

Influence of Sintering Temperature Studies on Al- Beryl Metal Matrix Composites

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Abstract: Aluminum based metal matrix composites (MMC) containing 10 wt. %, 20 wt. % and 30 wt. % beryl were fabricated using powder metallurgy route. The beryl as a mineral phase was initially crushed, and mechanically sieved to various sizes. The final particle sizes in the range of $50 \pm 10 \mu\text{m}$ were made. Commercially available Al powder with an average particle size of $40 \pm 5 \mu\text{m}$, and beryl content in Al was varied from 10, 20, and 30 wt. %. The green pellets were made to 25 mm diameter with a load of 1.02 MPa, were sintered in a vacuum furnace maintained at 500° , 550° and 600°C . The sintered samples with varying quantities of beryl, were subjected to hardness measurement and microstructural details. The hardness results clearly demonstrated that increasing the sintering temperature in powder metallurgy route was responsible for better interfacial bonding and reduced porosity, increased hardness values. Al-10, 20 and 30-wt% beryl MMC exhibited hardness of 55 VHN, 58 VHN, and 72 VHN, respectively. The microstructural examination clearly demonstrated that vacuum sintered at 600°C has led to improved density level. The interfacial bonding between the Al matrix and beryl particles observed was excellent. Sintering temperature of 600°C , showed superior hardness and strength values as compared to Al-beryl MMC processed through liquid metallurgy vortex route technique.

KEYWORDS: Sintering, Beryl, Metal matrix Composite, hardness, Powder Metallurgy

1. INTRODUCTION

Aluminium metal matrix composites possess better mechanical properties compared to their base materials [1- 2]. Composite materials are well known for tailor made properties by combining two or more properties. Al based MMCs have been extensively studied [3-6]. This is particularly due to the superior physical, mechanical, and tribological properties exhibited by incorporation of second phase particles such as Al_2O_3 , SiC, TiN, and TiO_2 . Most of the studies showed that the ceramic particles have high hardness, and high density. A large number of processing methods were used to synthesis Al based Metal Matrix Composites. Liquid metallurgy vortex route was one of the most elaborative methods [7, 8]. In this method, settling of ceramic particles was the limitations. Preparation of metal matrix composites are economical and advantages as compared to ingot metallurgy or diffusion welding, the main advantages is low manufacturing temperature that avoids strong interfacial reaction, minimizing the undesired reactions between the matrix and the reinforcement.

The present investigation is aimed with three specific points. The first one is selection of ceramic particles such as beryl with a density of $\sim 2.65 \text{ g/cc}$, which is lighter than other ceramic particles such as SiC, Al_2O_3 , TiN, and has similar density of Al. The beryl has a hardness ranging from 7.5 to 8.5 Mho's scale. The second aim is to fabricate Al based MMCs using beryl as reinforcing particles using liquid metallurgy vortex rote, and powder metallurgy route. The third aim is to study the influence of sintering temperature on Al/Beryl composites.

II. PROCESS DESCRIPTION

Commercial available Al powder with average particle size of $40 \pm 5 \mu\text{m}$ of Leo chemicals was taken as starting material. Beryl, abundantly available in Karnataka region in the form of mineral phase was selected. The beryl was

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initially crushed, and mechanically sieved to various particle sizes. The average particle size of $50 \pm 10 \mu\text{m}$ was considered. Aluminum pieces in the size range of ~ 30 to ~ 50 mm are taken and charged in to a graphite crucible that was inserted in an electrical resistance furnace. The operating temperature of the melt is constantly maintained at $800 \pm 5^\circ\text{C}$. The vortex method is mainly consisting of a motor that is attached to stirrer. The later is rotated at a speed of ~ 100 rpm. A SiC coating is given on the stirrer so that during stirring action, the liquid Al does not get adhered to the stirrer. The stirrer is exactly fixed through a movable attachment so that it can be brought exactly to the centre of the crucible. The beryl powder is pre heated to $\sim 200^\circ\text{C}$ and charged to the liquid melt. Appropriate quantities of beryl are added to liquid Al and to finally to yield, Al-10, 20 and 30-wt% beryl MMC. The liquid Al and beryl particles are stirred for ~ 3 min and the total mechanism of stirring is removed. The graphite crucible is taken out from the electric furnace using a metallic tong and poured in to cast iron split type metallic dies. Prior to the pouring, the dies are properly cleaned and pre heated to $\sim 100^\circ\text{C}$. The samples are swaged to the required dimensions for tensile, metallographic and hardness purposes. The powder mixture was thoroughly mixed using agate motor by adding a poly vinyl alcohol and a green cylindrical pellet of 25 mm diameter were prepared by applying a 1.02 MPa pressure. The pellets were sintered at 500° , 550° , and 600°C in vacuum/ inert atmosphere graphite furnace. Therlex Engineers (p) Ltd, Bengaluru. All samples after sintering were metallographically prepared and observed under optical and SEM.

