Journal of Engineering and Applied Sciences 3 (12): 933-936, 2008
ISSN: 1816-949X

Evaluating the Mechanical Properties of Aluminium-Based Composites Reinforced with Steel Fibres of Different Orientations

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Abstract: In this research, the mechanical properties of aluminium-based metal matrix composite reinforced with steel fibres of different orientation were experimentally investigated, presented and compared with those of unreinforced aluminium alloy. Unreinforced specimens and composites reinforced with longitudinal and transverse fibres were characterized by percentage elongation-a-fracture of 12.75, 27.50 and 11.00% respectively; ultimate tensile strength of 83.51, 96.75 and 66.71 MN m^{-2}, respectively; fatigue life of 209,458 and 16 cycles-to-failure, respectively at 550 MN m^{-2} and impact energy of 47.80, 51.20 and 45.00 Nm, respectively. The least values of mechanical properties exhibited by composite specimens with transverse fibres is attributable to the fact that transverse fibres create areas of stress concentration, which aids initiation and propagation of cracks resulting in early commencement of deformation during testing and fibre matrix debonding. However, the resistance to deformation offered by longitudinal fibres during testing is responsible to the highest values of mechanical properties displayed by composite specimen with longitudinal fibres.

Key words: Mechanical properties, aluminium composite, steel fibres, orientation, reinforced specimen

INTRODUCTION

Modern day engineering materials are required to be light weight and corrosion resistant, coupled with high strength and hardness. Since no material in nature processes all these properties alloys and composites have been developed. These materials are capable of withstanding operating conditions ranging from very cold to super-high temperatures and extremely severe weather. Composites and alloys are materials composed of >1 single material combined either mechanically or metallurgically.

Alloys consists of 2 or more materials formed by metallurgical process, while composites are engineered materials made from 2 or more constituent materials with significantly different 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 non-metals only.

Composites composed entirely of metals (and compounds) are referred to as Metal Matrix Composites (MMCs). MMCs are made by dispersing a reinforcing material into a metal matrix. The surface of reinforcement material may need to be coated to prevent chemical reaction with the matrix (Doghri *et al*., 1994; Pang *et al*., 1994). The reinforcement can be continuous or discontinuous. Continuous reinforcement uses monofilament wires or fibres embedded into the matrix (Allen *et al*., 1994), while discontinuous reinforcement uses whiskers, short fibres or particles.

Emphasis, for the last 3 decades, has been on metal matrix composites as potential materials for a variety of advanced technological applications and they have enjoyed patronage in research works ranging from analysis of the microstructure (Allen *et al*., 1994; Bozic *et al*., 2004; Soboyejo, 1994); failure mechanism (Gabb *et al*., 1993; Yeh and Krempl, 1992; Johnson, 1992; Kim, 1994; Marshal *et al*., 1994; Harmon and Saff, 1989) to studies into the effects of processing methods on mechanical properties (Assar and Al-Nmr, 1994; Doghri *et al*., 1994; Jeong *et al*., 1994). A primary motivation for these materials is their potentially improved performance at elevated and extreme conditions as compared to monolithic metals and polymers matrix composites.

Some of the factors that determine the strength of MMCs are the size (Aboudi *et al*., 1993), proportion (Surappa and Rohatgi, 1981) and orientation of the fibres (Nguyen *et al*., 1994). The 3rd case results in what is referred to as anisotropic structure, in which alignment of the materials affect its strength.

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In this research, the effects of steel fibre orientation on the mechanical properties of aluminium based metal matrix composites are experimentally investigated and presented. The mechanical properties evaluated are tensile, fatigue and impact properties.

MATERIALS AND METHODS

Work materials and specimen preparation: Fibre networks were obtained by arranging strips of galvanized steel wires of about 0.55 mm diameter through pieces of wood, 10×15×120 mm dimensions, to obtain a rigid rectangular fibre network to be placed inside the cavity of a sand mould. Galvanised steel wires were used to prevent reaction of aluminium with carbon present in steel while not compromising matrix-fibre bonding.

Thereafter, the rigid rectangular fibre networks were placed in the cavities of drag-and-cope assemblies of sand casting. Aluminium alloy scraps obtained from household utensils, internal combustion engines of motorcycles and electric cables were melted in a furnace at 700°C for 30 min, removed and poured into the mould cavity containing the fibre networks. After solidification and cooling, steel fibre reinforced aluminium slabs were obtained by shaking out the sand moulds. Also, aluminium slabs with no reinforcement were produced from which control samples were obtained for the purpose of comparison.

