Properties of Al7075-B_4C Composite prepared by Powder Metallurgy Route

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ABSTRACT

Aluminum matrix composites are emerging as advance engineering materials due to its high specific strength and stiffness, good wear resistance and high temperature properties. Properties of Al reinforced with Al2O3 and Sic are widely investigated. In the present study, mechanical properties (hardness, density and compressive strength), tribological properties and microstructure of B4C reinforced Al7075 matrix is investigated due to higher hardness and lower density properties than SiC and Al2O3. Aluminium 7075 composite reinforced with boron carbide (0, 5, 10, 15 wt %) was produced by powder metallurgy technique. Specimens were prepared by varying B4C content and sintering temperature. Wear analysis revealed that addition of wt% B4C increased wear resistance significantly. Results revealed that hardness and ultimate compressive strength of composite increases with increase in % B4C from 0% to 15% and Sintering temperatures from 450°C to 600°C.

Keywords: Al7075, B_4C, MMCs, powder metallurgy, sintering, mechanical properties, wear rate, microstructure.

1. INTRODUCTION

Powder metallurgy (P/M) is a highly evolved method of manufacturing, reliable net shaped components by blending elemental or pre-alloyed powders together. The P/M process is a unique part fabrication method that is highly cost effective in producing simple or complex parts at final dimensions. It is one of the established fabrication procedures which permit products of complex geometries to be produced with tailor made properties like high stiffness, high strength and high tolerances [2]. P/M has advantages over conventional methods of composite fabrication process. Metal matrix composites (MMC) consist of at least one metal and a reinforcement material as continuous fiber, intermetallics particles, compounds, oxide, carbide or nitride in order to achieve requirements and expected properties which cannot be met by single compound materials [3]. Nowadays production of metal matrix composites by liquid phase process is convenient in the production of MMCs reinforced with particles. The driving force behind the development of MMC has been the attractive mechanical and physical properties and enhanced elevated temperature capabilities [4]. Aluminium alloys, of 7xxx series shows a high resistance and these Al–Zn–Mg–Cu alloys have been studied by the point of view of alloy development using die compaction and sintering process [7]. In addition, aluminum matrix composites, reinforced with ceramic particles or whiskers, have received considerable attention because they can be formed by standard metal working practices. Apart from improved mechanical properties, other controlling attributes, such as coefficient of thermal expansion and wear resistance, are greatly improved by the addition of ceramic particles [5]. With good properties, such as high hardness, high melting point, good thermal and electrical conductivity, boron carbide ceramics are excellent candidates for neutron absorption materials], wear resistant materials, electrode materials and cutting tools. Among the outstanding physical and mechanical properties of boron carbide is its hardness, which is second after diamond and c-BN. This specific property comes along with other attractive properties such as high impact and wear resistance, low density, high melting point, and excellent resistance to chemical agents [2,6]. Final properties of the metal matrix composites (MMCs) depend on matrix and ceramic properties bonding between ceramic and matrix, size and distribution of the ceramic into the aluminium matrix. Following studies Al7075 aluminium alloy was reinforced with B4C and physical, mechanical properties and wear behavior were studied. Also the microstructure of these MMCs was studied and their influence on their properties was analyzed [1].

2. EXPERIMENTAL PROCEDURE

In this study, Aluminum 7075 is reinforced with 5, 10, and 15 wt% of B_4C particles to prepare a composite. The composite is fabricated by P/M technique. Atomized aluminum powders (99.99% purity, density 2.81 g/cm^3) were used as raw material. Aluminum 7075 is used as the matrix material. The chemical composition of Al7075 is given in table 2.1. Boron carbide (B_4C) is used as the reinforcement material. The matrix material Al7075 powder was commercially available in fine powder form. Specimens were prepared by compaction process where large loads are applied to the powder mix. Uni-axial compression testing machine (CTM) is used for preparation of green compacts. Sintering of specimens was carried out at four different temperatures (450, 500, 550 and 600°C). Microstructures of the composites were investigated by using scanning electron microscope (SEM) to identify the phases in Al7075 powder and different, weight (0, 5, 10, and 15%) B_4C. Mechanical properties like hardness and compressive strength are

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studied. Density measurements were carried. Hardness tests were performed on prepared samples by utilizing Rockwell hardness tester. Test load for each sample was 100 kg. Results of hardness tests were evaluated by averaging the results of 4 successive measurements. The compression tests were performed by using computerized universal testing machine (UTM) having capacity of 1000kN. Wear tests were carried to study the wear behavior of the composite using pin on disc tester. Design of experiments approach was used to study wear behavior and Taguchi technique was employed to study the effect of different parameters on wear rate.

