THE MECHANICAL AND WEAR PROPERTIES OF ALUMINUM ALLOY (AA2618) MATRIX COMPOSITE

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Keywords: *Composite, Reinforcement, Particulate, Fly Ash, Silicon Carbide, Titanium Carbide.*

Abstract: *Studies on the effects of various particulate reinforcements on the mechanical and wear properties of aluminum alloy (AA2618) matrix composites have been carried out. Compo-casting method was used in which 0vol%, 5vol%, 10vol%, 15vol%, 20vol%, 25vol% and 30vol% each of AA2618/SiC, AA2618/TiC and AA2618/fly ash composites were made. The cast specimens were machined to different dimensions for various mechanical and wear resistance tests. The mechanical tests done were ductility, hardness, yield strength, ultimate tensile strength, Young's modulus and density. Pin on disc computerized sliding wear resistance tests on the composite samples were also done. The results of mechanical characterization revealed that increase in vol% addition of these particles in the matrix of the alloy resulted in corresponding increase in all the mechanical property tests except the ductility that decreased with increase in vol% addition of the particles. AA2618/SiC composite recorded the highest value while the least value was shown by AA2618/fly ash composite. It was also discovered that addition of fly ash particles in the matrix of AA2618 recorded significant increase in strength without unduly compromising the ductility. The obvious facts of these developments are that these particles enhanced the mechanical properties of this alloy through dispersion strengthening by infringement on dislocation movements within the internal structure of the composite with corresponding increase in dislocation density. Sliding wear tests of these samples showed that there were improvements in wear resistance of the composites as a result of the presence of these particles within the matrix of the alloy. 20vol% addition of SiC and TiC and 25vol% addition of fly ash gave the best results of mechanical tests. Beyond this, segregation started and mechanical strength was reduced. Finally these particulate reinforcement's enhanced mechanical and wear properties of the composites with SiC particles recording the best result. Therefore, they are recommended for use in industrial applications as a result of their enhanced mechanical and wear properties.*

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1. Introduction

Pure aluminum obtained from the electrolytic reduction of alumina (Al_2O_3) is a relatively weak material [1]. Therefore, for applications requiring greater mechanical strength, it is alloyed with elements such as copper, zinc, magnesium, manganese etc, usually in combinations of two or more of these elements together with iron and silicon. Wrought aluminum alloys are divided into seven major classes according to their major alloying elements. In the internationally agreed four-digit system, the first of the four digits in the designation indicates the principal alloying element of the alloys within the group [1]. Aluminum alloy 2618 is a heat treatable Al-Cu-Mg-Fe-Ni etc cast alloy developed for high temperature applications, especially in the manufacture of aircraft engine components. This alloy has good elevated temperature strength up to 200^{o}C - 204^{o}C [3, 4].

This alloy derives its strength from a combination of precipitation and dispersion hardening [5]. The main precipitates are coherent Guinier Preston-Bagaryatskii (GPB) (Cu, Mg) zones which form rapidly on aging at temperatures up to at least 200^{o}C, and a semi-coherent S' (Al_2CuMg) phase [6]. The S' phase forms as rods or laths on the {210} matrix planes and nucleates preferentially on dislocation lines. The precipitation of S' in the matrix is known to be facilitated by silicon due to its effect on increasing the available concentration of vacancies and/or the stability of the pre-existing GPB (Cu, Mg) zones. The presence of stable intermetallic particles (such as aluminide particles of the phase Al_9FeNi) helps to control grain size and impede dislocation movement [7]. Here, balanced amounts of iron and nickel are needed; otherwise, these elements combine with some of the copper to form stable compounds which reduce the response of the alloy to age hardening [8, 9]. Composites formed out of aluminum alloys are of wide interest owing to their high strength, fracture toughness, wear resistance and stiffness. These composites are of superior in nature for elevated temperature application when reinforced with ceramic particles [2]. A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components [10]. Composites are used not only for their structural properties, but also for electrical, thermal, tribological, and environmental applications [11]. In order to gain background knowledge on this work in similar fields, various papers and journals were studied and the literature survey regarding some aluminum alloy systems and their composites were reviewed as follow. *IK Vijaya Bhaskar et al* reported that aluminum alloy composites are used in engineering applications such as aircraft, aerospace, automobiles and various other fields due to their excellent mechanical properties such as high strength, high stiffness, high strength to weight ratio and better wear resistance [12]. *Martin J. et al* in the studies of tribological behavior on A16061-Al_2O_3 composites concluded that a characteristic physical mechanism involves during the wear process [13]. *Kenneth Kanayo Alaneme et al* demonstrated that the mechanical properties of aluminum hybrid composites reinforced with groundnut shell ash (GSA) and silicon carbide

