Effect of Glass Particle Addition on the Mechanical Properties of Aluminum-Base Particulate Composites.

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ABSTRACT

This paper presents the influence of glass particle addition in the 0 to 40% range on the mechanical properties of aluminum-base particulate composites. Increase in the composition of glass particles in aluminum matrix from 0 to 20, and 40% caused the percentage elongation at fracture of specimen to decrease from 10.4 to 8.9, and 7.4, respectively; this could be attributed to the improved internal stress, due to the particulate reinforcement, having adverse effect on the ductility of the specimen.

Within the same glass particle compositional range, ultimate tensile strength increased from 82.7 MN/m^2 to 91.5 MN/m^2, and 111.8 MN/m^2, respectively while ultimate compressive strength correspondingly increased from 102.3 MN/m^2 to 114.6 MN/m^2, and 129.2 MN/m^2, respectively, and impact energy decreased from 24.2 Nm to 21.5 Nm and 17.5 Nm, respectively. Reduction in fatigue stress amplitude was found to increase the number of cycles-to-failure, a measure of the fatigue life of the specimens. Also, fatigue life was observed to decrease with increase in glass particles addition; at fatigue stress of 45 MN/m^2, the fatigue life of specimens with 0, 20, and 40% glass particles compositions are 398, 79 and 15 cycles-to-failure respectively. When the fatigue stresses on the respective specimens are 85 MN/m^2, 43 MN/m^2 and 29 MN/m^2, the specimens failed at 100 cycles–to-failure. These findings show that addition of glass particles into aluminum matrix improves the strength of the aluminum alloy at the expense of ductility, impact energy and fatigue life.

(Keywords: glass particles, mechanical properties, aluminum composites)

INTRODUCTION

Alloys and composites were developed to exhibit desired properties required of modern engineering materials for advanced technological applications. These properties are high strength and hardness, corrosion resistance, ability to withstand very cold to super-high temperatures and extremely severe weather, etc. No material in nature possesses all these properties. Metallurgical combination of two or more materials results in the formation of an alloy, however, composites are made from two or more constituent materials with unique physical and/or chemical properties that remain distinct on the macroscopic level within the finished structure. The components can be metals only or metal in combination with non-metals (like polymers or ceramics), or non-metals only.

In composites, reinforcement materials can be in continuous or discontinuous form. Continuous reinforcement uses monofilament wires or fibers embedded into the matrix (Allen *et al.,* 1994), while discontinuous reinforcement uses whiskers, short fibers, or particles.

Many research works had been carried out in the past on metal matrix composites. The works range from microstructural analysis (Allen *et al.,* 1994; Soboyejo, 1994; Bozic *et al.*, 2004), failure mechanism (Harmon and Saff, 1989; Johnson, 1992; Yeh and Krempl, 1992; Gabb *et al.*, 1993; Kim, 1994; Marshal *et al.*, 1994) to studies into the effects of processing methods on mechanical properties (Assar and Al-Nmr, 1994; Doghri *et al.*, 1994; Jeong *et al.*, 1994).

Some of the factors that determine the strength of metal matrix composites are the size of reinforcement materials (Aboudi *et al.*, 1993), proportion of reinforcement materials (Surappa and Rohatgi, 1981), and orientation of reinforcement fibers (Nguyen *et al.*, 1994). The third case results in anisotropic structure; in which alignment of the materials affects the strength of the composites. However, the second case is the basis of the present research work.

In this research, therefore, the effect of glass particles proportion on the mechanical properties of aluminum-base particulate composites are experimentally investigated and presented. The mechanical properties evaluated are tensile, compression, impact, and fatigue properties.

MATERIALS AND METHODS

Work Materials and Specimen Preparation

The research materials used in this investigation are aluminum alloy and glass particles. Aluminum alloy obtained from electric cable, household utensils and internal combustion engines of motorcycles were cut to smaller pieces and weighed on an electric weighing balance. For each 1,000g of aluminum alloy, appropriate amounts of glass particles, in the range of 100, 200, 300, and 400g, were set aside to obtain 10, 20, 30, and 40%w concentration respectively in the aluminum matrix.