Element	Chemical composition
Zinc	5.1-6.1
Magnesium	2.1-2.9
Copper	1.2-2
Iron	0.5
Silicon	0.4
Manganese	0.3
Chromium	0.18-0.28
Titanium	0.20
Aluminium	Balance

Table 2.1 Chemical composition of Al7075

3. RESULTS AND DISCUSSIONS

3.1 Hardness test

In present study Rockwell, hardness scale is used for measuring hardness value. Each specimen is subjected to hardness test with 2.5 mm ball indenter, 100kgf load and 20 seconds of dwell time. The figure 3.1 shows the variation in the hardness value of samples tested with respect to different percentage of reinforcement material and sintering temperature. It was, noticed that hardness value of the prepared composite goes on increasing with expansion in the content of B_4C particles. The increased hardness can be because of presence of boron carbide reinforcement particles which are basically very hard. The uniform distribution of SiC in the formed composites is also responsible for increasing hardness of the Al7075- B_4C composite. Another reason for increased hardness can be, attributed to sintering temperature. Because as the sintering temperature increases, the bonding between the matrix-reinforcement particles becomes stronger.

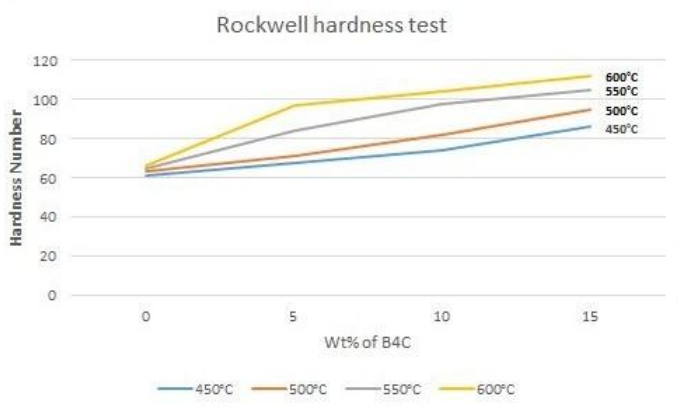

Fig.3.1 Variation of Hardness number with weight fraction of B_4C and sintering temperature.

3.2 Theoretical density and experimental density

By using rule of mixtures the theoretical density of sintered specimens was calculated. By utilizing mass and volume [$\rho = \frac{m}{v}$] relations experimental density is calculated.

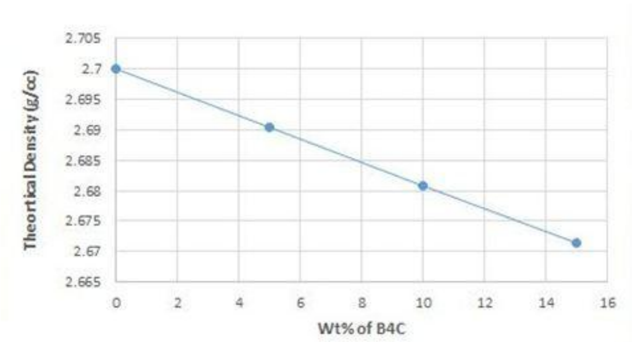

Fig.3.2 Variation of theoretical density with varying % B_4C

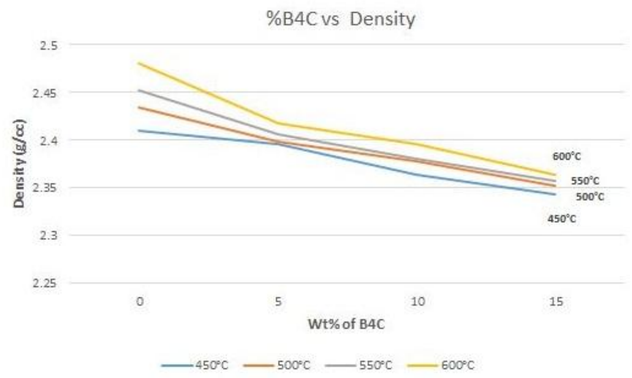

Fig.3.3 Variation in experimental density with varying % B_4C for different sintering temperature

From the Fig. 3.2 it can be noticed that the theoretical density of reinforced Al7075 is decreasing linearly with increase in, the amount of B_4C reinforcement. In this work, theoretical density was maximum for 15% B_4C-Al7075 for all the sintering temperatures that is specimen prepared by using different sintering temperatures. Fig. 3.3 shows that the densities of the samples approach to the theoretical density with increasing sintering temperatures for all different B_4C contents. However, low B_4C contents indicated closer results in density. The reason behind decreased theoretical as well as experimental density is 'attributed to addition of reinforcement' particles B_4C which has low density compared to base metal Al7075.