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showed remarkable increase in ultimate tensile strength, hardness and specific strength [14]. *H. C. How and T.N. Baker* in their investigation of wear behavior of A16061-saffil fiber concluded that saffil is effective in improving wear resistance of the composite [15]. *S. Dhanasekaran et al* states that increase in volume fractions of SiC and Al_2O_3 particle reinforcement on microstructure and mechanical properties of the aluminum alloys increase the tensile, yield strength and hardness properties. Dislocation density, precipitation hardening and changes in grain size are the main mechanisms enhancing the mechanical properties of particulate reinforced composites [16]. *Bharat et al* stated that the presence of fly ash particles enhanced wear and mechanical properties of aluminum fly ash composites by acting as infringement to dislocation movement within the matrix of the composites [17]. *Y. Reda et al* and *R. Clark et al* in their studies on A17075 reported that, pre-aging at various retrogression temperatures improves the hardness, tensile properties and electrical resistivity [18, 19]. *Sulardjaka et a*l reported that improved wear resistance and mechanical properties such as tensile strength and Young modulus were achieved in carbothermal reduced fly ash reinforced aluminum composites [20]. *V.Mahesh Kumar et al* reported on the effects of ceramic reinforcements of Al_2O_3 on the mechanical properties of Al-7072 for different weight fraction manufactured using the stir casting technique. Mechanical properties such as tensile strength, Young's modulus, ductility, compressive strength, hardness and impact resistance were evaluated for both samples Al-reinforced and unreinforced 7072. The results show that as the content of reinforcing particles increased, there was significant increase in mechanical properties such as breaking strength and compressive strength, hardness and ductility followed by a reduction in density [21]. *I.B. Ramgopal et al* reported that aluminum metal matrix composites with multiple reinforcements (hybrid metal matrix composites) have great potentials of satisfying recent demands of advanced engineering applications due to their improved mechanical properties such as hardness, stiffness, ultimate tensile strength, toughness etc [22]. *K. Komai et.al* reported the superior mechanical properties of A17075-SiC_w composites [23]. From the above discussions, it can be concluded that no data is available on the mechanical and wear resistance properties of particulate reinforced AA2618 composite. Hence, this present study is aimed to fabricate AA2618-SiC, AA2618-TiC and AA2618-fly ash composites containing various volume percentages of the particles and carry out comparative studies of their mechanical, and wear resistance properties for engineering applications.

2. Experimental Methods

Compo-casting method was used to fabricate aluminum alloy AA2618 used in this work. Thereafter, 500g of AA2618 was remelted during the production of each composite and the various volume percentages of (0vol%, 5vol%, 10vol%, 15vol%, 20vol%, 25vol% and 30vol %) each of the silicon carbide, titanium carbide and fly ash particulates reinforcement materials composites were fabricated. The melt temperature was raised to 720^{o}C, and then degassed by adding hexachlorethane tablets. Stirring of the melt was done electro-mechanically with the help of a mild steel stirrer

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when the various reinforcement particles had been added via vortex process at a stirring speed of 110 rpm for about 10 minutes. This was to achieve a homogenous mixture. Thereafter, the melts with various volume percentages of reinforcement particles were poured into preheated permanent metallic moulds at a temperature of $670^{o}C$ and were allowed to solidify. Various mechanical tests were carried out on the composites. The tests done were ductility, yield strength, ultimate tensile strength, Young modulus, hardness and density. Brinell hardness measurement method was used and the aim was to investigate the effects of the particulate volume percentage additions on the mechanical properties of aluminum alloy AA2618 composite. Load applied was 750kgs and the indenter was a steel ball of 5mm diameter. The tensile testing of the composites was done using an instron tensile testing machine. Furthermore, wear resistance tests were carried out on the fabricated composites. The displacement of material as a result of hard particles or hard protuberances when these hard particles are forced against a moving solid surface is called wear. Here, sliding wear tests were carried out on prepared composite specimens. A computerized pin on-disc wear test machine was used for these tests. The wear testing was carried out at a constant sliding velocity of 1m/sec with loads of 15N. Cylindrical pins of size 1.3cm diameter and 2.3 length prepared from the composite casting were loaded through a vertical specimen holder against a horizontal rotating disc. The specimens' surfaces were abraded. The rotating disc was made of medium carbon steel of diameter 45mm and hardness of 70HRC. Wear tests were carried out at room temperature without lubrication for 30min. The main objective of this investigation is to study the wear resistance of these composites and the control specimen for comparative study.