III. RESULTS AND DISCUSSION

The sieved beryl powder is subjected to particle analysis to understand the particle size distribution. A close observation of the particle size distribution (Figure 1) suggests the high volume fraction of particle size is $50 \mu\text{m}$.

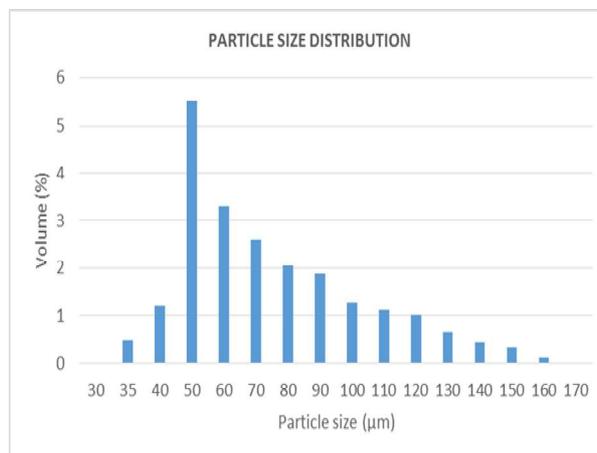


Figure 1.0: Particle size distribution of sieved average particle size of beryl powder is $50 \mu\text{m}$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

Figure 2 shows the XRD pattern of beryl particles to identify the mineral phases. All the phases are identified as $\text{Be}_3\text{Si}_6\text{O}_{18}$. The present results also further confirm that there are no other phases.

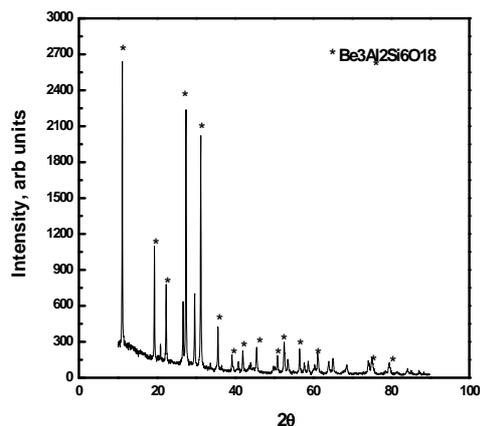


Figure 2: X-ray diffraction analysis of beryl particles

A. MICROSTRUCTURAL STUDIES

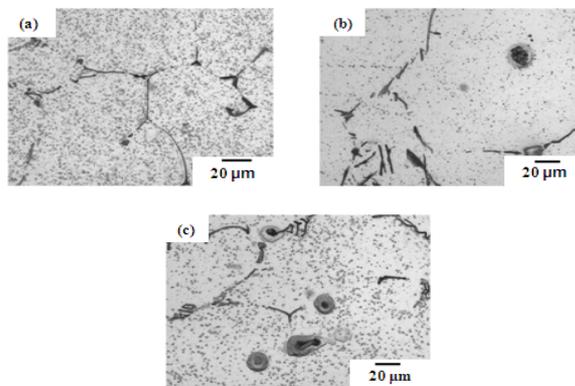


Figure 3 (a-c): Optical images of Al-beryl composites processed by LMVT route, containing average beryl particle size of $50\ \mu\text{m}$, (a) 5 wt.%, (b) 10 wt.%, and (c) 15 wt.%

Figure 3 (a–c) shows optical images of Al – beryl MMCs having average beryl particle size of $55\ \mu\text{m}$ with 5 wt.%, 10 wt.% and 15 wt. %. A close observation of the image demonstrates the average particle size is $\sim 20\ \mu\text{m}$. Also during casting there is a formation of slag which also contains a few beryl particles. Since the density of beryl is relatively lower than Al, a few particles floated on top of melt and mixed with the slag. This also resulted a low volume fraction of beryl content. It is observed that preparation of Al – beryl MMC through liquid metallurgy route has not shown encouraging results. Figure 4 (a-c) shows SEM images of vacuum sintered Al-beryl MMCs. The average beryl particle size of $\sim 50\ \mu\text{m}$ and sintering was done at a) 500°C , (b) 550°C , and (c) 600°C , The SEM images clearly demonstrated that vacuum sintered Al-beryl MMCs sintered at 600°C is responsible for low porosity levels as compared to samples sintered at 500°C and 550°C . Figure 5 (a-c) shows the light images of Al-beryl MMCs with an average beryl particle size of $\sim 50\ \mu\text{m}$, with varying beryl content. It is increased from 10 to 30 wt. %.

