

# 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.

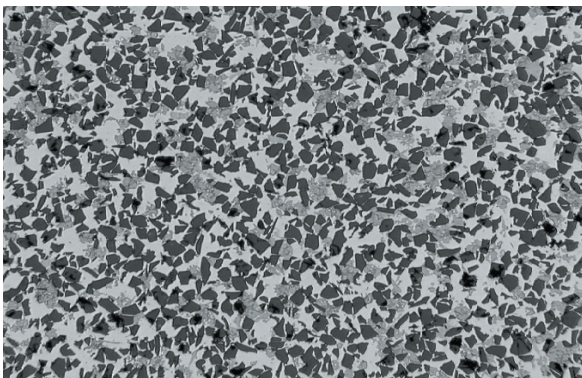


Fig. 1. Microstructure of a hybrid SiC/Al composite consisting of SiC (dark phase) and Ni<sub>x</sub>Al<sub>y</sub> (light phase) reinforcements in A242 aluminum matrix

## 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.

The objective of attaining improved high temperature property and wear resistance in an aluminum composite is to develop  $Ni_xAl_y$  intermetallic reinforcement in the matrix in addition to adding SiC particulate reinforcement.  $Ni_xAl_y$  is of interest because of its excellent strength and oxidation resistance at elevated temperature. The most interesting feature of the plastic deformation of  $Ni_xAl_y$  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.

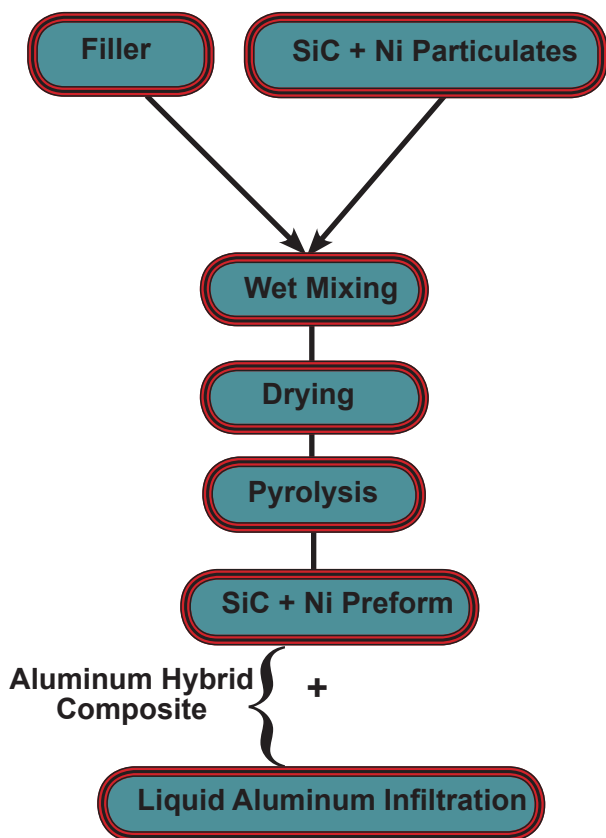


Fig. 2. Squeeze casting of hybrid aluminum matrix composite

### Fabrication Process for Hybrid Al MMC Composite

Traditionally, only one type of reinforcement is added to an alloy. In fact, there is no restriction if more types of reinforcement are added to further enhance the property of the alloy, as long as the fabrication method permits. A viable approach for making a hybrid composite with multi-functional properties is by the squeeze casting technique. This technique involves the preparation of a preform and subsequent infiltration of the preform with an aluminum alloy.

A preform is a three dimensional network of uniformly spaced reinforcement/reinforcements held together by a binder. Since homogeneously

distribution of reinforcement is already achieved at the preform stage, the eventual squeeze cast composite tends to have a very homogeneously distributed reinforcement in the matrix 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  $SiO_2$  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  $525^\circ C$  placed in a heated die, and molten aluminum at  $750^\circ C$  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  $Ni_xAl_y$  reinforcements. With the CANMET composite fabrication technique, a very homogeneous distribution of SiC and  $Ni_xAl_y$  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  $Ni_xAl_y$  intermetallics.

The formation of  $Ni_xAl_y$  intermetallics derived from the reactions between  $Ni$  powder and molten aluminum had been investigated [6,7,8], and formation of  $Ni_3Al$ ,  $NiAl$  and  $NiAl_3$  intermetallics phases were reported. Since the squeeze casting process promotes rapid solidification, many of the  $Ni_xAl_y$  phases might not have reached equilibrium. Consequently, the quantification of the volume percentage of each phase present, would not be trivial.