With the foundry sand, wooden patterns were used in obtaining the mould cavity inside a drag and cope assembly. A gating system of sprue and riser was incorporated to allow the flow of molten aluminum.

Thereafter, the 1,000g of aluminum alloy were melted in a furnace at $700^{O}C$ for 30 minutes; to obtain 10%w glass particles concentration in the aluminum matrix, 100g of glass particles were then added and stirred by a stir casting method. The mixture was then removed and poured into the mould cavity. After solidification and sufficient cooling to room temperature, the cast samples were obtained by shaking out the sand mould. Repeated processes were carried out to obtain specimens with respective particulate concentrations of 20, 30, and 40%w. It was observed that above 40%w, despite thorough mixing, the glass particles were not held in suspension in the molten aluminum but settled down before pouring was effected.

The samples were machined and prepared for tensile, compression, impact and fatigue tests. Unreinforced cast aluminum alloy was also obtained and machined to serve as control or reference sample.

Experimental Test Procedures

Tensile Test: Tensile test specimens from unreinforced and reinforced aluminum composites of varied concentration of glass particles were respectively subjected to constant extension rate tensile (CERT) test on a tensometer. As straining continued the maximum force (or ultimate load) exerted on each specimen before fracture, was recorded via a mercury column. The values were confirmed on a tensile force versus extension curve plotted on a recording sheet with the aid of a rotating drum and cursor on the tensometer. Ultimate tensile strength was obtained by dividing the ultimate load with the original cross-sectional area of the gauge section of the specimen. Also, the percentage elongation at fracture of respective specimen was determined. Repeated tests showed good agreement within a measurement accuracy of ±3%.

Compression Test: Cylindrical compressive test specimens were respectively compressed to fracture on the same tensometer used for tensile test. However, a compressive rig was used and the direction of loading was reverse compared to that of tensile loading. Ultimate compressive strength was obtained by dividing the compressive load by the original cross-sectional area of the specimen. Repeated tests showed good agreement within a measurement accuracy of ±4%.

Impact Test: Impact specimens of $60mm \times 10mm \times 10mm$ dimensions were notched at the middle to a depth of 3mm to create an area of stress concentration for initiating fracture. Each of the specimens (reinforced and unreinforced) was successively fixed on a Charpy impact testing machine to receive a blow from the fast moving hammer released from a fixed height on the machine. The reading on a dial gauge on the machine showed the impact energy absorbed by the respective specimen. Repeated tests, carried out to confirm initial readings, indicated an accuracy of ±3% in the recorded impact energy values.

Fatigue test: Unreinforced specimen was clamped on the grip of a completely reversed Avery 7305 bending fatigue testing machine with a zero mean stress in order to evaluate its fatigue properties. Thereafter, a bending load was imposed on the specimen by means of an oscillating spindle driven by means of a connecting rod, crank and double eccentric until a bending moment that corresponds to maximum fatigue stress amplitude of 85 MN/m^2 was attained. As the specimen was rotated via a flexible coupling by high speed motor, tensile and compressive stresses were applied simultaneously on it in the bent position. A revolving counter fitted to the motor recorded the number of cycles before the specimen fractured (number of cycle-to-failure). This procedure was repeated on identical specimens from unreinforced aluminum alloy at repeatedly reducing stress amplitudes of 75, 65, 55, 45, 35, 25, and 15 MN/m^2. The number of cycle-to-failure at each of the fatigue stress amplitude was recorded to plot the S-N curve for the unreinforced specimen.

The same procedures were applied to respective reinforced specimens of different concentration of glass particles.

RESULTS AND DISCUSSION

Effect of Glass Particle Addition on the Tensile, Compressive and Impact Properties: Table 1 shows the variation of the tensile, compressive and impact properties of unreinforced and reinforced specimens. Also, the graphical representations of these variations are shown in Figures 1, 2, 3, and 4.