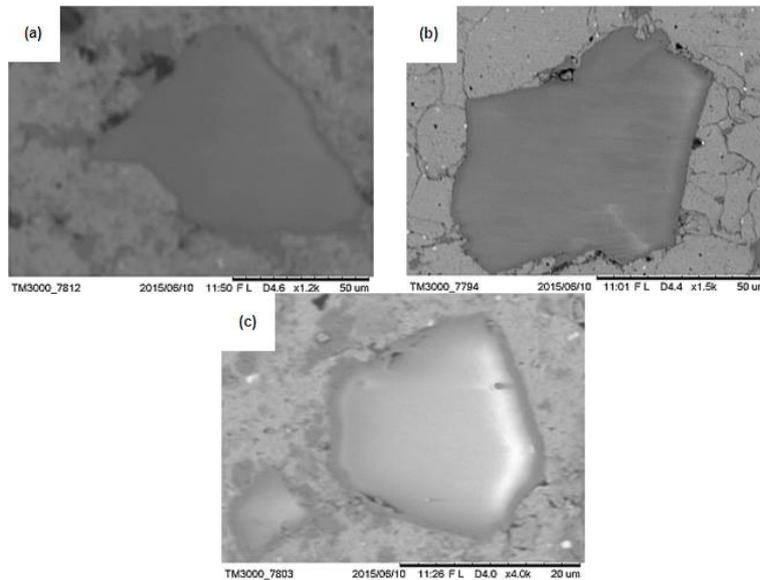


Figure 4 (a-c): SEM images of vacuum sintered Al-beryl composite, containing average beryl particle size of 50 μm , processed at various sintering temperatures, (a) 500°C, (b) 550°C, and (c) 600°C

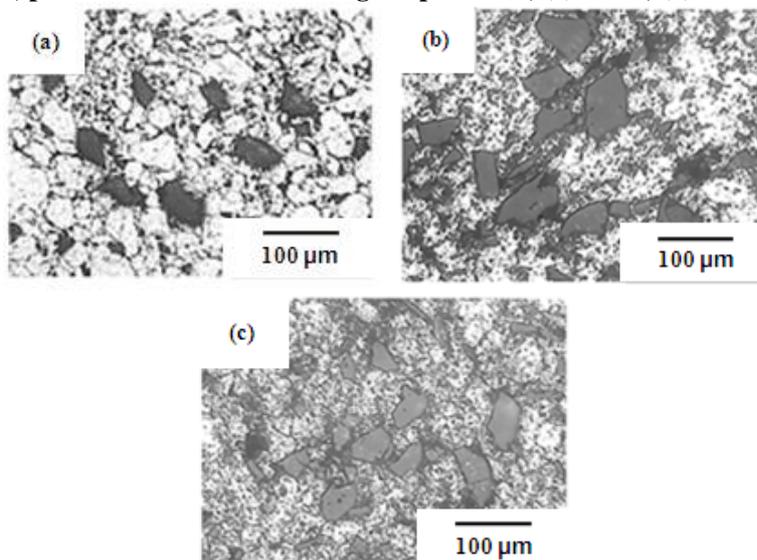


Figure 5 (a-c): Optical images of Al-beryl composites, containing average beryl particle size of 50 μm , vacuum sintered at 600°C (X 100), (a) Al-10 wt.% beryl, (b) Al-20 wt.% beryl, (c) Al-30 wt. % beryl

