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Microstructure and Mechanical Behaviour of ABOw Reinforced Aluminium Matrix Composite Synthesized by Powder Metallurgy route

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Microstructure and Mechanical Behaviour of ABOw Reinforced Aluminium Matrix Composite Synthesized by Powder Metallurgy route

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Abstract. In present study, the effect of Aluminum borate whiskers (ABOw) content (5, 10 and15 wt.%) on the development of Al-ABOw composite using powder metallurgy route has been investigated. Firstly, Aluminum borate whiskers (ABOw) were produced using sol-gel method. The commercial pure aluminum powder was used as matrix material in this investigation. Amongst, the various casting technology, the powder metallurgy route is most economical and extensively used by researchers. The microstructures of composites were observed using optical microscopy (OM), scanning electron microscopy (SEM). Transmission electron microscopy (TEM) analysis was performed for the observation of ABOw powder morphologies. The XRD analysis was carried out to confirm the phases and peak intensity of developed alloy and composites. The sintering was carried out at 600°C for all samples. After that, the bending test was carried out to calculate flexural strength of alloy and composites. The flexural strength 172±5 MPa was obtained maxima in composite with 10 wt.% ABOw along with improved hardness around 40.2HV. The result shows that, the composite exhibited better interfacial bonds, uniformity in microstructure and optimum flexural strength.
Keywords: Powder metallurgy, ABOw reinforcement, flexural strength, fractography.

1. Introduction

Aluminum and its alloys have been extensively used in military industries, aerospace, auto industries and transport, marine industries, construction structures and electrical industries. Although in some industrial uses, benefits of aluminum alloys have been limited because of lower mechanical strength, wear & erosion resistance and surface hardness. Aluminum-ceramics based composites are widely used materials as MMCs due to their light weight, low density, high tensile strength and ease of fabrication [1-3]. Reinforcements used may be continuous, discontinuous or particulate in nature. Whiskers are gaining their importance as reinforcements as they provide large surface area for bonding with matrix material. The whiskers mainly used as reinforcements are SiO_2, Al_2O_3, $Mg_2B_2O_5$, Mg_2Si and ABOw [2,4-9]. Among these ABOw is gaining importance as they are low cost one dimensional material. The ABOw($Al_{18}B_4O_{33}$) may have potential oxidation résistance, the physical properties such as bulk density 1.46g/cm^3, open porosity 54.4, linear shrinkage percentage -1.8% and flexural strength 55±2 at 1500°C sintering temperature[18]. Several fabrication techniques using whiskers as reinforcements have been reported for manufacturing of such composites such as squeeze casting, stir casting and centrifugal casting [10]. However, due to lack of research work reported on powder metallurgy route for the fabrication of ABOw whiskers reinforced composite, the many researchers are in favoured to develop the composites for high performance engineering components in automotive and aircraft industries. The ABOw whisker which is used as reinforced material was generally prepared using sol-gel method [11]. X. Gao et al.[12] found that, the coating of ABOw and the addition of soybean sacrificial filler can effectively decrease the volume fraction of whiskers in the composite without changing its ultimate tensile strength. However, at the room temperature, the elongation to fracture of the composite evidently increases around 11.1%. Many researchers have studied ZrO_2, Al_2O_3 reinforced aluminum metal matrix composites but their tensile and fracture behavior needs much improvement. Mehta, Niraj Singh, et al.[13] have studied that reinforcing with zirconia (ZrO_2) particles in porcelain ceramic. Roseline, S.et al.[14] varied zirconia percentage in ceramics and found that, the impact strength and tensile strength are slightly enhanced with improved ductility. The higher porosities developed in the composites due to stir casting process causes low strength of components. The adaption of powder metallurgy route shows better results in respect of lower porosities, defect free ceramic reinforced composites fabrications.

Powder metallurgy route as shown in Figure 1 was used to prepare the final objects for characterization; this method involves blending of finely powdered materials, consequently pressing the mixture into desired form by using metal dies, followed by sintering the compacted green specimens in a controlled atmosphere condition. The desired shape component was obtained which requires minimum machining. Powder metallurgy can also be used to produce fully finished components of automotive parts like connecting rods [15-17]. The aim of this investigation was to fabricate light weight and high strength composites.

