

***Synthesis, Characterization and Mechanical Properties  
of Uncoated and Coated  $ABO_w$  Reinforced Aluminium  
Matrix Composites***



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**By**

**Neeraj Pandey**

***DEPARTMENT OF CERAMIC ENGINEERING***

**INDIAN INSTITUTE OF TECHNOLOGY**

**(BANARAS HINDU UNIVERSITY)**

**VARANASI – 221005**

**Roll No. 16031007**

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## CHAPTER 9

### SUMMARY AND FUTURE WORKS

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The present investigation is an approach to develop aluminium and aluminium Al-319 alloy composites and their characterization. Two different categories of aluminium and Al-319 alloy composites and, as reinforcement, uncoated and 'SiO<sub>2</sub> coated ABO<sub>w</sub>' was developed.

The chemical composition and the reinforcing whiskers content of the metal matrix composites have been determined to characterize the metal matrix composite. The major conclusion of the present study is summarized under given below.

**9.1** Fabrication of composites and reinforcement.

**9.2** Analysis of fabricated material.

#### **9.1 Fabrication of composites and reinforcement**

i) Uncoated alumina borate whiskers were synthesized using hydrolysis and heat treated using powder metallurgy route. Whiskers were reinforced in the aluminium metal matrix by a wet dispersion process. Thereafter powder metallurgy route was followed to prepare the samples.

ii) Coated alumina borate whiskers were synthesized by liquid sol/hydrolysis route and heat treatment by powder metallurgy route. The coating of the whiskers was done by heating the dried sol of the coating material, and finally, the preforms were calcined to obtain the oxide coating on ABO<sub>w</sub> powder surfaces.

iii) Coated and uncoated whiskers were reinforced in Al-319 alloy using a compo casting process.

## 9.2 Analysis of Fabricated Material

### a) XRD analysis

- (i) In the case of uncoated  $ABO_w$ , XRD confirmed the presence of  $Al_{18}B_4O_{33}$  phase, crystalline between 1100-1300°C. As the mass fraction of  $ABO_w$  increased, the intensity of the  $ABO_w$  peak increased, whereas the aluminium peak decreased.
- (ii) In case of  $SiO_2$  coated  $ABO_w$  reinforced in aluminium matrix composites, no other phase was formed except aluminium,  $ABO_w$  and  $SiO_2$ .
- (iii) In the case of uncoated whiskers reinforced A-319 alloy except for  $ABO_w$  and Al,  $Al_2Cu$  phase was also present.  $SiO_2$  coated  $ABO_w$  reflected beta quartz phase after increasing the calcining temperature to 500°C.
- (iv)  $SiO_2$  coated whiskers reinforced Al-319 alloy reflected  $SiO_2$ ,  $Al_2Cu$ , and  $ABO_w$  phases. The tridymite structure of  $SiO_2$  is a high temperature resistant, sheet-like crystal with high density giving scope for uniform coating of whiskers for reinforcement. For Al-319 alloy, copper diffusion is the main factor in the formation and growth of the  $Al_2Cu$  phase [151-152].

### b) TEM investigation

- (i) Micro rods observed in  $Al_{18}B_4O_{33}$  phase were single crystals with orthorhombic structures. At 1400°C, the network formation of the whiskers has taken place, and they were not single crystals.
- (ii) For coated whiskers,  $SiO_2$  coating was uniformly deposited on the whisker surfaces and thickness 20-50 nm was observed. Zig-Zag formation of Silica was observed.

(iii) The Al-319 alloy reinforced with coated whiskers showed the formation of interfacial product  $Mg_2Al_2O_4$ , a continuous product distributed at the interface between  $ABO_w$  and A-319 alloy.

**c) SEM image investigations**

(i) The size of whiskers increased with an increase in temperature up to  $1300^\circ\text{C}$  (10-15 $\mu\text{m}$ ) but an increase in temperature further led to a decrease in aspect ratio of the crystals.

(ii) As the sintering temperature is increased to  $1200^\circ\text{C}$ , the particle range size has been increased (6-8  $\mu\text{m}$ ). Further, at a higher sintering temperature of  $1300^\circ\text{C}$ , particles size of whiskers of size 10–15  $\mu\text{m}$  are observed, resulting in an improvement in the aspect ratio of whiskers.

(iii) In the case of coating of whiskers,  $\text{SiO}_2$  coating is smoother and compact thickness 50 nm leaves no cavity and holes than oxide coating.

(iv) In the case of uncoated and coated fabricated composites, SEM images micrographs show almost uniform distributions of  $ABO_w$  throughout the volume of the composites. In ‘ $\text{SiO}_2$  coated  $ABO_w$  fabricated composites’, uniform reinforcement distribution in the matrix materials offers excellently refined microstructures.

**c) Porosity**

(i) The apparent porosity of uncoated  $ABO_w$  increased with increasing sintering temperature but dropped sharply after  $1300^\circ\text{C}$ .

(ii) Bulk density of these samples decreased up to  $1300^\circ\text{C}$  and increased again at  $1400^\circ\text{C}$  (The density decreases due to the whisker formation).

(iii) Among all the coated whiskers, the apparent porosity of SiO<sub>2</sub> coated whiskers was lowest and bulk density was highest (The tetrahedral structure of SiO<sub>2</sub> and grain boundary growth was responsible for this).

(iv) A decrease in density of composites reinforced with uncoated whiskers was observed, with an increasing percentage of whisker content.