B. EFFECT OF VACUUM SINTERING ON HARDNESS

The mechanical properties in particular to hardness values of vacuum sintered Al-10, 20, 30 beryl with various sintering temperature is given in Table 1. It can be observed from the Table 1 that the hardness value of Al-beryl MMC sintered at 550°C showed Bulk hardness of 58, 62, 68 Hv and 55, 60, 64 Hv to the same samples sintered at 500°C. Whereas sintering at 600°C, Al - 10, 20, 30 beryl MMC showed improved hardness values. These results clearly demonstrate that sintering is responsible for the enhancement of bulk hardness values. Moreover, the high sintering temperature of 600°C resulted high hardness values as compared to other two processing temperature of 500° and 550° C. In addition, the hardness values on the beryl particle and interface have not shown much difference while the sintering temperature is changed from 500° to 550° and to 600°C. A minor enhancement in interface hardness is

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

observed as the sintering temperature is increased. At sintering temperature of 600°C, 10 wt. % beryl exhibited 72 VHN which has been enhanced to 110 VHN when the beryl content is increased to 30 wt. %. Moreover, there is no appreciable change in the particle hardness is observed. The matrix hardness is substantially improved to 54 from 45 when the Al-beryl contains 10 wt. % beryl. Similarly, Al-30 wt. % MMCs showed improved matrix hardness of 65 from 52 when the beryl content 10 wt. %.

Table 1: Hardness of Al – beryl MMCs processed through vacuum sintering

| Sintering Temperature in °C | Volume fraction of beryl (%) | Bulk hardness (Hv _{100g}) | Micro hardness , Hv _{100g} | | |
|-----------------------------|------------------------------|-------------------------------------|-------------------------------------|-----------|--------|
| | | | Particle | Interface | Matrix |
| 500 | 10 | 55 | 1190 | 119 | 45 |
| | 20 | 60 | 1192 | 114 | 51 |
| | 30 | 64 | 1185 | 110 | 52 |
| 550 | 10 | 58 | 1200 | 125 | 48 |
| | 20 | 62 | 1195 | 121 | 52 |
| | 30 | 68 | 1190 | 120 | 58 |
| 600 | 10 | 72 | 1209 | 132 | 54 |
| | 20 | 90 | 1205 | 131 | 64 |
| | 30 | 110 | 1191 | 145 | 65 |

C. BALL INDENTATION TESTS

The ball indentation technique is used to evaluate the mechanical properties of Al-beryl MMCs. The beryl particles in Aluminum is 10 wt. %, the average size of the beryl particles is ~50 μm. The Ball indentation technique estimates the strain hardness coefficient, n, the strength coefficient, K, the yield strength (YS), the ultimate tensile strength (UTS) and the Brinell hardness number (BHN).

Table 2: Ball indentation result of Al – beryl MMC processed through vacuum sintering at a temperature of 600°C, consisting 10 wt. % beryl, and average beryl particle size is 50 μm

| Sample name | n | K(MPa) | UTS(MPa) | YS(MPa) | YR | BHN |
|--|------|--------|----------|---------|-------|-------|
| Al- 10 wt. % beryl composites with average Size of beryl particle is 50 μm | 0.14 | 341.77 | 227.44 | 107.05 | 47.07 | 67.36 |
| | 0.13 | 340.48 | 228.83 | 109.87 | 48.01 | 67.77 |
| | 0.14 | 347.99 | 228.94 | 106.43 | 46.49 | 67.66 |

Table 3: Ball indentation result of Al – beryl MMC processed through vacuum sintering at a temperature of 600°C, consisting 20 wt. % beryl, and average beryl particle size is 50 μm

| Sample name | n | K(MPa) | UTS(MPa) | YS(MPa) | YR | BHN |
|--|------|--------|----------|---------|-------|-------|
| Al-20 wt.% beryl MMC with average size of beryl particles is 50 μm | 0.17 | 434.44 | 268.98 | 113.03 | 42.02 | 75.32 |
| | 0.18 | 439.55 | 267.91 | 120.04 | 44.81 | 74.83 |

Table 2 and Table 3 shows the mechanical properties of Al- 10 beryl, and Al- 20 beryl MMC with an average beryl particle size of 50 μm. The UTS values are improved to ~268 MPa as compared to 228 MPa.

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VIII. CONCLUSION

Al- beryl MMCs were successfully prepared by using Liquid metallurgy vortex route, and pressure less sintering at 600°C, 2 h. Al- beryl MMCs were successfully sintered at 600°C and microstructural studies clearly suggest that this sintering temperature was optimum. Low levels of porosity and good interfacial bonding between Al matrix and beryl particles, thus it led to improved mechanical properties. Ball- indentation technique is an innovative method to evaluate mechanical properties of the small sized samples synthesized by powder metallurgy method.

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