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Effect of Nickel Coated of Carbon Fiber on Distribution of Carbon Fiber Reinforced Aluminium (AlSi7) Foam Composite by Powder Metallurgy

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Abstract

The aluminium foams have attracted increasing attention in fact of their low density and superior performances. The potential properties of carbon fiber aluminium foam based materials strongly depend on the dispersion and bonding of carbon fiber within the aluminium foam matrix. A chemical oxidation and coating of carbon fibers have been carried out to improve the distribution and the wetting of carbon fiber in aluminium foam. Chemical oxidation of carbon fiber with HNO_3 involves impregnating functional groups on the surface of carbon fiber. The functional groups are expected to react with inorganic materials by electroless deposition nickel. Carbon fiber $AlSi_7$ foams composites were produced by powder metallurgy. We used a v-shaped cylinder for the first time to generate a homogenous distribution of 0.5 wt % carbon fiber within 50 g $AlSi_7$ powders and 0.5 % wt% TiH_2 (as foaming agent). To produce the precursors, carbon fiber reinforced aluminium foams were produced under sintering conditions with the pressure of 450 MPa and temperatures of 300ºC for 2 hours. The foaming of precursors were investigated by heating up to 750ºC with 7 minutes foaming time. The effects of chemical oxidation and nickel coating on carbon fiber in the dispersion of carbon fiber in aluminum foam were confirmed by optical and scanning electron microscopic analysis. Observation of the distribution of the fibers in the aluminium foam matrix showed that the technique is effective in dispersing and increase wettability the carbon fibers coated nickel within the aluminum foam matrix. The results can have important implications for the processing of carbon fiber reinforced aluminum foam composites and their mechanical properties.

Introduction

Lightweight materials have gained major importance in most manufacturing sectors such as automative~~,~~ and aerospace industries. The Aluminium Foams have attracted increasing attention in fact of their low density and superior performance such as energy absorpsion, sound absorption and vibration reduction[1]. As potential candidates for structural applications, this material requires high specific strength and stiffness. Therefore, aluminum reinforcement is needed. One way to strengthen the aluminium is to manufacture a composite by the addition of one or more secondary phases or so called reinforcements. In fact, the second phase composition and distribution can be adjusted to meet certain requirements. Carbon fibres are used as reinforcement for aluminium alloy because they increase the strength and stiffness of the aluminium alloy, improving their electrical and thermal conductivities while reducing their density[2]. Carbon fibers and aluminium alloys have poor wettability, do to weak adhesion and poor bonding between fiber and matrix, so surface modification of carbon fibers is essential to improve the wettability. Chemical oxidation treatments increase the surface area, impregnating functional groups on the surface of carbon fibers and improve bonding between the fiber and the resin matrix[3]. One of the ways to increase the interfacial shear strength of carbon fiber reinforced aluminium foam composite is chemical oxidation of carbon fiber. Chemical oxidation is a way to increase wettability between carbon fibers and aluminium[4].

The functional groups are expected to react with inorganic materials by electroless deposition, to increase the dispersion of carbon fibers in metal matrix and increase the interfacial bonding strength between carbon fibers and metal matrix. Applying a metal coating to carbon fibers is one of the most effective methods of improving their wettability with molten metals. Ni-C bonding was formed by electrodeposition of Ni via defects. The presence of oxidizing groups help to nucleate the attachment of the inorganic material to the surface. Carbon fibers with COOH group could entrap much more Sn and Pd and following nickel nucleation sites and will help to incorporate the carbon fiber into metal matrix with strong bonding. Ni ions easily accept electrons and electrodeposit selectively on the defect sites rather than on other normal sites on the outer surface of the carbon fiber. This method is capable of causing uniform dispersion of carbon fiber and improving wetting property of carbon fiber for aluminium. Homogeneous dispersion and strong interfacial bonding of carbon fibers with metal can be achieved by electroless coating[5].The dissolved coating metals formed stable compounds with molten aluminum. The wettability of the metal-coated carbon fiber with molten aluminum was significantly improved compared to non-coated carbon fibers[6].

