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Experimental Investigation of AA2219 with ZrO_2-coal Ash Metal Matrix Composite

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Abstract

The matrix material AA2219 aluminum alloy is considered and the reinforcements were equally distributed thought out the matrix. Zirconium dioxide (ZrO_2)-coal ash reinforcements were widely known as alternative materials in aerospace mainframe structures, fuselage body in defence and aviation industry. Four different samples were fabricated by varying the ZrO_2 weight percent as (2, 4, 6, and 8 wt.%) with constant 10% coal ash reinforcement powders were prepared and used as reinforcement powders in fabricating AA2219 metal matrix composites (MMCs). The surface morphology of the fabricated samples was studied using the scanning electron microscope (SEM) and the mechanical properties were studied using the universal testing machine (UTM). Specimen with 8% ZrO_2 + 10% coal ash exhibited a good morphology with fine granular structure. From the tensile results it is found to be an elevation of tensile strength on increase of the ZrO_2 reinforcement. The tensile strengths are increased as 85, 96, 102, and 105 MPa with 2, 4, 6, and 8% of ZrO_2 filler. A substantial upsurge in mechanical properties has been pragmatic in the cases of 2 to 8% weight percentage accumulation of reinforcement of ZrO_2 with 10% coal ash constant. 8% weight addition exhibited a high durability. Thus, the optimum specimen can be used as an alternative material for airframe modules.

Keywords

AA2219, Metal matrix composites, Scanning electron microscope, Tensile strength, Zirconium dioxide, Coal ash

Introduction

The area of MMCs has taken application strides in the aerospace and defence industries [1]. The attributes of MMCs are high strength to weight ratio [2], specific strength attrition [3], and stiffness and wear resistance augmentation [4]. The most common alloys used in fuselage structures in the aerospace industries are AA2024 alloys, owing to its damage [5]. With limitations provided by the same, owing to its low yield strength (300 - 350 MPa), and subsequent drop in fracture toughness it has been replaced with AA7075 alloys, which has higher tensile strength, with increase in 25% fracture toughness and drop in weight by 20% [6]. This proved a good factor, but the cost of replacement came with a price and drop in corrosion resistance drastically in the areas of fuselage to upper wing airframe components [1, 3]. With the evolution of material and surge replacement coming into perspective AA2219 was considered to be an alternative providing high corrosion resistance, but could not enhance the materials tensile properties, which showed close to values of AA7075 alloys [2, 4]. For the same, scientists and researchers are working in the area of metal matrix composites with ceramic particles acting as reinforcements to improve the strength factor without compromising on its inherent parent property advantage [5].

The effect of Al_2O_3 has fast derived acceptance due to drastic increase in its physical and chemical properties of composite [7], but with increase in addition of alumina after 6%, there is a drop in the porosity and chemical reaction, which has its explicit effect on the wear and corrosion resistance of the composites. For the brief increase in AA2024 properties, SiC (silicon carbide) and ash was availed to bring a derivative of hybrid composites, which increased its tensile strength but with a drop in the wettability factor, particle distribution being minimal a decrement was observed in the elongation factor [8]. Scientists have investigated ash reinforced AA7075 alloys at disparate weight fractions [9], in order to bring about increase in the wettability and improvement in tensile properties. Furthermore, abrasive jet machining of hybrid composites was considered with boron carbide (B_4C) as reinforcements [10]. The presence of SiC in the AA7075 matrix showed enhanced hardness and strength which was perceived by the addition nanoparticles into the matrix composites [10]. A detailed analysis of yttrium oxide, B_4C, SiC as reinforcements was carried out to study the inherent changes it brings about the composites with respect to mechanical strength and wear resistance [11].

Though a wide set of work has been carried out in the aspect of composites making with respect to ceramic addition as reinforcements, it still leaves a lot of scope for evolution. One of the major deteriorating factors is its poor wear resistance of present alloys used in aerospace frames and upper wings, for which no work has been carried out in the area of making AA2219 with ZrO_2-coal ash as matrix and reinforcements respectively. With optimized values of addition, a total of four composite specimens were fabricated with varying reinforcement's weight % and having a constant addition of 12% coal fuel ash content for all four composite samples. The mechanical properties corresponding to tensile, hardness and wear was analyzed along with detailed characterization to comprehend the attrition properties.