3. Results and Discussions

The results of mechanical properties of AA2618 particulate composites containing different volume percentages of silicon carbide (SiC), titanium carbide (TiC) and fly ash are summarized in tables 1, 2 and 3 below and presented in graphical form in figures 1, 2, 3, 4, 5 and 6. Figure 1 presents the effects of particulate reinforced materials on the ductility of the composites. The graph shows that increase in the volume percentage addition of these particulates in the matrix of AA2618 decreases the ductility of the composite materials. This implies that there is remarkable decrease in the percentage elongation of the composites due to the addition of these particulate materials. It can also be seen that a major limitation in the engineering properties of particle-reinforced metal matrix composites (MMCs) is their rather low ductility as quantified by percent elongation. The tensile elongation decreases with increasing particle content [22]. The opposite changes in stiffness and ductility with increasing particle content reflects the interactions between particles and the intervening matrix within MMCs. From the graph, the least affected is AA2618 reinforced with fly ash. This shows that fly ash enhances the hardness of AA2618 without unduly compromising the ductility of the material. Silicon carbide (SiC) and titanium carbide (TiC) addition decreased the ductility of AA2618 remarkably with the highest affected being AA2618/SiC. The reason for this could be attributed to the brittle, hard and high densities of SiC and TiC particles [24]. Since these refractory materials are very brittle, when dispersed in the matrix of AA2618, they invariably decrease the ductility of the composite by exhibiting their brittle nature. Fly ash particles which are pliable and less dense will readily dissolve in the matrix of AA2618 and increase the strength without significantly affecting ductility. Furthermore, addition of these reinforcement particles to AA2618 matrix also increased yield strength, ultimate tensile strength, Young's modulus, hardness and density as can be shown in figures 2, 3, 4, 5, and 6 below respectively [15-22]. Figure 6, shows the effects of reinforcement particles on the density of the composites. The reinforcement additions increased the density of the composites [25, 26]. Another reason for the increase on other mechanical properties like ultimate tensile strength, Young's modulus; hardness and density of the composites with the addition of these particulates is that these dispersed particles enhanced the strength of the composites through Orowan and dispersion strengthening caused by resistance of closely spaced hard particles to the passing of dislocations. AA2618 alloy develops its strength via precipitation and dispersion hardening because it belongs to the class of (2xxx) of aluminum alloys [1, 5 and 27]. The presence of the reinforcement particles in the matrix of the alloy helps to impede dislocation movement [7]. This infringement on dislocation movement ultimately causes a remarkable increase in dislocation density of the composites. This phenomenon will lead to increase in mechanical properties [7, 28]. However, a critical look at the graphs show that beyond a certain volume percentage addition of the reinforcement particles the mechanical properties begin to decrease from their maximum values. At this point, segregation of the particles has developed in the matrix which will negatively significantly affect the mechanical properties of the composites. Figure 7 shows the wear behavior of the control sample (AA2618) and those of the composites of AA2618 with 15vol% each of SiC, TiC and fly ash. The data was obtained from the experiments using a fixed load, fixed sliding velocity and the same running time. The sliding velocity was 1m/sec and the total running time was 30minutes with a constant load of 15N. The results show a very small initial nonlinear wear regime. After a certain sliding distance, the wear increased linearly with time indicating steady state wear rate. The change from initial wear regime to steady state regime took place within few minutes (2-3min) of commencement of the test. From the figure, it is evident that wear rate of the control specimen i.e (AA2618) was the highest. This was followed by the 15vol% fly ash composite, then the sample with 15vol% TiC, and finally sample with 15vol% SiC. However, from the literature of this work, it was reported that increase in the volume percent of ceramic particles in the matrix of most aluminum based alloys decrease the wear rate of the composites. In this work, comparative analysis of these reinforcement particles has been carried out, and it has clearly shown that silicon carbide (SiC) particle has the highest wear resistance while the control sample recorded the least wear resistance. This behaviour is an indication that the particles retard the rate of wear of these composites. It is also clear that SiC has higher strength when compared to fly ash and TiC particles. The presence of ceramics particles like fly ash, titanium carbide (TiC) and silicon

