

# Development of Al7075-SiC Co-Continuous Composite by Gravity Infiltration

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**ABSTRACT:** A co-continuous composite was prepared by gravity infiltration of an Al-Zn-Mg alloy into a silicon carbide precursor. The hardness, weight density, weight and volume fraction of the composite was studied. The damping ratio of the manufactured composite was estimated. The tests show that the composite is light in weight and possess high hardness and good damping characteristics.

**KEYWORDS:** Co-Continuous Composite, C4, Al 7075, gravity infiltration, SiC

## I. INTRODUCTION

Co-continuous composites have been studied since the last decade for their unique properties over conventional composites. The isotropic nature of the co-continuous composite provides dominant mechanical consistency and better interfacial strength when compared with discrete-phase composites. Ceramics exhibit desirable properties like high strength, hardness, high elastic modulus, high temperature resistance, chemical inertness, wear resistance and low density which are desirable for different applications. However, ceramics exhibit poor performance in tensile, impact loading conditions and possess very poor toughness. The limitations of ceramics can be overcome by introducing a ductile metal phase in combination with ceramics thereby, forming a composite material. A composite thus manufactured would possess improved toughness and impact strength. [1, 2].

*Co-continuous composites* consist of two interpenetrating networks, in which both the phases remain continuous. A particular way is to use a ceramic precursor having a foam structure in which the pores in the ceramic will be three dimensionally continuous. When the pores in this ceramic structure are infiltrated with a metallic phase, a tri-axial continuous composite is obtained. The composite thus obtained would be isotropic in nature and hence have the same property in all the directions. Co-continuous composites can be manufactured by a variety of methods, as outlined in literature [2]. A few of the methods are listed in Table 1.

Table 2: Manufacturing Techniques for Co-Continuous Composites

Reactive Metal Infiltration	Lanxide Process	Squeeze Casting
Pressure Infiltration	Gravity infiltration	High pressure die casting
Hot solvent exchange reaction	Sacrificial oxide displacement	

Numerous researchers have investigated various processes to manufacture co-continuous composites and have documented its properties. A majority of research work is based on Reactive Metal Penetration (RMP) in which the metal and ceramic phases undergo a reaction at the interface, as shown in Eq. 1.



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G M La Vechhia et al. [3] performed reactive metal penetration using 99.9% pure aluminium and Al-Si (10%) alloy as infiltrating alloys. Microstructural analysis and the weight percentage of the metal and the ceramic were investigated in the study. Fracture toughness was found to be 5.2 MPa√m. A 40 % increase in the toughness was observed in comparison to the parent ceramic phase.

G.S Daehn et al. [4] studied the elastic and plastic behaviour of aluminium-alumina co-continuous composites. The study envisaged that, in the bilinear system, the elastic modulus of the composite could be increased to a greater extent if the stiffer component in the composite was continuous.

Manufacturing of co-continuous ceramic composites (C4) based on RMP was carried out by Matteo Pavese et al. [5] to study their high cycle fatigue characteristics. The fatigue limit was found to be 91 MPa at 10<sup>7</sup> cycles.

The SEM studies showed that a considerable diffused damage structure was evident before cracking occurred in the composite. Glenn S Daen et al. [6] had also studied co-continuous composites for friction and braking applications.

The friction coefficient of the co-continuous composite was found to be 0.25 at 800°C, equivalent to that of cast iron at 670°C

## II. EXPERIMENTATION

### Selection of Material Phases for Composite

**Metal Phase.** The infiltrating metal alloy used in the study was *aluminium 7075 alloy*. Among the aluminium wrought alloys, the 7-series alloys possess the highest strengths [7]. These alloys are generally used in aircraft industry owing to their low density and high specific strength. The major constituent of this alloy is zinc and magnesium. Commercial grade Al 7075 alloy sheet was purchased. High speed hack saw blade with 24 cutters per inch was used to cut the alloy