Materials and Method

Material derivatives: matrix and reinforcements

The matrix material taken in consideration are aluminum alloys AA7475,whose major alloying element is zinc and whose application in the aerospace modules of wings, fuselage, flaps are attributed to its inherent strength of 350 MPa (UTS). The microstructure and chemical properties of AA7475 alloys are depicted and tabulated in figure 1 and table 1, respectively.

ZrO_2 particle in powder form was obtained (40 - 50 µm), along with pulverised ash (obtained from Dr. Narla Tatarao Thermal Power Station (Dr. NTTPS, Vijayawada, Andhra Pradesh, India) and powdered to nano-powder availing high speed ball milling facility, for 8 h duration, 250 rpm speed availing tungsten carbide coated steel balls. The individual chemical properties for the same are listed in table 2 and table 3 for ZrO_2 and coal ash, respectively.

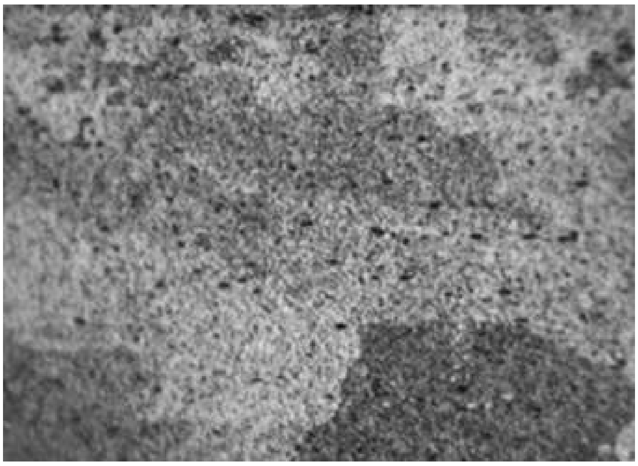

Figure 1: Base material microstructure of AA2219 alloy.

Table 2: ZrO_2 composition.

Constituent	ZrO_2	SiO_2	TiO_2	Fe_2O_3	Other
Wt.%	99.5	0.10	0.007	0.002	0.39

Composite fabrication: stir casting

In view of all mechanical processes, fabricating MMC's in batch production is easier in stir casting. In this method, percentage of reinforcement is added weight wise in molten matrix material and stirred in uniform speed availing coated stirrer to get uniform distribution of reinforcement [12]. The method of stirrer is vortex method. In order, a batch of 2 kg of AA2219 and its composites are melted using 6 kW electrical resistance furnaces just above melting point. Molten metal is stirred by a stirrer at a speed of about 200 rpm in order to have a uniform distribution of reinforcement varying in 2 to 8 wt.% in steps of two wt.%. Preheated reinforcement (up to 700 °C about 2 h) were added slowly and stirred for 10 - 15 min (Figure 2). The molten metal is allowed to be in static condition and then poured into preheated metallic moulds to obtain desired castings. Emphasis lies in the clean interfaces between the matrix and reinforcement a bit drastically attenuates the yield strength [13].

Experimental tests carried out to validate MMC's

A most important factor after fabricating an MMC is to experimentally test and validate the model for yield strength,

Table 1: Chemical composition of AA2219 (wt.%).

Element	Al	Cu	Sn	Mn	Fe	Si	Ti	V	Zn	Ni	Zr
Wt.%	91.97	6.8	0.03	0.316	0.17	0.05	0.04	0.155	0.05	0.021	0.07

Table 3: Constituents of coal bottom ash.

Constituent	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	MnO	ZnO	CuO	P_2O_5	LOI
Wt.%	65.50	16.21	4.90	1.20	0.75	2.80	0.12	0.20	0.040	0.080	Remaining

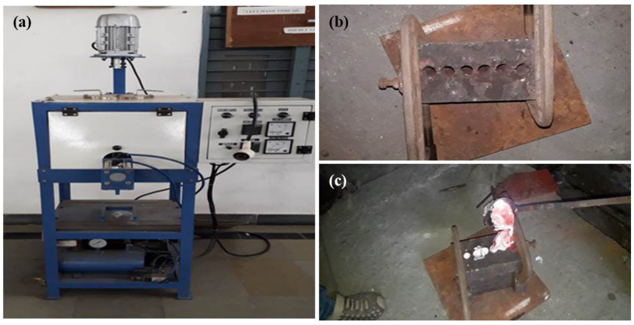

Figure 2: (a) Stir casting experimental setup, **(b)** Mold to make MMC's, and **(c)** Molten metal (M+R) poured to make cylindrical ingots.