3.3 Compression test

The sintered specimens were subjected to compression test. For carrying test "computerized universal testing machine (UTM)" was used. All the tests here were carried at the room temperature. Since the UTM was computerized one it was able to get accurate readings of ultimate compressive strength. All tests were carried with 0.5 mm/min cross head speed. The specimen was placed on base plate and load was applied until the crack was noticed. The reading of load applied to cause a crack in specimen was noted. Same procedure was adapted for all other reinforcement content and sintering temperature.

Fig. 3.4 shows the variation of ultimate compression strength with increase in Wt% of B4C and sintering temperature on the specimen for different specimens. It is seen that the compressive strength of the fabricated specimens is increased with increase in the content of B4C from 0% to 15%. Also it is seen that compressive strength of prepared composite increased with increase in sintering temperature from 450 to 600 degree Celsius. For 0% B4C content and 450°C sintering temperature the ultimate compressive strength is found to be 178.5 MPa. Ultimate compressive strength steadily increases for higher content of B4C and sintering temperature and for 15% B4C content and 600°C sintering temperature ultimate compressive strength increased to 294 MPa. The reason for this may be because of addition of B4C particles to the matrix and also due to increase in sintering temperature.

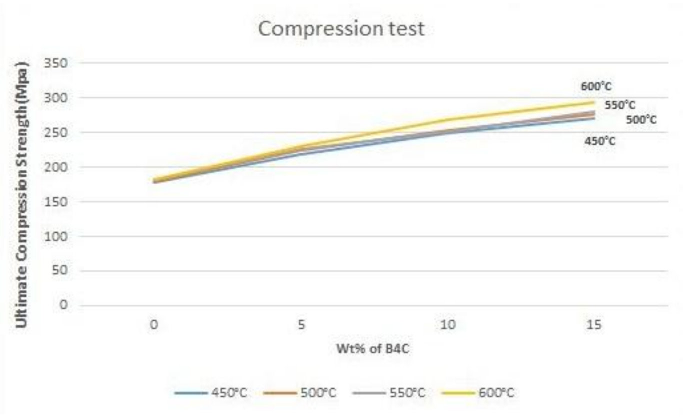

Fig.3.4 Plot of compression strength for different weight fractions of B_4C

3.4 Tribological test results

The wear test was conducted for different compositions of reinforcement on pin-on-disk machine and analyzed by taguchi technique. The wear behaviors of components are determined by conducting different set of experiments. The parameters chosen are speed of the rotating disc, Pan loading, material combination and wear distance traversed by the specimen. The variations of the wear results for the conducted specimens are as shown in the table 3.1. The experiments were, performed based on the levels and factors chosen for orthogonal array. In an experiments conducted L9 orthogonal array was chosen. The condition of wear factors are material with three different levels and load and three different speed levels and different abrading distance.

Wear parameters were analyzed using the software Minitab version 17 to find out predominant parameters that control the wear. The parameters selected were speed of the rotating disc, Pan loading, material combination, wear distance traversed by the specimen based on the plots of signal to noise ratio and the ranked components on those values for each parameter.

Level	material	Load	speed	distance
1	26.98	30.06	28.87	28.89
2	29.38	28.82	28.82	29.10
3	30.48	27.96	29.15	28.85
Delta	3.50	2.09	0.32	0.25
Rank	1	2	3	4

Table 3.1 Wear response for signal to noise ratio

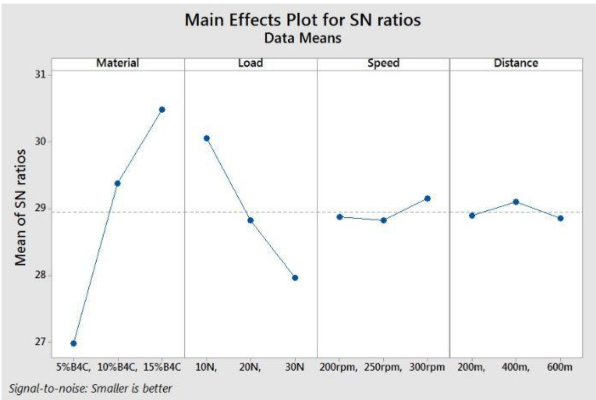

Fig.3.5 Wear response plot for Signal to Noise ratio of test specimens

From the analysis of the wear parameters based on the results from Taguchi technique it concludes that material of the component is primary factor that play important role in wearing of the specimen next important role is played by load followed by speed, the distance traversed by the specimen shows least effect on the wearing of the component. From the plots of SN ratio we can observe that for material condition 15% B4C, speed of rotating disc 300rpm, the traversing distance of 400m and pan loading of 10N shows the least wear.