Table 3: Spectroscopic analysis of Aluminium 7075

METAL	Al	Zn	Mg	Cu	Cr	Fe
% WEIGHT	89.57	6.728	1.868	1.37	0.194	0.122
METAL	Ti	Mn	Si	Ag	B	Ba
% WEIGHT	0.054	0.019	0.005	0.0013	0.0016	0.001
METAL	Be	Bi	Ca	Cd	Co	Ga
% WEIGHT	0.0003	0.0044	0.0002	0.0005	0.0016	0.011
METAL	In	Li	Mo	Na	P	Pb
% WEIGHT	0.0034	0.000002	0.001	0.0005	0.0052	0.0057
METAL	Ti	St	V	Zr	Sb	Hg
% WEIGHT	0.004	0.001	0.0085	0.0028	0.007	0.002

**Spectroscopic Analysis.** In order to check the chemical composition, the alloy was subjected to *spectroscopic analysis*. The experiment was conducted using a Q4 Tasman optical emission spectrometer. From the study it was verified that, the chemical constituents of the alloy shown in Table 4 conformed to ASM Data sheet specifications.

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**Ceramic Phase.** The ceramic preform used was silicon carbide (SiC) foam. The composition of the foam was SiC - 75%, Al<sub>2</sub>O<sub>3</sub> - 20% and silica. The porosity of the ceramic preform used was 85%. High speed blades were used to cut the ceramic preforms as, the foams were brittle in nature. The SiC foam is shown in Fig 1.

Gravity infiltration technique was followed to fabricate the composite. Here, the molten metal alloy was infiltrated into the ceramic foam without application of pressure.

The infiltration was performed in a resistance furnace with a rated maximum temperature and power of 1100°C and 4500 W respectively. The SiC foam is shown in Fig 4.

**Reference source not found..** A schematic of the experimental setup is shown in Fig 5. Initially, the silicon carbide preform was cut into a 50.8\*25.4\*25.4 mm cubical specimen. The melting point of commercial Al 7075 annealed alloy was 623°C. The preform and alloy were preheated for two hours in a resistance furnace to a temperature of 800°C. This preheating temperature ensures that Al 7075 alloy melts and was maintained at liquidus period of time. After the stipulated time of two hours, the crucible containing molten Al 7075 was poured into the preform floating on to the surface due to the buoyancy effect, a carbon rod was used to hold the preform in place inside the crucible. The open porous structure of silicon carbide preform enabled entry of molten aluminium alloy from all sides. The infiltration setup was kept at a temperature of 800°C for one hour. After the stipulated time, the crucible was taken out and kept for cooling at room temperature for one hour. The composite thus fabricated, was machined out with outmost care using a sequence of operations like turning, milling and grinding. About 87 g of pure molten aluminium alloy was poured into a cylindrical mould for conducting tests.

**Evaluation of Density** - Density of the composite was evaluated using Archimedes principle. The composite was weighed in a weighing balance and the weight in air was noted. A setup was made to collect the amount of water displaced by the composite when it was completely immersed inside water. The weight of this displaced water was found out. Using the empirical formula, density of the composite was determined. The setup is shown in Fig 2.

**Volume and weight percentage of the composite** - Archimedes principle was used to determine the volume of the composite. Initially, a graduated beaker was filled with water to a known level (150ml). After completely immersing the composite with the help of a thin thread of negligible mass, the rise in volume in the beaker was noted. On estimating the difference in volume, the volume percentage of the composite was calculated. Volume percentage of Al 7075 phase was also estimated. A similar procedure was followed for finding the weight percentage of each of the phases in the composite.

**Hardness Test** - Brinell hardness testing was performed on the composite as shown in Fig 3. The testing was also conducted for the pure aluminium alloy. The values were noted for 5 mm and 10 mm diameter indenters with 500 kgf and 750 kgf loads respectively. The average hardness value of three observations was taken for the composite and pure Al alloy.

**Damping ratio of composite** - Damping ratio of the Al-7075-SiC co-continuous composite was determined using a piezoelectric unidirectional accelerometer as shown in Fig 4. The accelerometer was mounted to the composite and vibrations were induced in the sensitive direction of the composite. The system was integrated to LabView software and the variation of amplitude of acceleration with time was observed.

**Compression Testing** - Universal Testing Machine was implemented in determining the compression strength of the metal-ceramic co-continuous composite as shown in Fig 5. The stress-strain graph was obtained for the composite and Young's Modulus was determined approximating the stress-strain relationship to be linear.