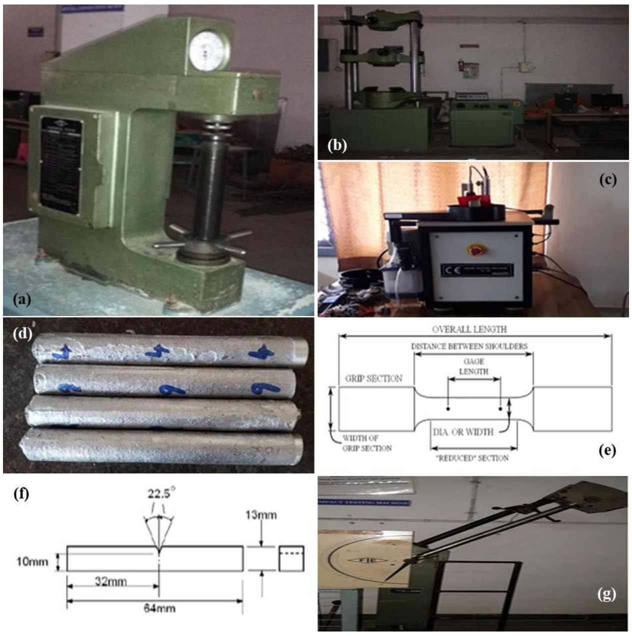

Figure 3: Experimental setups for validating model. **(a)** Hardness testing setup, **(b)** Tensile testing specimen, **(c)** Wear testing specimen, **(d)** Cross sectional view of specimen, **(e)** Tensile specimen details, **(f)** Impact test specimen dimension, and **(g)** Specimen taken for impact test.

hardness, amount of strain rate it can absorb before failure, and the wear resistance it can withstand owing to high end application [14]. Figure 3, depicts the images in detail of all the test experimental setups for validating the MMC.

Results and Discussion

Influence of hardness in MMC's

Brinell's hardness is tested for four composite samples at five different locations and an average value is taken in consideration, and the values are indicated in figure 4. For 2% ZrO_2 + 10% coal bottom ash composition the minimum value of hardness is achieved, this is owing to decrease in weight percentage, with an increase of 4%, 6%, and 8% of ZrO_2, the hardness value increased by 185 BHN, 200 BHN, and 217 BHN, respectively. The maximum value for hardness is observed at 8%, this owing to the fact of its high mechanical resistance and abrasive properties [15]. With the addition of materials beyond this would cause a drop in thermal resistivity causing a change in potential value, thereby causing a drop in

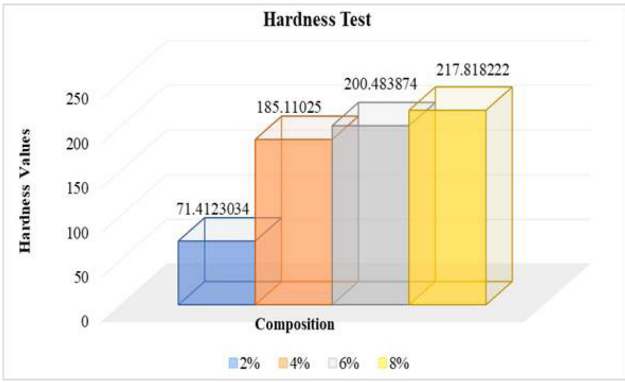

Figure 4: Hardness test of MMC's at varied weight percentage.

