ACHIEVING MULTI-FUNCTIONAL PROPERTIES VIA SQUEEZE CAST HYBRID METAL MATRIX COMPOSITES

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Abstract

Traditionally, when selecting a composite for a product, a manufacturer chooses from the commercially available composites. Very seldom, attention is paid in optimizing the functional properties of the product with the use of a “designed” composite meant specifically for that product. That is, the avenue of improving the functional performance of a product with a composite having a specially tailored property is rarely pursued. The main reason is often the misconceived notion of major challenges involved in the development of a “designed” composite.

In this presentation, the concept of designing and fabricating composites with tailored properties via squeeze cast hybrid composites is introduced. This type of composite is known to provide properties which are different from the commercial composites. In this case, a hybrid SiC/Al is compared with a commercial SiC/Al in terms of both the room and elevated temperature properties. Figure 1 shows the microstructure of the hybrid SiC/Al, which consists of two reinforcements instead of one as in traditional commercial composites.

Introduction

For an aluminum alloy, its property can be easily modified by the addition of an reinforcement to form an aluminum matrix composite [1]. Presently, the most commonly available aluminum matrix composites are silicon carbide particulate reinforced and alumina particulate reinforced aluminum. These composites are known to have improved properties over the aluminum alloy such as strength, modulus, wear resistance, coefficient of thermal expansion, high temperature property, etc. Despite the property improvement, it does not mean that the aluminum composite property is optimized and useful for any aluminum product that required better product performance.

One approach to assure that the functional performance of a product is improved, is to have a clear understanding on the performance requirements and develop a composite with the specific properties in mind by the proper selection of a matrix alloy and a reinforcement or reinforcements. That is, the reinforcement or reinforcements to be incorporated into the matrix has/have to be chosen with a view of their inherent property and how each of them can contribute to the final property of the hybrid composite.

In this paper, the concept of developing a hybrid composite with specific properties in mind via the squeeze casting technique is introduced. An example of a hybrid aluminum matrix composite being developed here, is to achieved improved high temperature property compared to those commercial silicon carbide particulate reinforced aluminum composite which offers high wear resistance. The major differences between the aluminum composite and the hybrid aluminum composite in terms of microstructure as well as various aspects of the physical, mechanical and thermal properties area also described in the following sections.

Fig. 1. Microstructure of a hybrid SiC/Al composite consisting of SiC (dark phase) and Ni₃Al, (light phase) reinforcements in A242 aluminum matrix
The objective of attaining improved high temperature property and wear resistance in an aluminum composite is to develop $\text{Ni}_x\text{Al}_y$ intermetallic reinforcement in the matrix in addition to adding SiC particulate reinforcement. $\text{Ni}_x\text{Al}_y$ is of interest because of its excellent strength and oxidation resistance at elevated temperature. The most interesting feature of the plastic deformation of $\text{Ni}_x\text{Al}_y$ is the marked increase in yield and flow stresses with increasing temperature [2,3,4,5], thus it is well suited to improve the elevated temperature property of the aluminum alloy.

The main processing steps for the fabrication of aluminum hybrid composite are captured in a flow chart as shown in Fig. 2. The key processing steps of this CANMET process are described as follows:

**Step 1 Preform Fabrication**

A preform consists of a three dimensional network of reinforcement, interconnected by a ceramic binder is first prepared. In this case, SiC and Ni particulates are the reinforcements, and $\text{SiO}_2$ is used as the ceramic binder. The preform was made with 40 vol % SiC and 2.8 vol % Ni powder.

The technique of squeeze casting of Al MMCs allows for the flexibility of using different grade of cast and wrought aluminum alloys. In this work, aluminum A242 alloy was used for its relatively good high temperature property compared to other grades of cast aluminum alloys.

**Step 2 Squeeze Casting**

Direct squeeze casting process was employed. In this process, the preform was heated to 525°C placed in a heated die, and molten aluminum at 750°C was transferred into the die. A punch was dropped into the die, forcing the molten aluminum to infiltrate into the preform. Solidification of the cast piece was allowed to take place in less than a minute under a pressure of 75 MPa.