Fig 1 SiC Foam

temperature for sufficient  
7075 was poured into the



Fig 2 Density Measurement



Fig 3 Hardness Measurement

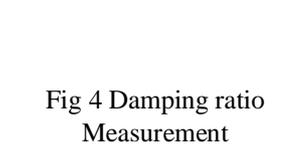


Fig 4 Damping ratio Measurement



Fig 5 Compression Testing

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## III. RESULTS

Density of the composite was found to be  $2.92 \text{ g/cm}^3$ . The density of Al 7075 is  $2.81 \text{ g/cm}^3$  and the density of SiC is  $3.21 \text{ g/cm}^3$ . Using Archimedes' principle the volume of the composite was estimated to be  $23.25 \text{ cm}^3$ . The approximate volume percent of the Al 7075 and SiC phases was found to be 83% and 17% respectively. The approximate weight percent of Al alloy and SiC phases was determined to be 81% and 19% respectively. Hardness of the composite was found to be 96 HB. The un-heat treated aluminium alloy's hardness was found to be 79 HB. The measurements in both load conditions showed almost similar values. Damping ratio of the composite was estimated using Eq. 2 [8]

$$\ln(x_1 - x_2) = 2\pi\epsilon/\sqrt{1 - \epsilon^2} \quad (2)$$

Damping ratio of the composite was evaluated to be  $0.02$ . Logarithmic decrement was estimated to be  $0.126$ . The compressive strength of the composite was found to be  $330 \text{ MPa}$ . The tensile strength of un-heat treated Al7075 was  $275 \text{ MPa}$ .

## IV. CONCLUSION

Hence, the density of the composite was found to be *in-between* the density of the metal and ceramic phase. It was also evident that, in terms of both volume fraction and weight fraction, Al 7075 alloy was the major phase in the composite. The composite thus manufactured was found to exhibit a 20% increase in the hardness when compared with the pure Al alloy. The damping ratio was observed to be close to Al-SiC metal matrix composites produced by powder metallurgy process [9]. Additionally, the damping ratio of the fabricated composite was found to be in the range of continuous metallic structures [10]. There had been an increase of 20% in the compressive strength of the composite. The results suggest that C4 composites could be used in structural and machine tool applications where damping is essential.

## REFERENCES

- [1] Jonathan S. Everts, B.S., Advanced Processing Techniques for Co-Continuous Ceramic Composites, A Thesis, The Ohio State University 2008,
- [2] Jae Seong Park, Effect of Contiguity on the Mechanical Behaviour of Co-Continuous Ceramic Metal Composites, A Thesis, Purdue University Graduate School.
- [3] G M La Vechhia, C Badini, F Derrico, Co-continuous Al/Al<sub>2</sub>O<sub>3</sub> composite produced by liquid displacement reaction: Relationship between microstructure and mechanical behavior, JOURNAL OF MATERIALS SCIENCE 38(2003)3567 – 3577.
- [4] G S Daehn, b. Starck, l. Xu, k. F. Elfishawy, j. Ringnalda and h. L. Fraser; Elastic and plastic behaviour of a co-continuous alumina/aluminium composite, U.S.A, Vol. 44, No. I, PP. 2499261, 1996, Acta Metallurgica Inc
- [5] Matteo Pavese, Paolo Fino, Daniele Ugues and Claudio Badin Politecnico di Torino; High cycle fatigue study of metal- ceramic co-continuous composites Scripta Materialia 55 (2006) 1135–1138
- [6] Glenn S. Daehn and Michael C. Breslin, Co-Continuous Composite Materials for Friction and Braking Applications, Low-Cost Composites in Vehicle Manufacture.
- [7] Ron Cobden, Alcan, Banbury Aluminium: Physical Properties, Characteristics and Alloys, TALAT Lecture 1501
- [8] Ming Rao and Haiming Qiu. Process control engineering: a textbook for chemical, mechanical and electrical engineers. CRC Press, (1993)
- [9] X. Jiang, L. Ouellet and D. Nikanpour, dynamic mechanical properties of Particulate reinforced metal-matrix composites at low temperatures, Advanced Materials and Thermal Group, Space Technologies, Canadian Space Agency 6767
- [10] Vince Adams and Abraham Askenazi, Building Better Products with Finite Element Analysis, OnWord Press, Santa Fe, NM.