3.5 Microstructure observations

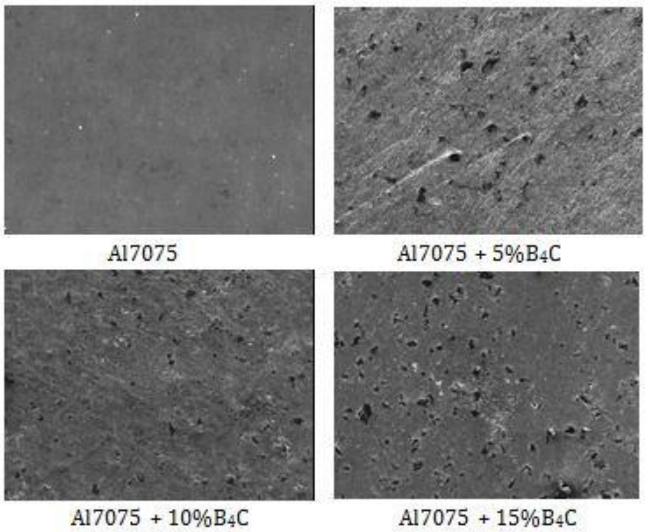

Fig. 3.6 Microstructure observations 0% B_4C, 5% B_4C, 10% B_4C & 15% B_4C reinforced Al7075 alloy by SEM

In order to examine the microstructure of the prepared specimen, the specimens were cleaned and polished thoroughly. Then these specimen's microstructure was studied using Scanning Electron Microscope(SEM) of resolution of 3nm at 30 KN (high vacuum) and high magnification of 5X to 1000X was used. From the figure 3.6 of microstructure of the prepared specimen, it can be detected that there is a reasonably uniform distribution of the reinforcement particles (boron carbide)' in the fabricated composite. It was found that the compacted specimen is subjected to sintering these particles with increase in grain boundary and bonding causes tendency for particles accumulate in masses. It is known that with increase in reinforcement content from 5 to 15 weight percentages there will be increase in porosity, but in microstructure images no porosity was seen which may be due to high compaction load applied while preparing the specimens and sintered the specimens at 600°C.

4. CONCLUSIONS

Aluminium and its alloy based MMCs are the most auspicious materials for the future automobiles, aviation and other applications. The fabrication and experimentation of aluminium alloy Al7075 reinforced with varied weight fractions of boron carbide (B4C) successfully synthesized by using powder metallurgy technique. The results of the test conducted were tabulated and results are compared. Tribological test are conducted to determine wear loss physical properties like density and mechanical properties, such as compression and hardness of fabricated composites are evaluated and SEM analysis is conceded out to determine the microstructural uniform distribution of, reinforcement in the matrix.

The following conclusions can be given from this attempt

- Al7075 alloy MMCs reinforced with different weight percentages of B_4C particles (5%, 10% & 15%) have been commendably produced by powder metallurgy strategy. The optimum conditions of fabrication process were that compaction load accounted is 60 KN with sintering time of 2 hours at temperature of 600°c.
- Density studies revealed there was decrease in theoretical density (2.7 to 2.67137 g/cc) with increase in % B_4C content from 0% to 15%. Also for different combination of Sintering temperatures (450°C to 600°C) experimental density increased with expansion in Sintering temperature but decreased with expansion in % B_4C content.
- Compression strength results revealed that ultimate compressive strength increases with expansion in % B_4C from 0% to 15% and Sintering temperatures from 450°C to 600°C.
- Hardness test results revealed that with expansion in Sintering temperature (450°C to 600°C) and reinforcement content (from 0% to 15%), the hardness of fabricated composite increased when compared to base 7075 alloy matrix.
- Wear results showed that addition of wt% B_4C increased wear resistance significantly. From Taguchi analysis it was found that least wear was noticed at 15% B_4C, 10N load, 300 rpm speed and 400 m distance. Hence, increment in content of reinforcement leads to improved wear resistance.
- The microstructure observation of specimen is conducted by using scanning electron microscope (SEM). And the observations revealed that fair uniform dispersion of B_4C can be seen in the base material.

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