**Results and Discussion**

In the following sections, properties of aluminum A242, a commercial stir cast aluminum composite with 20 vol % SiC particulate reinforcement and a CANMET hybrid composite are compared.

**Microstructure**

Figure 3 shows the microstructure of the hybrid aluminum composite, which consists of SiC and $\text{Ni}_x\text{Al}_y$ reinforcements. With the CANMET composite fabrication technique, a very homogeneous distribution of SiC and $\text{Ni}_x\text{Al}_y$ reinforcements in the aluminum matrix is achieved.

The hybrid composite was derived using SiC and Ni particulates and A242 aluminum alloy. During the second stage of composite fabrication, molten aluminum was infiltrated into the SiC and Ni particulate preform, the molten aluminum reacted with the Ni particulates to form $\text{Ni}_x\text{Al}_y$ intermetallics.
The formation of Ni\textsubscript{x}Al\textsubscript{y} intermetallics derived from the reactions between Ni powder and molten aluminum had been investigated \cite{6,7,8}, and formation of Ni\textsubscript{3}Al, NiAl and NiAl\textsubscript{3} intermetallics phases were reported. Since the squeeze casting process promotes rapid solidification, many of the Ni\textsubscript{x}Al\textsubscript{y} phases might not have reached equilibrium. Consequently, the quantification of the volume percentage of each phase present, would not be trivial.

Thermal Property

A material with high coefficient of thermal expansion (CTE) is undesirable for high temperature applications, since it expands substantially at elevated temperatures and lead to distortion and thermal fatigue due to the development of thermal stresses. Al MMC can be made to have much lower CTE than aluminum alloy. The CTE of an aluminum is 23.8 ppm/°K. With the CTE of silicon carbide being 4.3 ppm/°K, the incorporation of SiC particulate in aluminum will have the CTE of aluminum lowered. One can use either the Turner \cite{9} or Kerner \cite{10} models for the CTE estimation of particulate reinforced composite.

In this work, the linear expansion of our hybrid composite over a temperature range between 323 to 723°K was measured, and is provided in Fig. 4. The CTE of the hybrid composite between 323 to 423°K is estimated to be 13.7 ppm/°K which is substantially lowered than the CTE of 23.8 ppm/°K measured from the A242 aluminum alloy.

Mechanical Property

It is well known that the yield strength of both aluminum and Al MMC decreases with the increase in temperature, and this is especially the case for commercial MMC using matrix alloy that are not meant for high temperature application.

In this work, it is desirable to improve the elevated mechanical property temperature of aluminum composite at a temperature range between 400 to 450°C. For example, a commercial Al MMC uses A359 aluminum alloy as the matrix alloy, and this alloy has a compressive yield strength (in as cast condition) of 130 MPa and 30 MPa at room temperature and 400°C respectively. And aluminum A242 alloy, meant for high temperature application, has a compressive yield strength (in as cast condition) of 235 MPa and 50 MPa at room temperature and 400°C, respectively. One can definitely see the need in improving the elevated temperature property of aluminum composite.

Figure 5 shows the compressive yield strength versus temperature of A242 alloy, commercial Al MMC and the CANMET hybrid composite. Both the A242 alloy and the commercial Al MMC exhibited substantial drop in compressive yield strengths with the increase in temperature. It also points out the fact that though the Al MMC is loaded with 20 vol.% of SiC particulate, no improvement in elevated temperature strength is demonstrated. With the hybrid composite, an overall improvement in high temperature property is evident. And the influence of reactive Ni\textsubscript{x}Al\textsubscript{y} does contribute to the high temperature property of the composite.

Conclusions

The concept of designing and fabricating composites with tailored properties via squeeze cast hybrid composites is introduced. This is achieved with the development of Ni\textsubscript{x}Al\textsubscript{y} intermetallic reinforcement, in addition to adding SiC particulate reinforcement, to an aluminum alloy to attain improved high temperature property. The hybrid composite is found to provide improved elevated temperature property over the test temperature even up to 400°C.
References


