Compaction, Sintering and Characterization of TiC Reinforced Aluminum Metal Matrix Composites

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Abstract

In the development of Metal Matrix Composite (MMC), Titanium Carbide (TiC) of 5, 10 and 15 weight percentage has been reinforced in to pure aluminum (Al) using Powder Metallurgy (PM) technique. Aluminum and TiC were mixed in a horizontal ball mill to obtain a uniform mixture followed by pressing in a cylindrical die. Specimens so prepared were subjected to sintering at a two different temperatures of 4000C and 4500C in a tube furnace under nitrogen atmosphere for 4 hours. In this work, an attempt is made to study the influence of TiC in aluminum on physical properties like density, porosity and mechanical properties such as Hardness, Compression strength and Roughness of the surface.

Keywords - *Aluminum matrix, Al-TiC, EDAX, Powder Metallurgy, SEM, Sintering.*

I. INTRODUCTION

In the recent past, MMC's are being used for different applications in the field of automotive, biotechnology, electronic, sporting and aerospace etc. [1-3]. Reinforcement of non-metallic materials in the metal matrix improves the properties of the base metal. Common reinforcement particles are SiC, B4C, and Al2O3 [4, 5]. Aluminum Matrix Composites developed by reinforcing the ceramic particles show improved mechanical properties that make them promising structural materials for aerospace and automobile industries [6-9].

Titanium Carbide (TiC) another reinforcement material is more attractive due to its high hardness, Elastic modulus, low density and low chemical reactivity. Aluminum alloys exhibit high specific strength and specific modulus but are limited to low temperature applications. This phenomenon could be improved by introducing the TiC reinforcement particles in to aluminum matrix [10, 11].

Both solid and liquid state processing techniques such as Powder Metallurgy (PM) and stir casting respectively are suitable to develop Particulate reinforced MMCs. It has been widely reported that to have better mechanical properties, MMCs must have homogeneous distribution of reinforcement particles in the matrix material. Further metal should not react with reinforcement during processing of MMC's [12]. The above said drawbacks can be avoided by using PM Processing technique. Hence the PM products normally have superior properties over that of their cast counterparts. It was also reported that aluminum matrix composites processed via powder metallurgy technique exhibit good isotropic properties and green density greater than 90 % of theoretical density by using low compacting pressures between 200 to 250 MPa [14].

The present work therefore focuses on preparation of aluminum based composites containing 5, 10 and 15 weight percentage of TiC through PM technique. Here, the influence of TiC reinforcement and sintering temperature on physical and mechanical properties of composites has been investigated.

II. MATERIAL AND EXPERIMENTAL METHODS

A. Materials

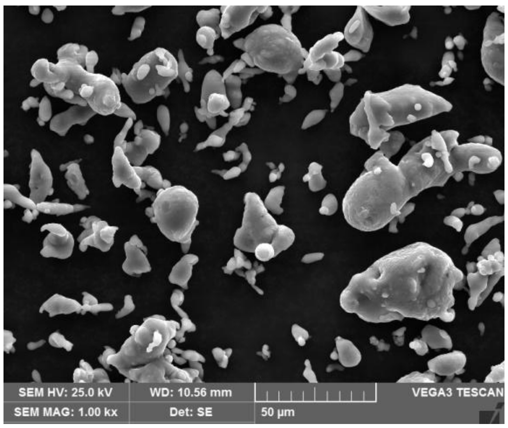
Atomized Aluminium (Al) powder (99.5 % pure) and Titanium Carbide (TiC) as supplied by Metal Powder Company Limited, India and Sigma Aldrich, Germany was used as matrix and reinforcement materials respectively. The specifications of Al and TiC powder are shown in Table I and Table II respectively. Figure 1 (A) and (B) shows the SEM images of Al and TiC powders. The particle size of Al lies in the range 50-74μm with some fine particles in the range of 5-10 μm. As TiC powder was prepared by carbiding Ti sponge, the micrograph if TiC powder shows porous structure.