**d) Differential thermal and Thermo-gravimetric analysis.**

(i) Analysis revealed negligible weight loss and weight change of ABO<sub>w</sub> whiskers.

(ii) Below 700 °C, no reaction takes place between B<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub>. Initiation of 2Al<sub>2</sub>O<sub>3</sub>. B<sub>2</sub>O<sub>3</sub> phase formation occurs between 700 °C–800 °C, which reacts with excess alumina above 950°C, giving Al<sub>18</sub>B<sub>4</sub>O<sub>33</sub> phase.

**e) Hardness testing**

(i) Hardness of ABO<sub>w</sub> reinforced aluminium composites fabricated by conventional powder metallurgy route was increasing with an increase in whisker content in the matrix. It was obtained maximum, i.e. 40H<sub>V</sub> for samples with 10 wt% of reinforcement.

(ii) The hardness of composite samples reinforced with SiO<sub>2</sub> coated ABO<sub>w</sub> in 10 wt% was obtained maximum, i.e. 46.2 H<sub>V</sub>. Further increase in reinforcement % led to a decrease in hardness due to agglomeration causing localized shrinkage strains.

**f) Mechanical properties**

(i) The cold and hot modulus of rupture of ABO whiskers at room temperature and at 700°C for different sintering temperatures increased with increasing temperature upto 1300°C, thereafter a decrease in bending strength was observed as the formation of brittle glassy phase initiates at 1400°C.

- (ii) Plastic deformation due to high thermal stresses led to a decrease in HMOR values. HMOR values were higher at 700°C, i.e. 42 MPa. HMOR values for SiO<sub>2</sub> coated alumina borate samples were found maximum at 800°C, i.e. 53 ± 2.2 MPa. It was minimum for uncoated, and ZnO coated samples at 1000°C, i.e. 43 ± 2.2 MPa.
- (iii) Flexural strength around 172 MPa, in composites reinforced with 10% ABO<sub>w</sub> samples were obtained. Flexural strength of SiO<sub>2</sub> coated (ABO<sub>w</sub>) – Al matrix composites were found to be maximum, i.e. 178 MPa in 10 wt% SiO<sub>2</sub> coated whisker reinforced Al composites.
- (iv) It can be concluded that SiO<sub>2</sub> coating on whiskers provided better bending strength to whisker reinforce composites.

**g) Compression testing**

- (i) Maximum compressive strength i.e. 324 MPa was obtained in composites with 10 wt% ABO<sub>w</sub> reinforcement.
- (ii) Diametral compression test (DCS) and Young's modulus test of SiO<sub>2</sub> coated ABO<sub>w</sub> reinforced composites were calculated. The maximum values of DCS and Young's modulus for samples sintered with 10 wt% of whiskers were obtained i.e. 142 MPa and 89 GPa, respectively.
- (iii) With the higher content of ABO<sub>w</sub>, the proportion of the region representing the flow localization increased, and the matrix has to accommodate the deformation between the region of plasticity and non-plasticity.
- (iv) The occurrence of localized plasticity signifies improvement of plastic deformation capacity.
- (v) Coated ABO<sub>w</sub> from the matrix proved to be unbreakable under the application of load, thus affecting the mechanical properties of the composites.

**h) UTS and  $\delta$  testing** -The UTS and  $\delta$  of the composites increased firstly and then decreased with the increasing of the coated  $ABO_w$  content. The composite with a suitable coated  $ABO_w$  content ( $SiO_2/7.5\%ABO_w/Al-319$  composite) can attain the highest values of the UTS (238 MPa) and  $\delta$  (6.4%).

**i) Dry sliding behavior**

- (i) 7.5wt.% $ABO_w/Al-319$  exhibits the best dry sliding wear resistance.
- (ii) Increasing the coated  $SiO_2 /ABO_w$  in the alloy may increase the hardness and oxide layer from at the surface.  $SiO_2$  is also strongest because of its high density and low porosity.

**k) Wear test**

- (i) Oxide layer developed on the surface may affect the wear resistance properties which act as a protective layer and decrease the wear rate (a reason why the  $SiO_2 /ABO_w /Al- 319$  exhibits a fairly good wear resistance)
- (ii) Uncoated worn surface of  $Al-10wt. \% ABO_w/Al$  composite is much smoother and almost free from wear debris.
- (iii) With 15 wt. %  $ABO_w$ , shallow surface scars with fine cracks, and subsequent delamination are observed. The whiskers are dislodged due to non-uniform dispersions forming larger quantities of debris.

### **9.3 Suggestions for future work**

The following suggestions are made for future investigations based on the present results and analysis with regards to the phase evolution, mechanical stability, and microstructural study:-

1. Chemical corrosion behaviour of SiO<sub>2</sub> coated alumina boron-based refractory application for the petrochemical industry.
2. Microstructure and high-temperature mechanical properties of compo-cast SiO<sub>2</sub> - coated ABO<sub>w</sub> reinforced Al-319 Composites.
3. Erosion behaviour of SiO<sub>2</sub> coated ABO<sub>w</sub> reinforced aluminium alloy for automotive application.
4. Wet/Lubrication wear and corrosion behaviour of SiO<sub>2</sub> coated ABO<sub>w</sub> –Al 319 composites.
5. Fatigue behaviour of coated and uncoated ABO<sub>w</sub> reinforced Al-319 composites.