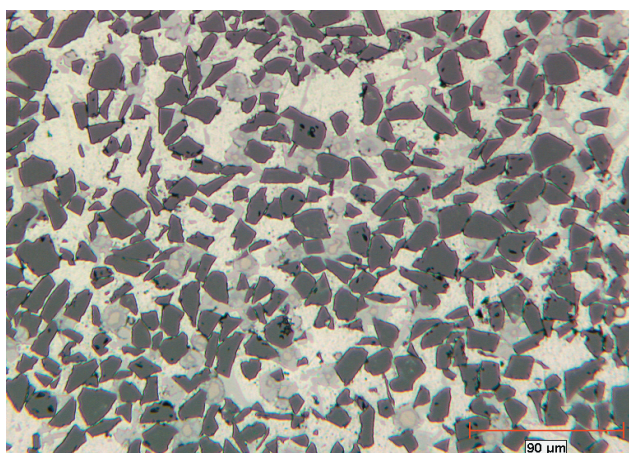


Fig. 3. Microstructure of an aluminum hybrid MMC consisting of a light gray  $Ni_xAl_y$  intermetallic phase for strengthening the matrix alloy at elevated temperature, a dark gray SiC phase for improved wear resistance and white background of aluminum matrix

### 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  $23.8 \text{ ppm}/^\circ\text{K}$ . With the CTE of silicon carbide being  $4.3 \text{ ppm}/^\circ\text{K}$ , the incorporation of SiC particulate in aluminum will have the CTE of aluminum lowered. One can use either the Turner [9] or Kerner [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  $723^\circ\text{K}$  was measured, and is provided in Fig. 4. The CTE of the hybrid composite between  $323$  to  $423^\circ\text{K}$  is estimated to be  $13.7 \text{ ppm}/^\circ\text{K}$  which is substantially lowered than the CTE of  $23.8 \text{ ppm}/^\circ\text{K}$  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.

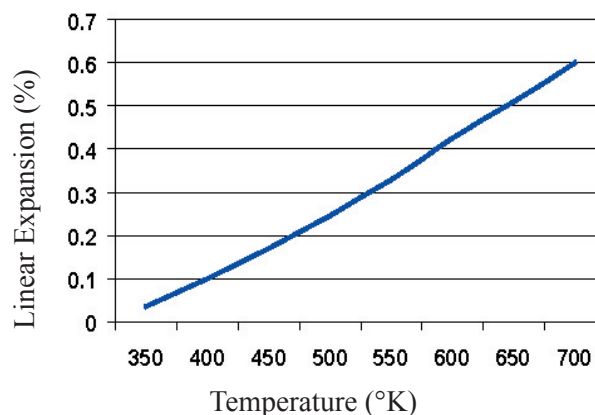


Fig. 4. Linear expansion of CANMET hybrid composite with respect to temperature

In this work, it is desirable to improve the elevated mechanical property temperature of aluminum composite at a temperature range between  $400$  to  $450^\circ\text{C}$ . 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  $130 \text{ MPa}$  and  $30 \text{ MPa}$  at room temperature and  $400^\circ\text{C}$  respectively. And aluminum A242 alloy, meant for high temperature application, has a compressive yield strength (in as cast condition) of  $235 \text{ MPa}$  and  $50 \text{ MPa}$  at room temperature and  $400^\circ\text{C}$ , respectively. One can definitely see the need in improving the elevated temperature property of aluminum composite.

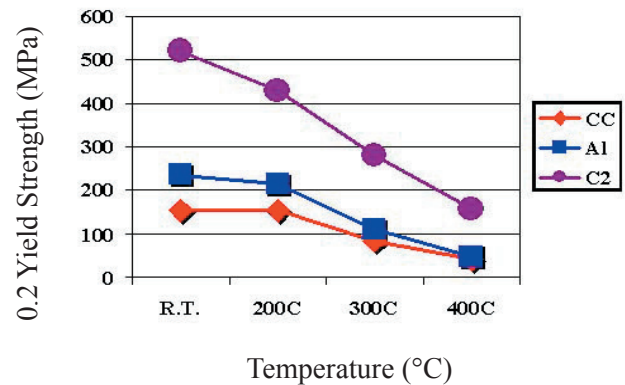
Figure 5 shows the compressive yield strength versus temperature of A242 alloy, commercial Al MMC and the CANMET hybrid composite. Both the A242 alloy and the commercial Al MMC exhibited substantial drop in compressive yield strengths with the increase in temperature. It also points out the fact that though the Al MMC is loaded with  $20 \text{ vol.}\%$  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  $Ni_xAl_y$  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  $Ni_xAl_y$  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  $400^\circ\text{C}$ .

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A1 – A242 Al; CC – Commercial composite ;  
C2 – CANMET composite with 2.8 vol %;

Fig. 8. Compressive yield strengths of A242 aluminum, commercial MMC and CANMET hybrid MMC