Table I - Specification of AL Powder

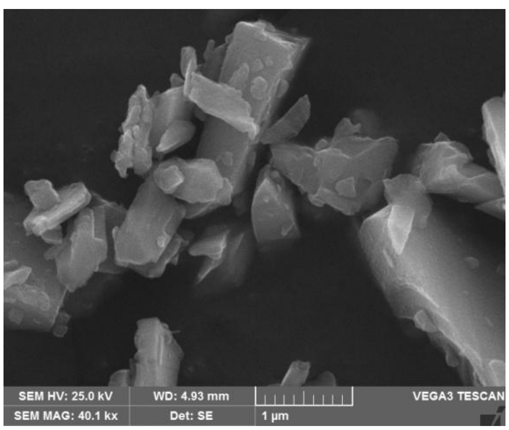
Parameters	**Particle Size**	**Atomic weight**	**Arsenic**	**Lead**	**Iron**
Specification	74 µm	26.98	0.0005 %	0.03 %	0.5%

Table II - Specification of TIC Powder

Parameters	**Particle Size**	**Molecular weight**	**Melting point**	**Density**
Specification	< 4µm	59.88 g/mol	31400C	4.93 g/cc



(A)



(B)

Fig 1: Scanning electron micrograph of as received (a) Al powder and (b) TiC powder.

B. Preparation of Composites

TiC powder in 5, 10 and 15 weight percentages were mixed with aluminum powder using horizontal mill for about 30 minutes with powder to ball ratio 1:2.5. During mixing a control agent was added to avoid agglomeration and cold welding of powder particles. Blended powders were pressed at 300 MPa using uniaxial hydraulic press for determining compression strength of the sintered compacts according to ASDM-D 618. The hardened steel die cavity and punch were lubricated in order to reduce the frictional resistance and easy ejection of specimen. The Green compacts were sintered in nitrogen atmosphere at 400^{0}C and 450^{0}C for 4 hours in tube furnace and are as shown in figure 2

Fig 2: Compacted and sintered Al-TiC composite

The density of compacts were measured using volumetric method, in which weight and dimensions were measured with the help of an accurate weighing balance (±0.01mg) and a micrometer (±0.1 mm) respectively. The Rockwell hardness (RB) of the compacts was measured and also the compression strength, roughness of surface of the compacts was determined. Scanning electron micrographs were used to study the microstructure of sintered specimens.

III. RESULTS AND DISCUSSIONS

A. Density of Composites

Figure 3 depicts the variation in green and sintered densities of Al-TiC compacts pressed at 300MPa and sintered at 400^{0}C and 450^{0}C.

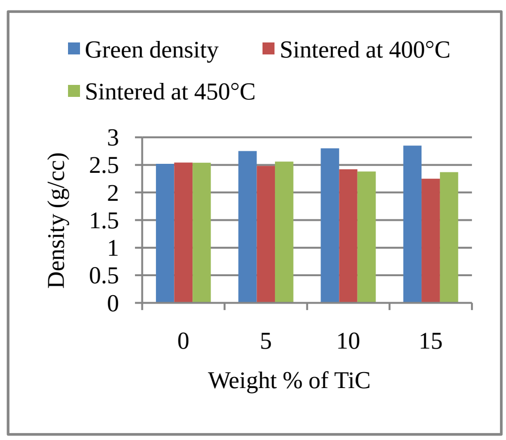


Fig 3: Variation of green and sintered densities for different weight percentage of TiC reinforced Al composites sintered at various sintering temperature

The results indicate that there is a reduction in the sintered density due to over pressing of the green compacts. Figure 4 depicts the comparison between the theoretical and measured density of Al-TiC composites. The theoretical density of compacts increases with increase in weight percentage of TiC due to high density of TiC. The measured density does not show similar trend owing to the presence of porosity.

Figure 5 depicts the porosity of Al-TiC composites in sintered condition. The percentage of porosity in the sintered composites varies from 6 to 18 and is found greater in the composites consisting of 15% of TiC by weight.

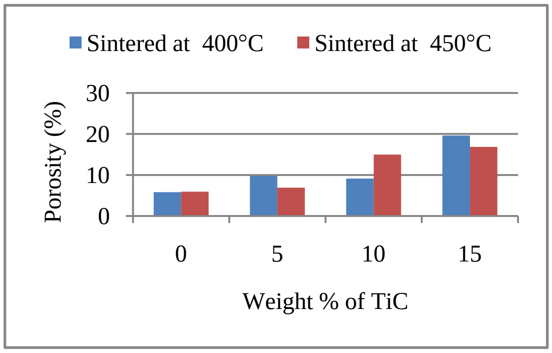


Fig 4: Variation of theoretical and measured densities for different weight percentage of TiC reinforced Al composites at various sintering temperature.