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carbide (SiC) in the matrix of the composites retard the rate of wear of the material [19, 20]. The mechanism of this phenomenon is as follows: In the initial wear regime, the reinforced particles act as load carrying elements and as inhibitors against plastic deformation and adhesion of matrix material. In the later wear regime, these worn out particles get dislodged from their positions in the matrix and get mixed with the wear debris. The wear debris containing matrix materials, worn particles and iron (Fe) from the disc get pushed with the craters formed by dislodging of particles and act as load bearing elements. As a result, the presence of these hard particles reduces the rate of wear of the composites as shown in the graph.

Table 1: *Mechanical properties of AA2618 alloy & AA2618/SiC composites*

Specimens	Ductility (%EL)	Yield Strength (MPa)	Ultimate Tensile Strength(MPa)	Young's Modulus (GPa)	Hardness (BHN)	Density (g/cm^3)
AA2618 + 0 vol% SiC	10.4	370	435	75	68	2.713
AA2618 + 5 vol% SiC	9.86	374	452	95.3	84.2	3.282
AA2618 + 10 vol% SiC	9.28	379	456	98.9	89.3	3.331
AA2618 + 15vol% SiC	8.56	382	462	102.1	92.1	3.344
AA2618 + 20 vol% SiC	8.92	384	464	105.3	95.1	3.451
AA2618 + 25 vol% SiC	7.09	386	465	105.1	94.2	3.491
AA2618 + 30 vol% SiC	7.48	385	461	104.4	92.4	3.661

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Table 2: *Mechanical properties of AA2618 alloy & AA2618/TiC composites*

Specimens	Ductility (%EL)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Young's Modulus (GPa)	Hardness (BHN)	Density (g/cm^3)
AA2618 + 0 vol% TiC	10.4	370	435	75	68	2.713
AA2618 + 5 vol% TiC	9.22	372	447	88.1	76.8	3.101
AA2618 + 10 vol% TiC	8.8	375	452	90.8	80.2	3.142
AA2618 + 15 vol% TiC	8.14	378	459	93.7	82.1	3.221
AA2618 + 20 vol% TiC	7.31	381	463	98.4	86.3	3.242
AA2618 + 25 vol% TiC	7.89	383	464	97.6	88.6	3.248
AA2618 + 30 vol% TiC	6.31	383	463	96.6	81.1	3.257

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Table 3: *Mechanical properties of AA2618 alloy & AA2618/Fly ash composites*

Specimens	Ductiliy (%EL)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Young's Modulus (GPa)	Hardness (BHN)	Density (g/cm^3)
AA2618 + 0 vol% Fly ash	10.4	370	435	75	68	2.713
AA2618 + 5 vol% Fly ash	8.22	371	440	76.1	70.2	2.682
AA2618+ 10vol% Fly ash	7.71	373	442	79.2	72.6	2.711
AA2618+ 15vol% Fly ash	5.04	374	449	83.1	73.8	2.733
AA2618+ 20vol% Fly ash	4.38	376	453	82.3	75.1	2.768
AA2618+ 25vol% Fly ash	4.97	378	455	82.8	75.8	2.801
AA2618+ 30vol% Fly ash	3.52	376	452	81.1	73.5	2.956