Percentage elongation was found to decrease with increase in glass particles addition. This could be attributed to the improved internal stress, due to the particulate reinforcement, having adverse effect on the ductility of the specimen. Increase in the composition of glass particles in aluminum matrix from 0 to 10, 20, 30 and 40% caused the percentage elongation at fracture of specimen to decrease from 10.4 to 9.6, 8.9, 7.7, and 7.4, respectively (Figure 1); however, within the same glass particles reinforcement range, ultimate tensile strength increased from 82.7 MN/m^2 to 88.4 MN/m^2, 91.5 MN/m^2, 94.3 MN/m^2 and 111.8 MN/m^2 respectively because of the improved internal stress (Figure 2). Also, ultimate compressive strength correspondingly increased from 102.3 MN/m^2 to 104.9 MN/m^2, 114.6 MN/m^2, 122.7 MN/m^2 and 129.2 MN/m^2 and impact energy decreased from 24.2 Nm to 22.8 Nm, 21.5 Nm, 18.9 Nm and 17.5Nm, respectively.

Effect of glass particles addition on fatigue properties: Table 2 shows the variation of the fatigue properties of unreinforced and reinforced specimens. However, the graphical representation is shown in Figure 5. Reduction in fatigue stress amplitude was found to increase the number of cycles-to-failure, a measure of the fatigue life of the specimens. Also, fatigue life was observed to decrease with increase in glass particles addition; this could be attributed to the areas of bending stress concentration in the particulate reinforcement creating crack propagation during fatigue bending. At fatigue stress of 45 MN/m^2, the fatigue life of specimens with 0, 20, and 40% glass particles compositions are 398, 79 and 15 cycles-to-failure respectively. When the fatigue stresses on the respective specimens are 85 MN/m^2, 43 MN/m^2 and 29 MN/m^2, the specimens failed at 100 cycles–to-failure.

Table 1: Variation of Tensile, Compression, and Impact Properties of Specimens.

Glass particles concentration (%w)	Percentage elongation at fracture (%)	Ultimate tensile strength (MN/m^2)	Ultimate compressive strength (MN/m^2)	Impact energy (Nm)
0	10.4	82.7	102.3	24.2
10	9.6	88.4	104.9	22.8
20	8.9	91.5	114.6	21.5
30	7.7	94.3	122.7	18.9
40	7.4	111.8	129.2	17.5

Table 2: Variation of Number of Cycles-to-Failure with Fatigue Stress Amplitude.

Fatigue stress amplitude, S (MN/m^2)	Unreinforced (0%w)		10%w-glass reinforced		20%w-glass reinforced		30%w-glass reinforced		40%w -glass reinforced	
	N_f	Log N_f	N_f	Log N_f	N_f	Log N_f	N_f	Log N_f	N_f	Log N_f
85	100	2.00	40	1.60	7	0.84	3	0.48	2	0.30
75	126	2.10	49	1.69	13	1.11	4	0.60	3	0.48
65	159	2.20	78	1.89	25	1.40	8	0.90	4	0.60
55	200	2.30	126	2.10	50	1.70	16	1.20	8	0.90
45	398	2.60	199	2.30	79	1.90	50	1.70	15	1.18
35	1259	3.10	501	2.70	316	2.50	155	2.19	40	1.60
25	6309	3.80	1995	3.30	1000	3.0	316	2.50	158	2.20
15	199526	5.30	19953	4.30	12589	4.10	2512	3.40	252	2.40

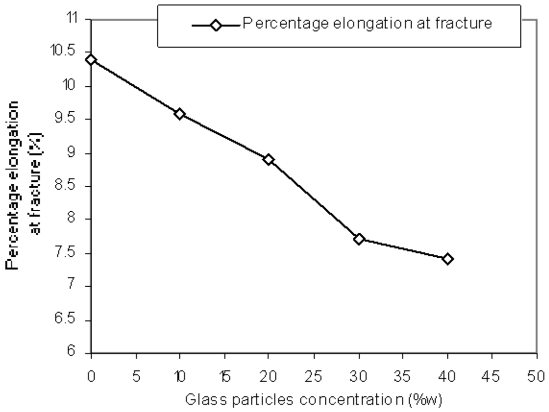

Figure 1: Plot of percentage elongation at fracture versus glass particles concentration