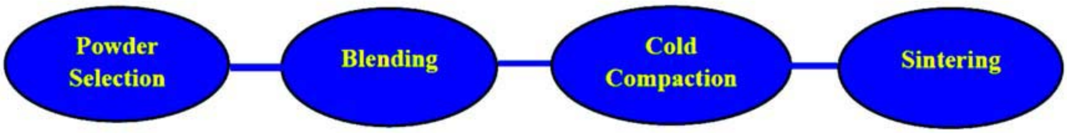

Figure 1. Powder metallurgy processes

2. Experimental Procedure

Aluminum borate whiskers reinforcement was synthesized using sol-gel method calcinized at 1300°C. The aluminum powder was used as matrix material procured from Poly-Chem private India Limited Bangalore. Pure aluminum metal powder (purity 99.5%) and particle size 20-40 µm was used as matrix. It was vigorously mixed with ethanol in magnetic stirrer for 40 min then ABOw was added in required percentage at 80°C and further mixed through magnetic stirrer for 15 min. After hydrolysis sol was dried in oven at 110°C for 4 hours, then dried sol was mixed with PVA (Polyvinyl Alcohol) solution and pellet was pressed with hydraulic press at 180 MPa. Rectangular pellets of dimension 50x10x10 mm were obtained. The pellets each were fired in Argon gas environment in a sintering furnace at heating rate 5°C/min followed by heating at 600°C and 2h soaking time then cooled to room temperature.

X Ray Diffraction by Rigaku Smart Lab at 40kV and 15mA using CuKα (λ= 0.154 nm) radiation was used to confirm the phases in sintered composite samples. Microstructures were studied using Scanning Electron Microscopy (SEM) ZEISS EVO 18 operating at 20 kV was used to identify the morphologies of sintered composites. Transmission electron microscopy (TEM TECHNAI G^2 T20) operated at 200 kV was carried out for morphology and crystal structures of ABOw reinforcement. Density of the composites was calculated using Archimedes ‘immersion method. The flexural strength is measured by universal testing machine using Tinius Olsen (H10KL). Bending strength was calculated using the following expression as given below.

$$\text{Bending strength}=\frac{3FL}{2bt^2}$$

where F is the load at failure, L is the distance between the supports, b is the sample width, and t is the thickness of the sample.

3. Result and Discussion

The density of three samples of each composite with different volume fraction was calculated using immersion method, based on Archimedes' principle. Finally, the average porosities were calculated of each composite. The details of this method can be found in ASTM C20.The results obtained as shown in Table 1. From Table 1 it can be observed that, the density of the specimens decreases with increasing the volume fraction of whiskers in the aluminum matrix. It shows the micro sized whiskers decrease the density of the specimens with increased percentage in matrix. Also the increased percentage of whiskers increases the average porosities in the sintered composites. In contrast, composite with 15%ABOw shows decrease in porosity percentage due to more interlocking and rounded shape of whiskers.

The optical microscopy images for all samples with variations of ABOw percentages are shown in Figure 2.Figure 2(a) shows the microstructure without addition of ABOw reinforcement. It clearly confirms the dark flaky pattern which represents silicon eutectic phase and white phase as matrix grains. In contrast, optical microstructures of composites reinforced with 5%, 10% and 15% ABOw whiskers shown in Figure 2(b),(c) and (d) clearly confirmed the ABOw whisker particles in the form of clusters.

Table 1. Table captions should be placed above the tables.

Composites/Al Powder	Sample Number	Experimental density(g/cc)	Theoretical density ($\rho_{th}=V_f\rho_f+V_m\rho_m$)	Average porosity (%)
Al-Powder	1	2.56	2.70	5.43
	2	2.53		
	3	2.58		
Al(ABOw)$_5$	1	2.47	2.65	7.48
	2	2.48		
	3	2.45		
Al(ABOw)$_{10}$	1	2.32	2.61	11.17
	2	2.30		
	3	2.29		
Al(ABOw)$_{15}$	1	2.30	2.57	9.86
	2	2.33		
	3	2.32		