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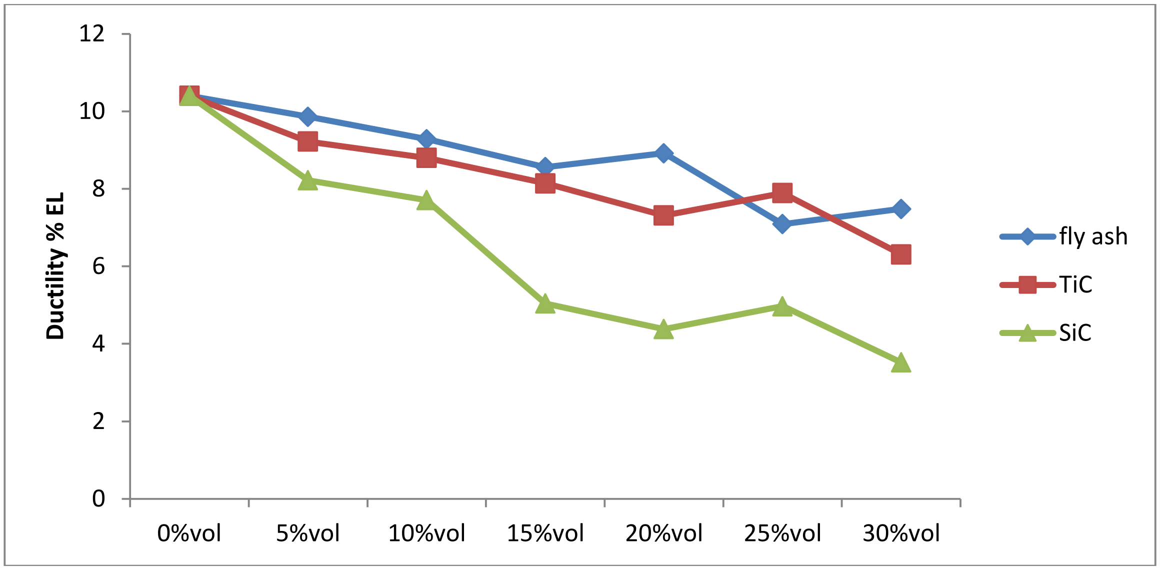

Figure 1: *Effects of vol% addition of the various particulates on ductility of AA2618*

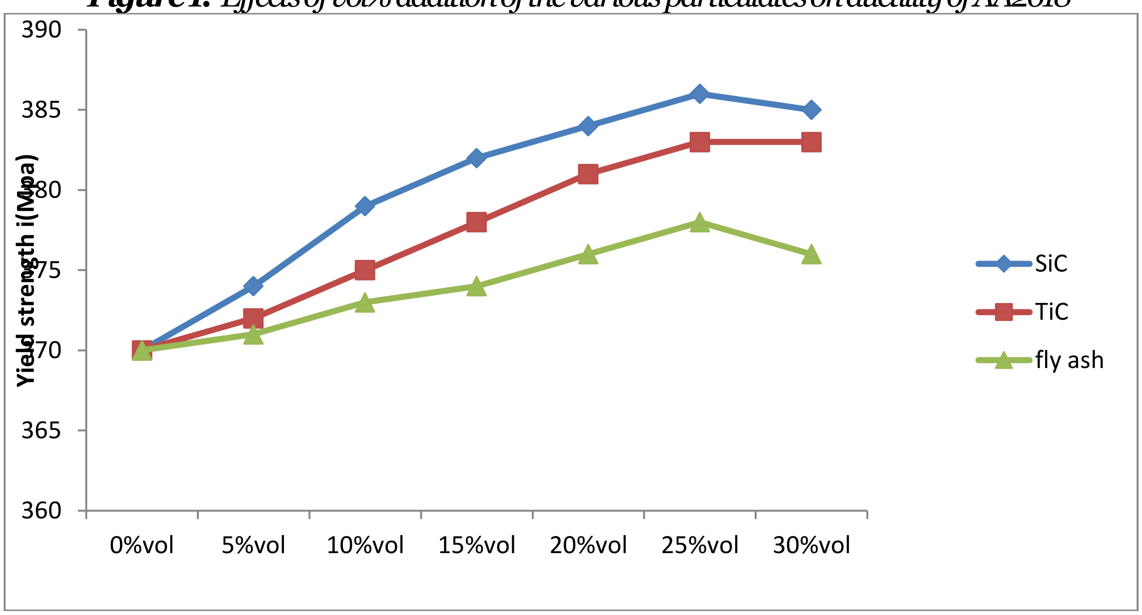

Figure 2: *Effects of vol% addition of the various particulates on yield strength of AA2618*