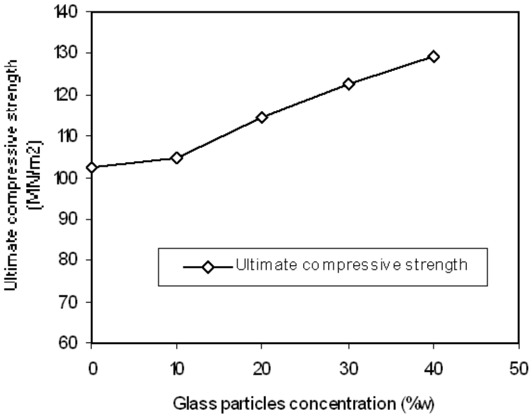

Figure 3: Plot of ultimate compressive strength versus glass particles concentration

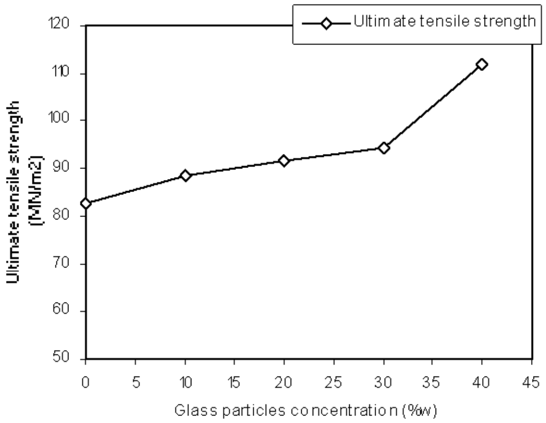

Figure 2: Plot of ultimate tensile strength versus glass particle concentration

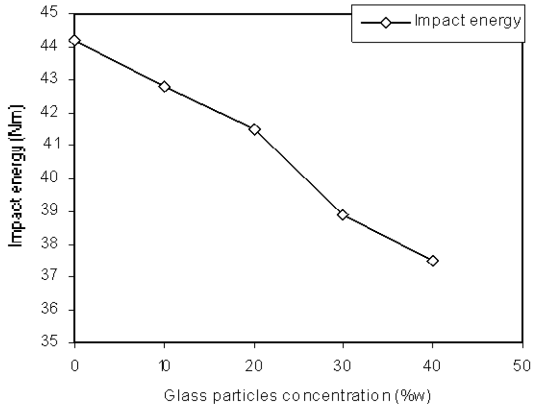

Figure 4: Plot of impact energy versus glass particles concentration

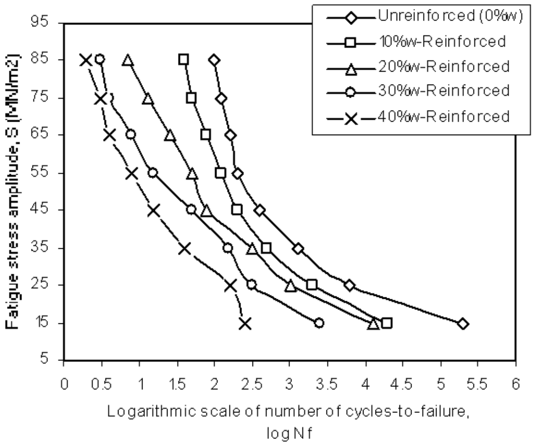

Figure 5: Plot of fatigue stress amplitude versus logarithmic scale of number of cycles-to-failure

CONCLUSION

The findings in this research work can be concluded as follows:

(1) Increase in the composition of glass particles in aluminum matrix caused the percentage elongation and impact energy at fracture of specimen to decrease, while ultimate tensile strength and ultimate compressive strength increase correspondingly.

(2) Reduction in fatigue stress amplitude was found to increase the number of cycles-to-failure, a measure of the fatigue life of the specimens. Also, fatigue life was observed to decrease with increase in glass particles addition.

(3) These findings show that addition of glass particles into aluminum matrix improves the strength of the aluminum alloy at the expense of ductility, impact energy and fatigue life.

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