Two sets of test samples were cut from the slabs with reinforcement, parallel to the fibres to obtain specimens with fibres in longitudinal orientation and at right angles to the fibres for specimens with fibres in transverse orientation and a 3rd set was cut from the slab without reinforcement. The samples were machined and prepared for tensile, fatigue and impact tests. The tensile test specimens comply with ASTM standard E 8 and E 8 m (standard methods for tensile testing of metallic materials). V-notches were made at the middle impact test specimens (dimension 10×10×60 mm) using a 3 mm end mill on a universal milling machine. Fatigue test specimens were machined on a lathe to conform to standard E 466 (standard practice for cutting constant amplitude fatigue test metallic materials). The schematic of the fatigue test specimens is shown in Fig. 1.

Tensile test: Tensile test specimens from unreinforced aluminium alloy and longitudinal and transverse fibre-reinforced composites were respectively subjected to Constant Extension Rate Tensile (CERT) tensile test on a tensometer. As straining continued the maximum force (or ultimate load) exerted on each specimen before they fractured was recorded via a mercury column. The values

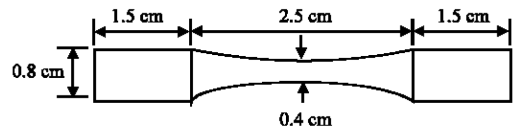

Fig. 1: Fatigue test specimen

were confirmed on a tensile force versus extension curve plotted on a recording sheet with the aid of a rotting drum and cursor on the tensometer. Ultimate tensile strength was obtained by dividing the ultimate load by the original cross-sectional area of the gauge section of the specimens. Also, the percentage elongation at fracture of respective specimen was determined.

Fatigue test: The fatigue properties of the unreinforced specimens were evaluated by respectively clamping them on the grips of a completely reversed avery 7305 bending fatigue testing machine with a zero mean stress. Thereafter, a bending load was imposed on a fresh specimen by an oscillating spindle driven by means of a connecting rod, crank and double eccentric until a bending moment that corresponds to a maximum fatigue stress amplitude of 850 MN m^{-2} was reached. Tensile and compressive stresses were applied simultaneously on the specimen in the bent position as it was rotated via a flexible coupling by high speed motor. 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 aluminium alloy at repeatedly reducing stress amplitudes of 700, 550, 400, 250 and 100 MN m^{-2}. The same procedures with repeated cyclic loading at the specified stress amplitudes were applied to composite specimens.

The number of cycles-to-failure at each of the fatigue stress amplitude was recorded to plot the S-N curves for each of the specimens.

Impact test: Each of the impact test 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 energy absorbed at fracture was determined from a gauge on the machine. Repeated tests were carried out on fresh specimens to confirm the readings.

RESULTS AND DISCUSSION

Tensile properties: The variations of the tensile properties of unreinforced specimens and composite specimens are shown in Fig. 2 and 3. Composite

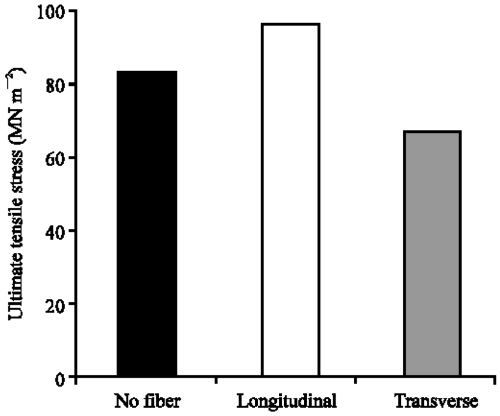

Fig. 2: Plot of ultimate tensile stress of specimen

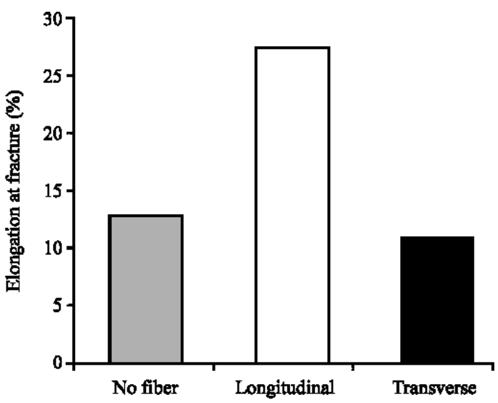

Fig. 3: Plot of percentage elongation of specimens

specimens reinforced with longitudinal fibres were found to exhibit highest percentage elongation at fracture, 27.50% and the highest ultimate tensile strength of 96.75 MN m^{-2} while the least percentage elongation at fracture and least ultimate tensile strength were recorded with composite specimens with transverse fibres, 11.00% and 66.71 MN m^{-2}, respectively.