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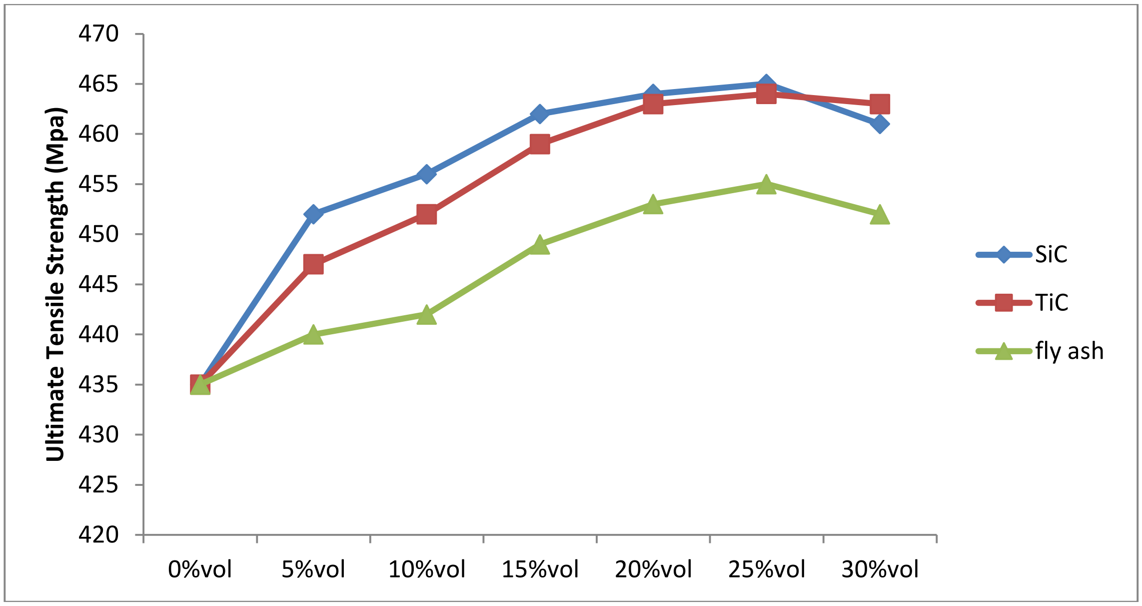