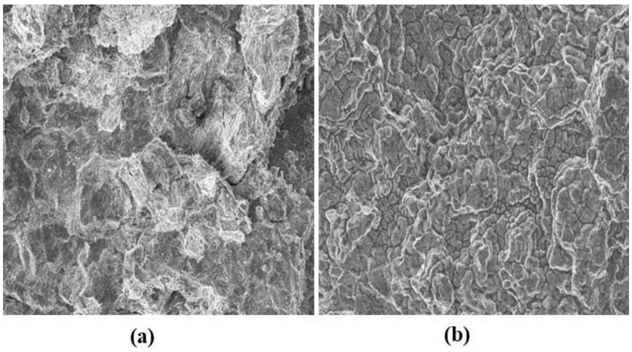

Figure 5: Comparison of SEM micrographs for (**a**) AA2219 parent and (**b**) 8% ZrO_2 + 10% coal ash reinforced material.

resistance to corrosion resistance. The same can be observed in the surface morphology images as mentioned in figure 5. A fine refined percentage of grains are observed in figure 5, in comparison with parent material. The grain structure being coarse in nature, as indicated in figure 5a, will have lower surface morphology, lower elongation strength, and deterioration in hardness. In figure 5b, it is observed that fine grain structures present increase the residual stress inside the body, owing to higher corrosion factor, and increase in hardness [16].

Influence of tensile strength in MMC's

The tensile strength is tested and average strength is identified for all four samples. With an increase in weight fraction an increase in tensile strength is observed, 2% wt of ZrO_2 sample is 85 MPa, 4% wt of ZrO_2 sample is 96 MPa, 6% wt of ZrO_2 sample is 102 MPa, 8% wt of ZrO_2 sample is 105 MPa. With the distribution of reinforcements evenly, the sample has witnessed higher tensile strength, as indicated in figure 5. AA2219 possess only 3 - 5% of elongation strength in correlation to weight added based reinforcements, as indicated in figure 6 [17].

With the presence of coal ash, it acts as a suitable dispersion medium which encompasses the whole reinforcements uniformly in the matrix, which aids in elongation properties with an overall increase in mechanical strength [18]. Elongation is a measure of the ductility of a material as determined by a tension test. The increase in a sample's gauge length measured after a rupture or break divided by the sample's original gauge length is referred to as elongation (Figure 7). Greater

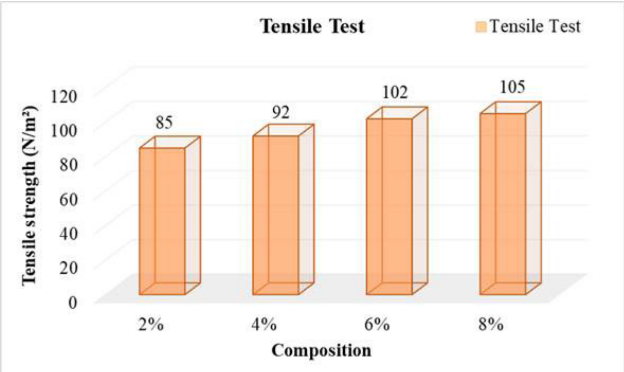

Figure 6: Comparison of tensile testing specimen.

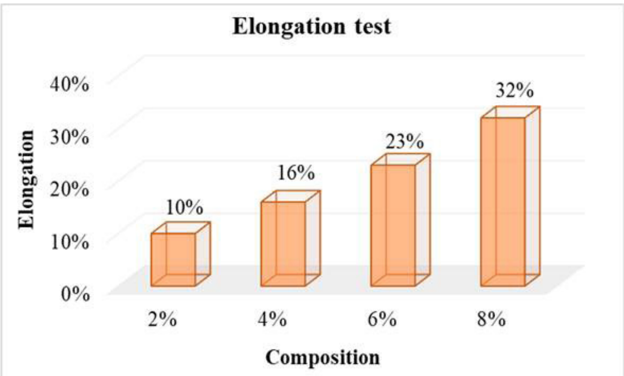

Figure 7: Comparison of elongation of the specimen.

the elongation higher the ductility or elasticity of the material [19]. From figure 8 it is observed that, though it is coarse in nature the toughness drop is high in correlation to fine grained structure, owing to dendrite formation which locks the phase of defects passing on [20]. Also, presence of coal ash increases the dispersion phase accommodating higher tensile and elongation strength [21]. This is attributed to continuous phase along the reinforcement and with the uniform spread throughout the material, a higher property of elongation is observed.