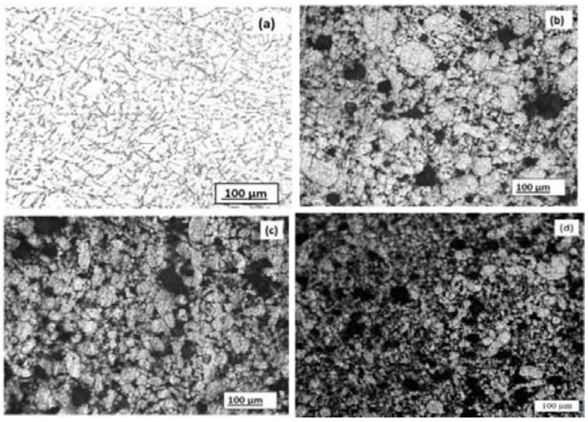

Figure 2. Optical images of (a) Aluminium alloy (b) Composite with 5% ABOw (c) Composite with 10% ABOw (d) Composite with 15% ABOw sintered at 600°C

The dark clustures represent the ABOw particles and white regions represent the metal matrix respectively. The scanning electron micrographs are shown in Figure 3 calcinized at 1300°C .The scanning electron micrograph shows the distribution of ABOw whiskers throughout the volume of cast composites. It was found that, after sintering, the uniform distribution of reinforcement in matrix materials offered excellent wear resistance and mechanical properties. However some regions show agglomeration of whiskers which may be due to the porosity incorporated in composite during sintering process.

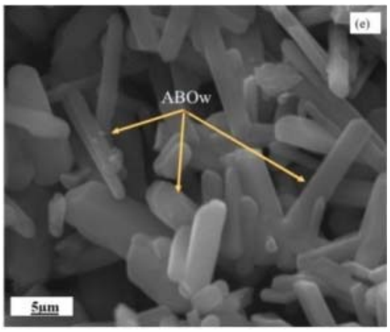

Figure 3. SEM micrographs of ABOw used as reinforcement calcinized at 1300°C

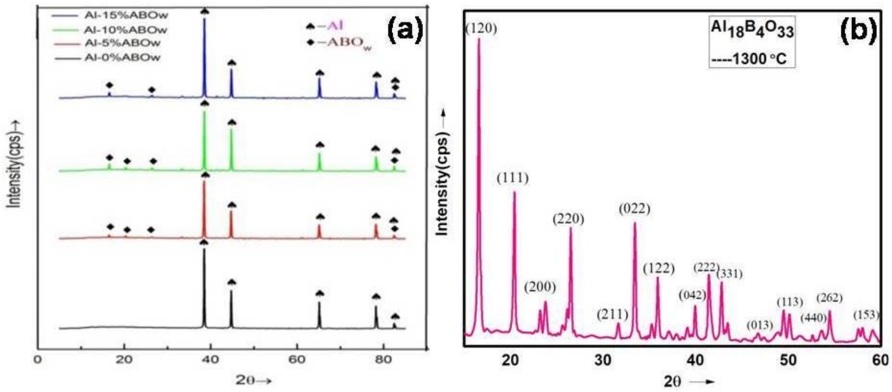

Figure 4. XRD patterns of (a) composites sintered at 600 ^{o}C-2h with different composition (b) ABOw reinforcement calcinized at 1300°C.

XRD patterns of aluminum matrix composites samples sintered in the range of 600°C is shown in figure 4.It shows that except aluminium and ABOw, no other phases were present in the composites manufactured. As the volume content of ABOw increases the height of aluminium peaks decreases whereas height of ABOw peaks increases. Moreover, From XRD results shown in Fig.4 (b), it is clear that, with higher ABOw percentage, more $Al_{18}B_4O_{33}$ (JCPDS, 32-0003), phases are present and due to their high flexural strength, high hardness (Mohs 7) [3] can be improved mechanical and physical properties of fabricated composites. The XRD pattern of ABOw as shown in Figure 4(b).