***Figure 3:** Effects of vol% addition of the various particulates on ultimate tensile strength of AA2618*

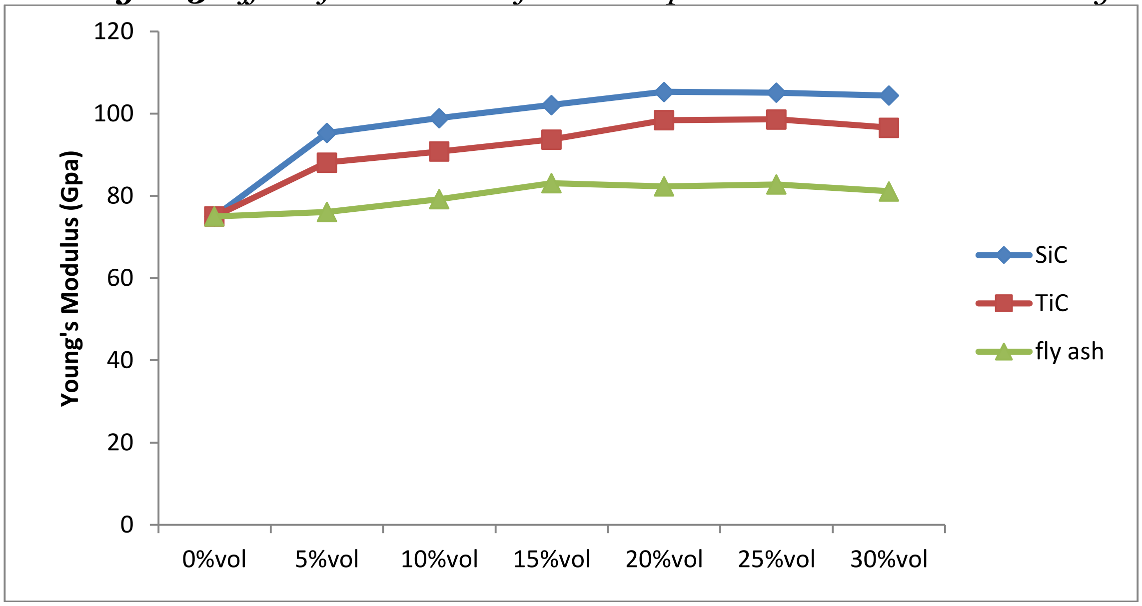

***Figure 4:** Effects of vol% addition of the various particulates on Young's modulus of AA2618*

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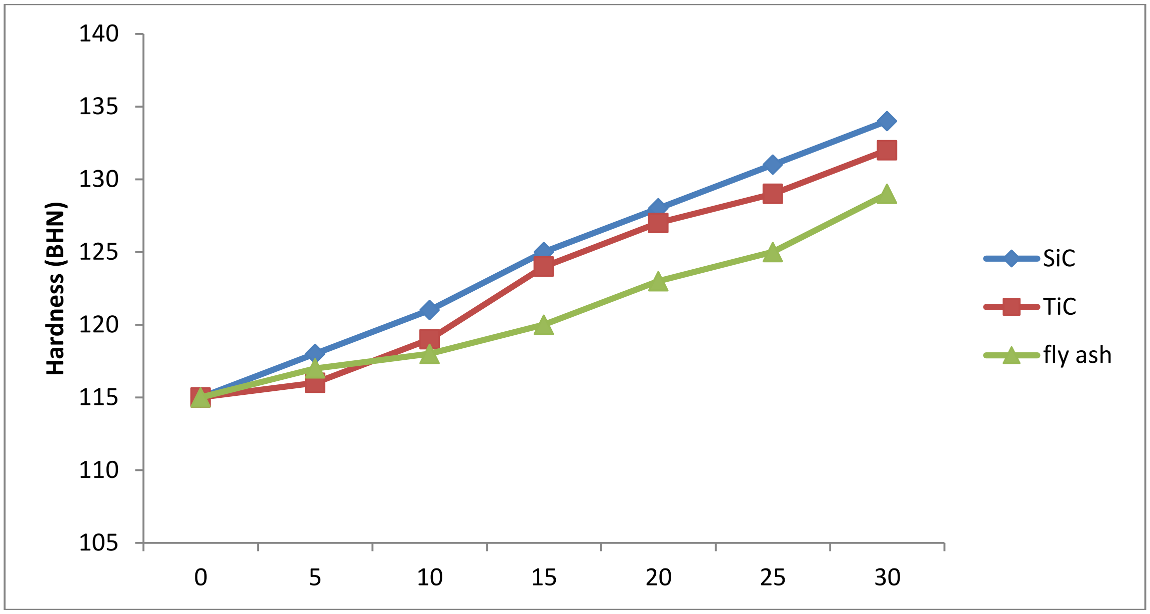

Figure 5: *Effects of vol% addition of the various particulates on hardness of AA261*