Some studies have been conducted to increase mechanical properties about carbon fibers reinforced aluminium foam. Aluminum foams stabilized by carbon fibers were prepared, it was concluded that change in foam structure can be slowed down by increasing fiber fraction, which would led to more stable foam[7]. Copper-coated carbon fibers were added to aluminum foam to stabilize metal films. Observation of the cell structure and the distribution of the fibers in the metal films shows that the stabilization was based not just on the presence of fibers but on both fibers and particles[8]. Short copper-coated carbon fibers have been found to be a novel stabilizer for aluminum foam. Volume fraction of carbon fibers needed to stabilize liquid aluminum foam is at a very low level of 0.35 vol.%. And the stability of liquid foams is significantly improved when 1.7 vol.% copper-coated carbon fibers were used[9]. The compressive behavior of closed-cell copper-coated carbon fiber/aluminum composite foam with 1 and 5 wt.% fibers was assessed under quasi-static and high-strain-rate loading conditions via the melt route. The uniform distribution of fibers in the cell wall, indicating the good wettability at the fiber–Al melt interface[10].

Experimental

Surface Treatment Carbon Fibers.

Aluminum closed cell foams were prepared using from powder metallurgy process. Aluminium alloy powder ($AlSi_7$), titanium hydride powder (0.5 wt.%, as blowing agent) and carbon fiber (0.5 wt.%, as reinforcement) were used as main starting materials in this examinations. Carbon fibers are oxidized in concentred nitric (97% (w/w)) acids at 90 minute. After the treatments, all the samples are thoroughly wash with freshly boiled demineralized water[11]. After this treatment, the procedure of electroless plating Nickel can be divided into three steps: sensitization, activation and plating. Carbon fiber are immerged in a sensitization solution (0.1M $SnCl_2$/0.1MHCl) and sonicate for 30 min. The Sn^{2+}-sensitized carbon fibers are further stirred in an activating solution of 0.001M $PdCl_2$/0.25M HCl for another 30 minutes. The activated Carbon Fiber are washed with deionized water and introduced into an electroless plating bath. After 10 minutes plating, the plated Carbon fiber are washed with distilled water then with methanol rinse. The morphology of the nickel-coated carbon fibers are analyzed by SEM[12].

Manufacture of Aluminium Foam Composite**.**

The process started with the mixing of appropriate amounts of basic ingredients, $AlSi_7$ powder, Carbon Fiber (0.5 wt%) and TiH_2 (0.5 wt%) as blowing agents, inside a container, which was rotated on a rotary mill in order to form a homogeneous powder mixture. In the foam expansion experiments, Al and 0.5 wt% Carbon fiber/Al MMC compacts were prepared inside a stainless steel die by hot compaction at 300°C for 2 hours under a pressure of 450 MPa. Precursor (volume: 19.1228) were then inserted into a pre-heated furnace at a temperature of 750°C. Optical Micrograph and Scanning Electron Microscopy (SEM) techniques are employed to characterize the samples to examine the dispersion of the Carbon fibers within the Al Foam matrix[13].

Results and discussion

Carbon Fiber Coating Nickel.

SEM has been used to observerse the morphologhical feature of Ni deposited carbon. Figure 1 show SEM images of carbon fibers before and after coating. Comparisons between images a and b show a significant difference in the morphology of the two samples. In Figure 1 b, It can be seen that the fibers are coated uniformly and the nickel coating is continuous over it. The thickness of the coating is homogeneous throughout the fiber circumference. During coating, nickel deposits over the energetically favoured sites which covers the entire fiber surface. The coating shows compact fine-grain appearance without obvious drusy structure. The distribution of Ni-deposition is more complete, homogenous, and continuous than non coating. HNO_3 treatments were used to create a variety of oxygen containing functional groups on the sidewalls of the carbon fibers (supporting information), the nitric acid can wet and funtionalize the inner wall and the outer wall of the carbon fibers simultaneously.

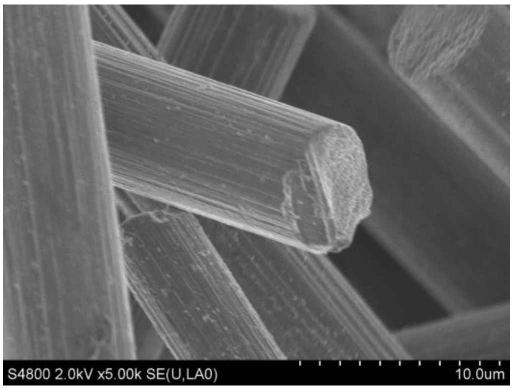

Figure 1a shows carbon fibers without decorated with nickel electroless deposit, b shows a carbon fibers densely decorated with nickel electroless deposit.