Influence of wear rate in MMC's

A wear analysis is conducted availing pin on disk apparatus, the reason for fracture and breakage of specimen is observed here as depicted in figure 9. As depicted presence of void decreases its strength, but to a large extent a lot of material has been devoid of voids, this attributed to the presence of coal ash (dispersion medium) and through proper stir casting method [22]. The presence of ZrO_2 material, aids in increase of wear resistance due to its inherent nature of attenuating mechanical strength [23]. The presence of voids aids in drop in tensile strength, but due to fine grain structures, around the void as seen figure 9, it aids in deflection of crack propagation around the void, thus thereby decreasing the chances of failure extensively [24]. The importance of reinforcements is justified, as AA2219, material is highly porous thus, having lower wear resistance strength in correlation to 8% ZrO_2 + 10% coal ash reinforced metal matrix composite.

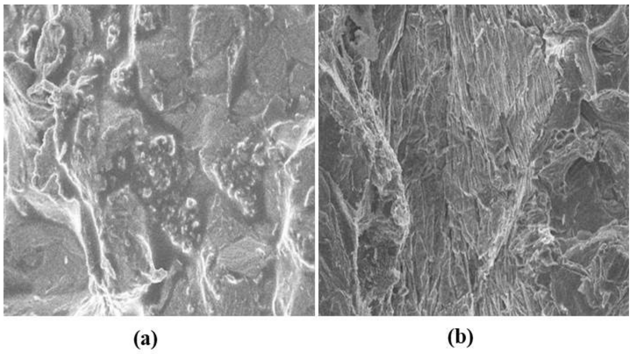

Figure 8: Comparison of SEM micrographs for (**a**) AA2219 parent and (**b**) 8% ZrO_2 + 10% coal ash reinforced material (after tensile and elongation test).

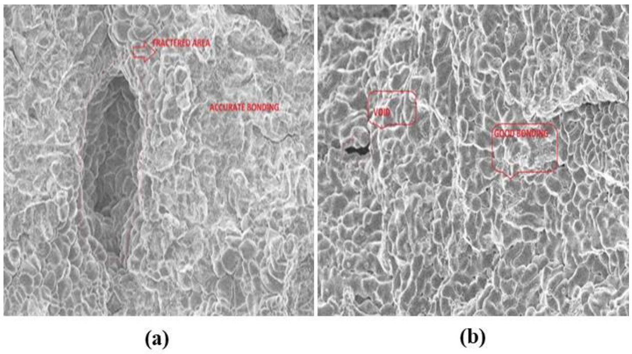

Figure 9: Comparison of SEM micrographs after wear test in 8% ZrO_2 + 10% coal ash reinforced material.

Conclusions

For addressing, aerospace mainframe structures, fuselage body in defence and aviation industry, an alternative metal matrix material is made by availing ZrO_2-coal ash as reinforcements, for which following conclusions have been derived:

- Stir casting method was adopted to successfully manufacture metal matrix composite with ZrO_2-coal ash as reinforcements, by equal dispersion of reinforcements throughout the matrix material AA2219.
- An appreciable increase in mechanical properties has been observed in the cases of 2 to 8% weight percentage addition of reinforcement of ZrO_2 with 10% coal ash constant. 8% weight addition showcased high durability, in correlation with others.
- For airframe modules, experimentally test and validation of the matrix reinforced model was done based on yield strength, hardness, amount of strain rate it can absorb before failure, and the wear resistance.
- For 2%, 4%, 6%, and 8% of ZrO_2 + 10% coal ash; the hardness value increased by 71 BHN, 185 BHN, 200 BHN, and 217 BHN, respectively. This increase is due to reinforcement's mechanical capability and abrasive nature.
- Fine granular structure, observed in 8% of ZrO_2 + 10% coal ash, increases the residual stress inside the body, owing to higher corrosion factor, and increase in hardness.

- The tensile strength 2% wt of ZrO_2 sample is 85 MPa, 4% wt of ZrO_2 sample is 96 MPa, 6% wt of ZrO_2 sample is 102 MPa, 8% wt of ZrO_2 sample is 105 MPa, and this is attributed to the even distribution of reinforcements inside the matrix.
- An elongation of 10 - 32% is observed with weight addition of reinforcements, was the dispersion medium encompasses the whole reinforcements uniformly in the matrix, aiding in elongation properties with an overall increase in mechanical strength.
- The presence of voids aids in drop in tensile strength, but due to fine grain structures, encompassing the void increases deflection of crack propagation around the void, thus thereby decreasing the chances of failure extensively.

Acknowledgements

None.

Conflict of Interest

None.

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