Being oriented in the direction of tension, longitudinal fibres were able to resist tensile deformation thereby improving the tensile strength and deformation capacity of the specimen contrary to transverse fibres that become detached from the matrix during tensile test.

Fatigue properties: Variations of fatigue properties of the test specimens are shown in Fig. 4. Increase in fatigue stress was found to shorten the fatigue life of the respective specimen. The number of cycles-to-failure is a measure of the fatigue life of test materials. At specific fatigue stress application, specimen with longitudinal fibres was found to exhibit the longest fatigue life, while specimen with transverse fibres exhibited the shortest

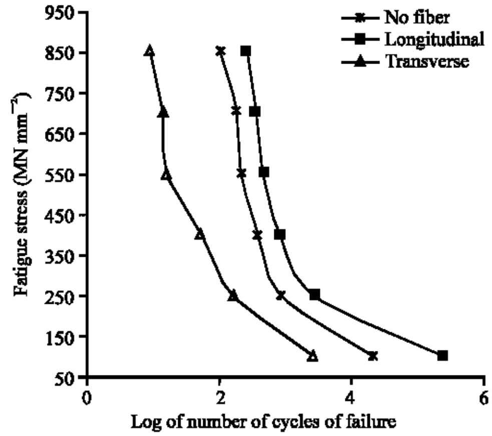

Fig. 4: Plot of fatigue stress vs log of number-of-cycles to failure

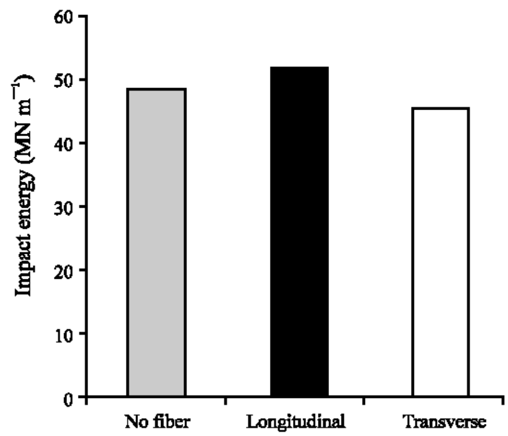

Fig. 5: Plot of impact energy of specimens

fatigue life. At fatigue stress of 550 MN m^{-2} longitudinal and transverse fibre reinforced specimens failed after 458 and 16 cycles, respectively, while unreinforced aluminium alloy failed after 209 cycles. This is expected because longitudinal fibre-reinforced aluminum matrix composites possess better fatigue properties (Christian, 1975).

Fatigue test involves applying a bending a bending stress at one end of the specimen and rotating it at the other, thus, subjecting the specimens to a series of repeated or cyclic tension and compression. It is therefore, evident that longitudinal fibres would improve the specimens resistance to deformation by bending.

Impact properties: Figure 5 shows the variations of impact properties. Here, the impact energy of longitudinal fibre reinforced composite specimen was observed to be the highest, while that of transverse fibre-reinforced composite was the lowest. Longitudinal fibres resisted to a large extent the deformation of the specimen at the v-notch region after receiving the blow of the pendulum arm of the impact testing machine. However, transverse fibres aided the deformation of the specimen because of weaknesses created in the direction of fracture, which enhanced concentration of stress at point of force application.

CONCLUSION

The findings of this research shows that aluminium based composites reinforced with longitudinal steel fibres are characterised by tensile, impact and fatigue properties that are higher than those of unreinforced aluminium alloy. The least values of mechanical properties recorded were exhibited by composites reinforced with transverse fibres.

The resistance to deformation offered by longitudinal fibres is responsible for the highest values of mechanical properties displayed by composite specimens with longitudinal fibres. Whereas, the lowest values of mechanical properties recorded for transverse fibre-reinforced specimens are attributable to the discontinuous nature of the fibres in the longitudinal (or lengthwise) direction and also the weaker adhesive forces existing between the molecules of the matrix (aluminium) and fibre (steel) in comparison to those exiting between the molecules of the matrix.

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