The hardness of the samples increases with increasing the percentage of whiskers in the matrix refer Table2.This may be due to inhibition of the progress of plastic deformation by whiskers present in the matrix.As agglomeration of whiskers proceed in specimens with 15% ABOw volume fraction then on uniform sintering driving force leads to localized shrinkage strains introducing more defects (dislocations and point defects, etc.) at the interfaces of ABOw and matrix during grain growth so that the interface strength decreases during sintering. This behavior of composite increases with increasing volume fraction in aluminum matrix [13] .The flexural strength of the samples were calculated using three point bending test, with a span of 30 mm and a crosshead speed of 0.5mm/min. Resultant, it was found that in Al-10wt%ABOw have more flexural strength upto 172Mpa refer Table 2.The TEM Bright field images with corresponding diffraction patterns of ABOw powder prepared by sol-gel method as shown in Figure 5.The morphological and discontinuous structure of the micro rods were characterized and the crystal parameters are determined as a=7.6874 Å, b=15.0127 Å and c=5.6643Å. The parameters confirm the orthorhombic of ABOw reinforcements [11].

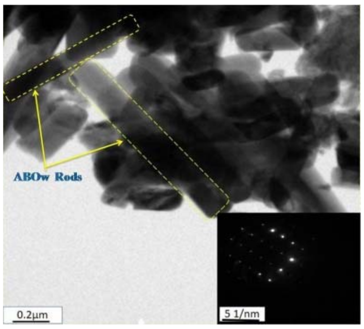

Figure 5. Bright field Image and corresponding SAED (inset) of ABOw powder calcinized at 1300 °C

Table 2.Bending Strength and Vickers Hardness of samples

Volume fraction of ABOw	Bending Strength at room temperature (MPa)	Hardness(HV)
0	125±5	27
5%	160±5	37.8
10%	172±5	40.2
15%	165±5	39

The SEM fractographs of sintered composites is as shown in Figure 6. It was observed from Figure 6(a) the fractured surface of aluminum alloy shows a ductile nature of the fracture along the micro holes and dimples on the surface. The fractographs of Al/ABOw composites in figure 6(b), (c) and (d) reflect brittle nature of fracture specifically at whisker and matrix interface. Figure 6(b) shows more agglomerates of aluminum on the fractured surface and whiskers may provide better interfacial bonding and enhanced mechanical properties were observed .From Figure 6(c) more sites of whisker pull out reflect that the interfacial bonding between matrix and whisker led to load transfer from matrix to the whisker thus giving good bending strength to the composite.

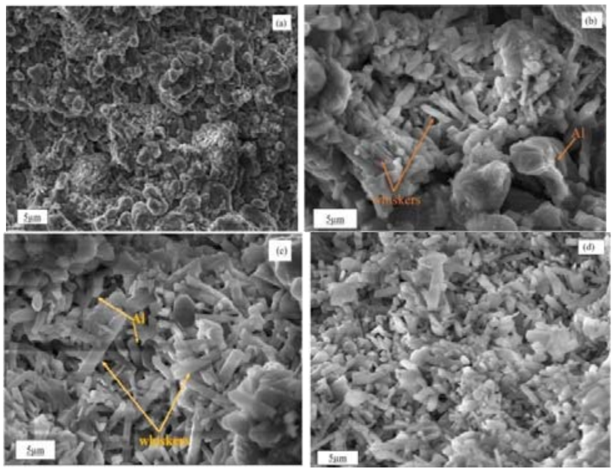

Figure 6. Fractographs of (a) Aluminium alloy (b) Composite with 5% ABOw (c) Composite with 10% ABOw (d) Composite with 15% ABOw sintered at 600°C

4. Conclusion

In this study, Al-(ABO)w metal matrix composite with the variations of ABOw whiskers reinforcements in pure commercial aluminum metal powder used as matrix materials has been synthesized using powder metallurgy route.

The sol-gel method for preparation of ABOw reinforcement was used. The OM, SEM were used for microstructures observations i.e. phases as well as grain structure and TEM analysis was done to characterized the morphological and discontinuous structure of the micro wishkers. The density of the composites is decreases with increasing percentage of whisker in the matrix due to increase in porosity with increasing content of whisker. The micro hardness of composite improved in Al-10%ABOw with reduced porosity and more interfacial bonding between matrix and reinforcement. The flexural strength around 172 MPa with 10%ABOw reinforcement was observed due to lower porosity than other sintered samples. The study clearly shows whisker content in the composite led to improvement in mechanical properties due to effect of grain refinement. This grain refinement was achieved after sintering the samples. The fractographs of fractured samples show more agglomerates of aluminum on the fractured surface along with whiskers which may provide more interfacial bonding and enhanced mechanical properties.

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