INTERFACE STRUCTURE AND MECHANICAL PROPERTIES OF 3D CARBON FIBER WEAVE REINFORCED A206 ALUMINUM ALLOY COMPOSITES

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Introduction

Continuous fiber reinforced metal composites have long been studied due to their potentially superior mechanical, thermal and tribological properties and are considered as ideal candidates for use in structural, thermal and electrical applications [1]. These materials have been synthesized by deposition processing, powder metallurgy and metal casting techniques, however to date, the full commercial application of continuous fiber MMCs has not been realized. Of the techniques available for synthesizing these materials, solidification processing is perhaps the most versatile, allowing for the synthesis of unique, controlled microstructures as well as complex bulk shapes.

Unidirectional fiber reinforced composites materials have excellent in-plane properties, but fare poorly when out-of-plane, through-thickness properties are required [2]. These composites produced by creating laminates of unidirectional or woven fibers suffer from poor interlaminar strength that eventually results in failure due to delamination. In addition to the type of fiber and matrix, the reinforcing fiber architecture is a major factor determining the mechanical performance of a composite [3]. The objective of this work is to develop optimum methods of producing a 3D fiber reinforced metal matrix composites (MMCs) and to eventually specify the desired 3D woven fibers weave pattern or patterns for use in these fiber reinforced MMCs.

Experimental

A series of A206 alloy (4.2-5% Cu, 0.05% Si, 0.2-0.35% Mg, 0.2-0.5% Mn, 0.15-0.25% Ti, balance Al) composites reinforced with 3D carbon fiber weave (CFW) were synthesized through the squeeze infiltration technique described elsewhere [4]. The IM7 PAN based carbon fiber 3-dimensional weaves used for the present work was received from T.E.A.M. Inc. Textile Engineering and Manufacturing. The architecture of the weave is shown in Figure 1.

The fiber preform was placed in the bottom of a rectangular mild steel mold, and the entire mold/preform assembly was preheated to 500 °C under cover of argon gas. The aluminum alloy was induction melted and cast onto the fibers at a temperature of 800°C. A steel punch was used to apply direct pressure to the melt of approximately 15 MPa to initiate infiltration into the voids between the fibers of the weave. The composite casting was then allowed to cool down to ambient temperature in sand.

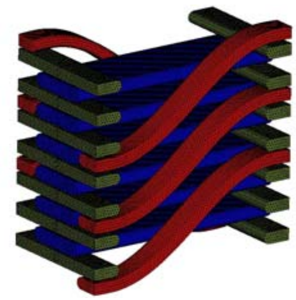

Fig. 1: 3D CFW showing weave nomenclature; Stuffers shown in blue = Warp fibers, X-direction; Filler shown in green = Fill fibers, Y-direction; Warp Weaver shown in red = Z-direction

After solidification, three sections were taken in the warp direction from the castings with dimensions 8 cm × 2 cm × 7 cm. Selected samples were heat treated to the T7 condition (510-516˚C for 2hr, followed by a 14-20 hr soak at 526-532˚C and water quench, followed by artificial aging at 199 °C for 8 hours). The composites were characterized using optical microscopy, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and Transmission electron microscopy (TEM). In addition, the affect of the T7 heat treatment on the matrix microstructure between fibers and the interfaces between the fibers and the matrix was examined. Selected mechanical properties including the macro and microhardness of the specimens were measured before and after heat treatment.

Result and discussion

The as-received 3D CFW has relatively smooth surfaces, yet exhibits an intermittent coating of a sizing. Fiber preheating at 500°C in the presence of Argon for 30 min apparently did not lead to any significant changes in the appearance of the surface of the fibers. The squeeze casting method implemented in this work resulted in completely infiltrated samples, and aluminum was found in intimate contact with carbon fiber in both in the interstices between filaments, and within the spaces between tows in the carbon fiber weave.

However, the fiber weave was distorted by the liquid aluminum on a macroscale level and the solidification front may have also acted to distort the filaments on a microscale level, resulting in a deviation from the weave design shown in Figure 1.