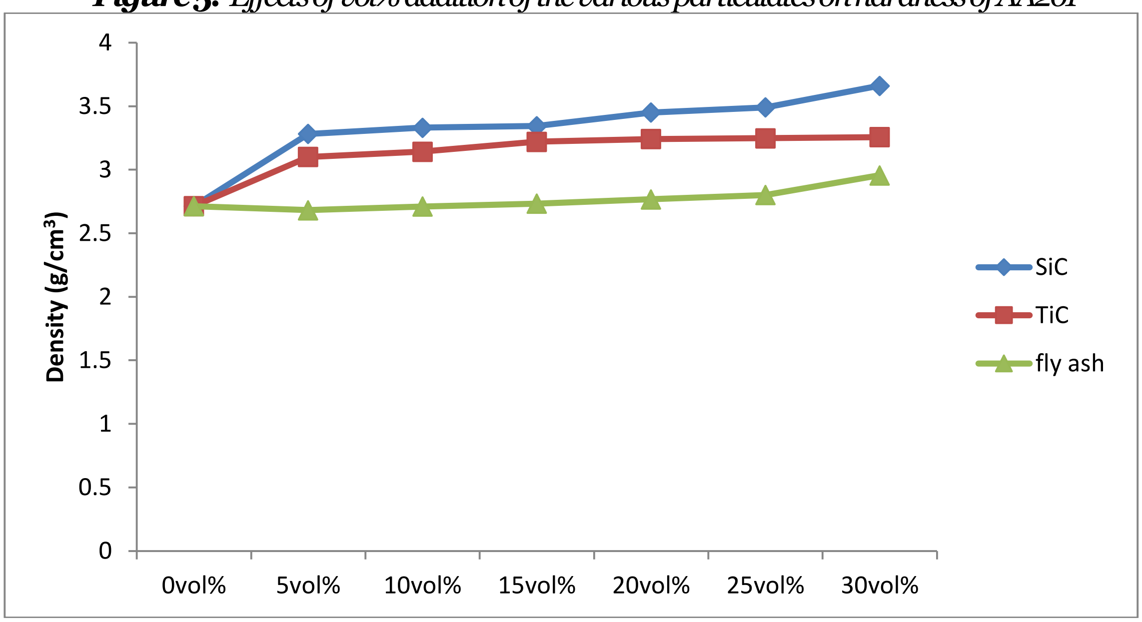

Figure 6: *Effects of vol% addition of the various particulates on density of AA2618*

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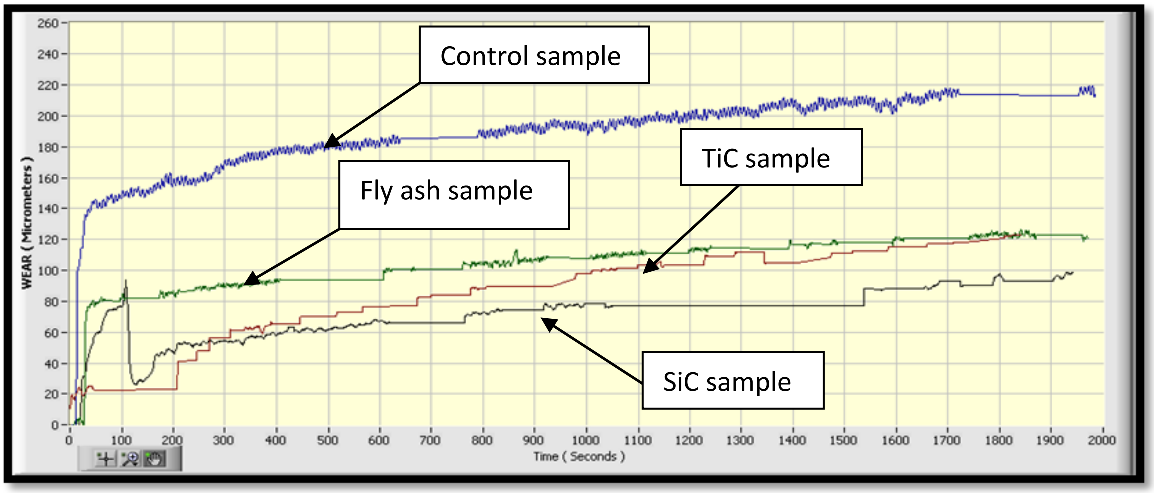

Figure 7: *Comparative study of the specimens' wear rates.*

4. Conclusion

The results of mechanical tests show that these reinforcement particles increased the mechanical properties of the composites as volume percentage addition increased, except the ductility that was reduced. The reason for this increase is that these dispersed particles enhanced the strength of the composites through dispersion strengthening. Their presence in the matrix of the alloy helped to impede dislocation movement. These infringements on dislocation movements caused remarkable increase in dislocation density of the composite right from the onset of plastic deformation. It was also discovered that beyond certain values of volume percent addition, there were reductions of these mechanical properties as a result of particle cluster/segregation which formed at 20vol% addition for silicon carbide and titanium carbide particles and 25vol% addition for fly ash particles. Sliding wear resistance tests indicated that AA2618/SiC has the highest wear resistance followed by AA2618/TiC, AA2618/fly ash while the least value was shown by the control sample AA2618. This behaviour is as a result of the presence of these reinforcement particles that helped to retard the rates of wear of the material. They act as inhibitors against plastic deformation and adhesion of matrix material.

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