Carbon Fiber reinforced aluminium foam

The results of OM and SEM analysis of carbon fibers reinforced aluminum foam show a uniform distribution of carbon fibers in aluminum foam matrix, this figure shows the effect of chemical oxidation and nickel coating on the distribution of CF on aluminum matrices are well. Figure 2 a shows optical micrograph of the 0.5% carbon fibers reinforced $AlSi_7$ foam and the typical distribution and shape of the presence of carbon fibers in foam cell walls. Picture 2 a shows OM on the plateau border and cell walls of $AlSi_7$ 0.5 wt.% carbon fiber-aluminium foam. Carbon fiber is uniformly distributed on the borders of the plateau, while fibers that are embedded in thin cell walls lead almost parallel to the surface of the cell wall. Carbon fiber distribution is the key to obtaining good carbon fiber reinforced aluminum foam. The microstructure shows clear evidence that carbon fibers are dispersed separately, stretched and aligned randomly in the aluminum matrix.

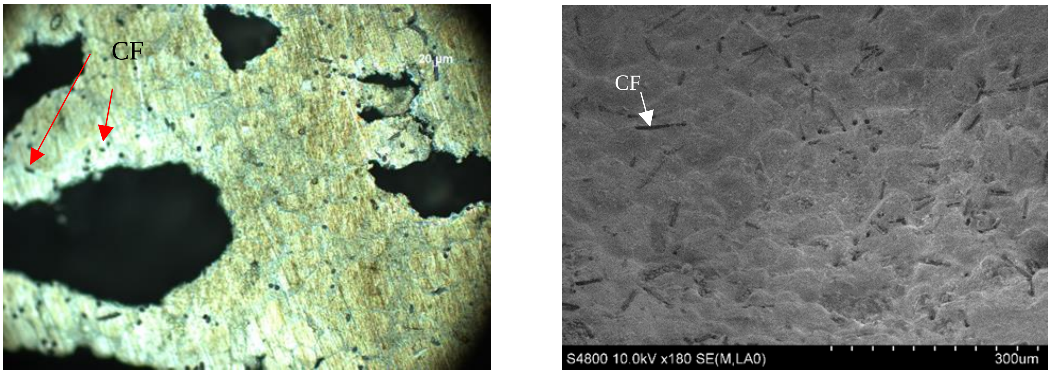

Figure 2a Optical Micrograph of distribution CF in Al Foam (10x), b. SEM of distribution CF in Al Foam

Figure 2b shows that the distribution of carbon fiber in aluminum foam is uniform fiber distribution on the cell wall, which means good wettability at the carbon fiber-aluminium foam interface. The solution to overcome the problem of wettability in reinforced metal foams are chemical oxidation and electroless deposition nickel coating for carbon fiber where the nickel layer can function as a medium for adhesion to the interface between carbon fiber and the $AlSi_7$ foam matrix. Figure 3 show, after coating on carbon fiber surfaces with nickel metal, strong interfacial bonding of carbon fibers with aluminium matrix can be achieved. It will improve the wetting between carbon fiber and the matrix due to better wetting properties between carbon-Ni and Aluminium. $NiAl_3$ are deposited adjacent to carbon fiber and the fiber surface seems to act as a nucleation center. Composites made of carbon fiber with nickel electrolyte layers also show the same carbon fiber distribution. But carbon fiber is related to $NiAl_3$ deposits. Composites made with nickel-plated carbon fiber without electricity also show a fairly equal distribution of carbon fiber in the matrix with intermetallic aluminum $NiAl_3$. The intermetallic formation of $NiAl_3$ with a matrix prevents the interaction between fiber and matrix. In addition, during coating, nickel must have interacted with carbon fiber surfaces, possibly forming a kind of chemical bond that cannot be disturbed by fluid flow.