The microstructure of the as-cast composite and its corresponding dot maps are shown in Figure 2. Copper was observed near the carbon fibers in the as-cast structure. In as-cast A206 alloy, Al_2Cu precipitates are found in the interdendritic regions. Mortensen et al [5] made the observation that in the case of aluminum alloy solidification in the presence of fibers, dendrites will form in the interstices between filaments in a tow leading to a higher concentration of the solute near the fibers.

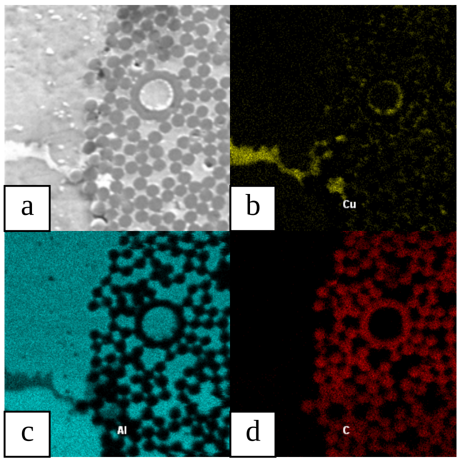

Fig. 2: SEM, and EDS Dot mapping of A206-CFW composite. a) SEM microstructure of transverse section of fibers b) Cu dot map, c) Al dot map, d) C dot map.

Bright field TEM images of the as-cast and T7 heat treated composites are shown in Figure 3. Each was observed to consist of FCC Aluminum surrounding carbon fibers having a layer of tetragonal Al_2Cu precipitate, as well as varied amounts of Al_4C_3. The presence of Al_2Cu coupled with Al_4C_3 may cause the interface between the carbon fibers and the aluminum alloy matrix to be brittle.

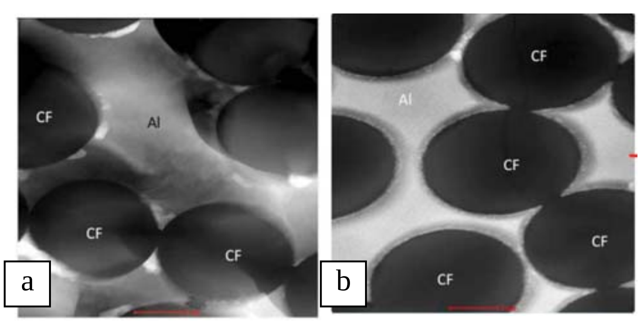

Fig. 4: TEM images (fiber diameter approximately 5 microns) of the A206-CFW composite. a) As-cast, b) T7 heat treated.

Widmanstätten Al_2Cu precipitates were observed in the matrix of the heat treated specimen in contrast to the as-cast microstructure which contained no precipitates within the matrix. In both the as-cast and heat treated specimens there were no amorphous Al-O-C layers, or direct Al-Carbon fiber contact observed, due to the presence of a reaction layer consisting of the Al_2Cu and Al_4C_3 phases. The layer thickness of the as-cast composite was on the order of 100 nm, and of the heat treated composite was 200 nm. The solutionizing and aging heat treatment was not sufficient to reduce the amount of Al_2Cu precipitates at the interface between the carbon fiber and the aluminum matrix and led to the formation of larger amounts of Al_4C_3. Load transfer is therefore expected to be largely dependent on the properties of local fibers rather than the global properties of the tow as the interface will be brittle.

The Rockwell B macrohardness of the as-cast and heat treated specimens showed dependence on the region within the composite tested. Due to the deformation of the weave, distinct fiber rich and fiber poor regions existed with different mechanical properties. The hardness of the fiber rich region (55 HRB) was observed to be on the order of twice the hardness of the fiber poor regions (25 HRB), likely due to the refinement of the microstructure in these regions compared to the matrix alloy. In the case of the heat treated composite, the average hardness within the fiber rich region was 72.5 HRB compared to the fiber poor region hardness of 37.1 HRB.

Conclusion

1) Squeeze casting is a viable method for producing aluminum alloy-carbon fiber-3D CFW metal matrix composites
2) The microstructure consisted of three distinct regions: Aluminum alloy matrix, an interfacial reaction layer and carbon fiber.
3) The interfacial reaction layer consisted of Al_2Cu and Al_4C_3 and doubled in size after the T7 heat treatment from 100 to 200 nm.
4) The Rockwell B hardness of the composite regions was double that of the unreinforced regions.

References

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