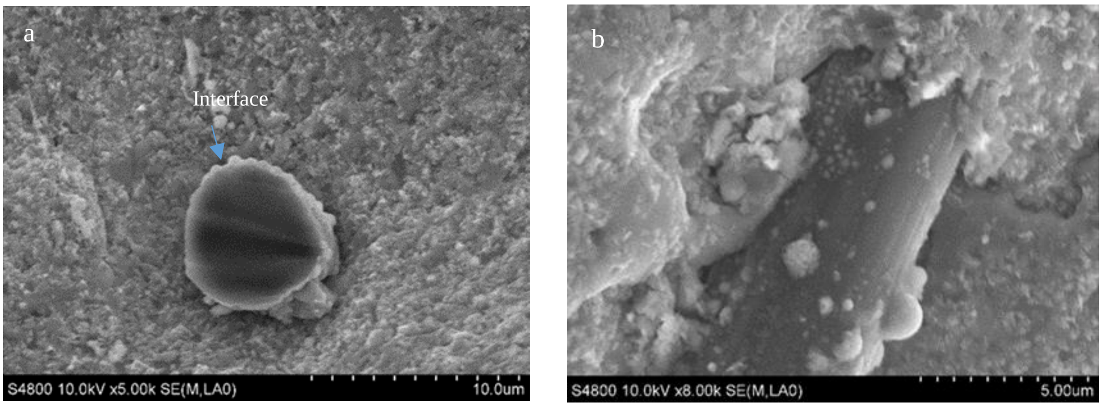

Figure 3 a and b. SEM of wettability and interface of CF reinforced aluminium foam

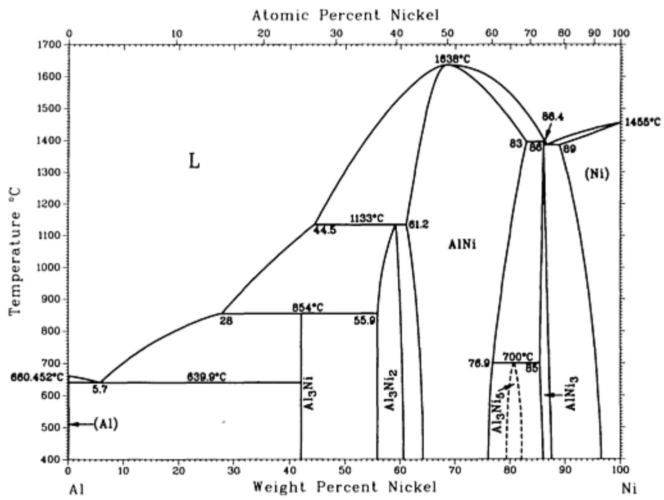

Fig. 4. Equilibrium phase diagram for Ni-Al[14].

According to the aluminum-nickel phase diagram (Figure 4), all nickel deposited on the surface of carbon fiber are dissolved and no nickel is found at the interface. But a small intermetallic nodules are found on the interface. The formation of intermetallic particles is believed to precipitate when cooling on the interface. This shows that the phase formed in the reaction of Aluminum-Carbon fiber coated with nickel is Al_3Ni intermetallic which is formed from the reaction between aluminum and nickel coating. The results also show that the Ni layer on carbon fiber has a function, first it can prevent aluminum matrix directly related to carbon so that the interaction of the fiber matrix can be removed (carbide formation which decreases the mechanical properties of composites). Second, coherent interface bonds must be made possible between matrix and fiber. The morphology of the layer will play an important role in the interface and mechanical properties of composites. The $NiAl_3$ phase seems to bind carbon fibers in many places to the aluminum matrix. These results indicate that the nickel layer on the fiber will facilitate the dispersion of fibers in the aluminum matrix.

Conclusions and Future Perspectives

0.5 wt. % carbon fiber reinforced $AlSi_7$ foam composite powders were successfully fabricated by powder metallurgy process. The result of treatment chemical oxidation and electroless deposition on carbon fibers would be expected that good dispersion of carbon fibers in aluminium foam. OM analysis showed that, distribution of carbon fiber in composites with 0.5% carbon fiber has been well distributed in composites. This proves that nickel coating on carbon fiber is an effective process for dispersing carbon fiber in $AlSi_7$ foam. Coatings increase the carbon fiber wetting behavior with molten aluminum because the formation of the $NiAl_3$ intermetallic compound at the matrix-fiber interface limits the fiber segregation to obtain a homogeneous amplifier distribution. Nickel coating also reduces the trend to form aluminum carbide which decreases the composite mechanical properties. The aluminum-nickel intermetallic compound formed increases the strength of the aluminum matrix.

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