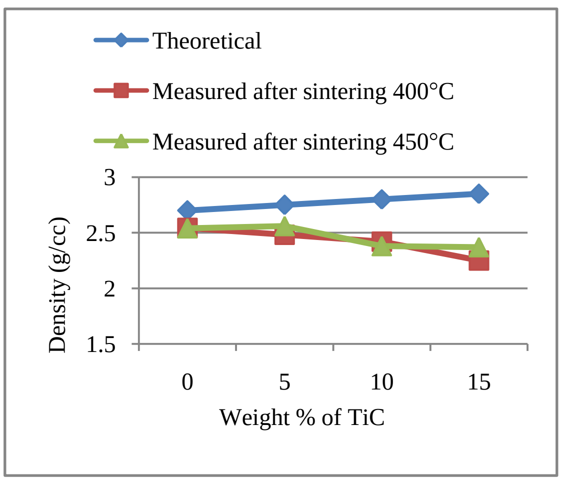


Fig 5: Variation of Porosity for different weight percentage of TiC reinforced Al composites at various sintering temperature.

B. Hardness

Figure 6 depicts the variation of hardness for the three MMCs sintered at 4000C and 4500C.The increase in the content of TiC results in greater hardness. It can be concluded that the improvement in the hardness of the compacts having TiC particles is not only dependent on amount of reinforcement particle but also on size, uniform distribution of reinforcement and interface bonding.

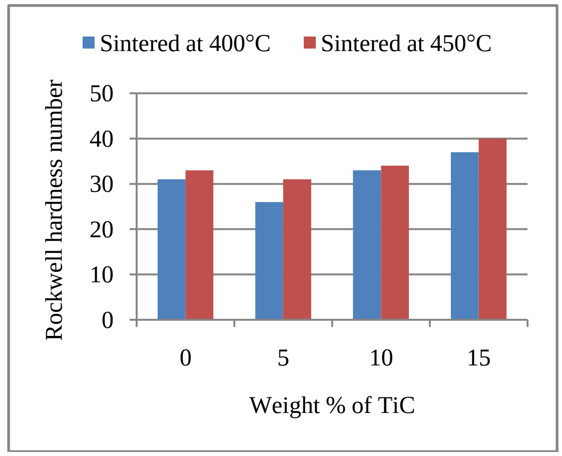


Fig 6: Variation of Rockwell hardness number (Rb) for different weight percentage of TiC reinforced Al composites at two different sintering temperatures.

The hardness of 15 % TiC reinforced aluminum composite was found to be 33 % higher than unreinforced aluminum. It was observed that Al-TiC composites pressed at 300 MPa, followed by sintering at a temperature of 450^{0}C for a sintering of 4 hours exhibit higher hardness.

C. Compression Strength

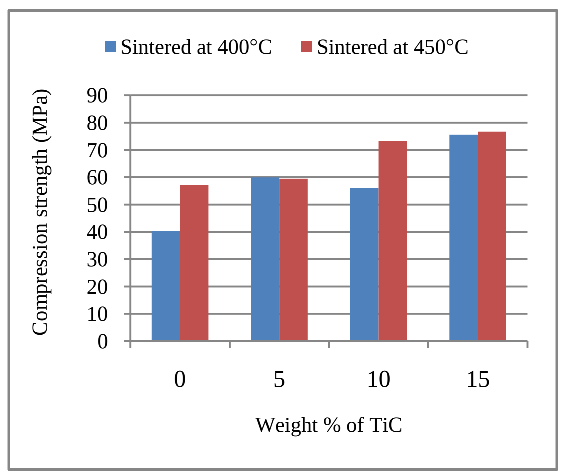


Fig 7: Variation of compression strength for different weight percentage of TiC reinforced Al composites at various sintering temperature

Figure 7 depicts the variation of compression strength for different weight percentage of TiC reinforced Al composites sintered at 400^{0}C and 450^{0}C. As the weight percentage of TiC increase from 0 to 15 percent, it is observed that compression strength of the composite increases. This improvement in compression strength is attributed to the presence of hard ceramic particles.

The strength of the compact was found to depend on compacting pressure, sintering temperature and time. The compression strength of 15 wt% TiC reinforced aluminum composite was found to be 35 % higher than the unreinforced aluminum. The composite material sintered at 450°C exhibits better compression strength.

D. Microstructural Analysis

The micrograph of the Al-TiC composites was investigated by SEM and respective micrographs of the compact taken at their cross-section are shown in Figure 8. The amount of porosity, pore size, shape and distribution within the samples were investigated using SEM equipped with EDAX analysis.

The micrographs indicate that there is a uniform distribution of TiC particles within the matrix. The composite with 5 wt% (Figure.8B) shows the presence of TiC particles (bright area) uniformly throughout the Al matrix (dark areas). As the content of reinforcement increases from 5 to 15 wt%, there is an improvement in overall distribution of these particles in the matrix. The micrograph of the composites reveals the presence of porosity, since the sintered density of composite is between 85 to 95% of theoretical density. Medium size pores and small interconnected micro pores were observed at grain boundaries.

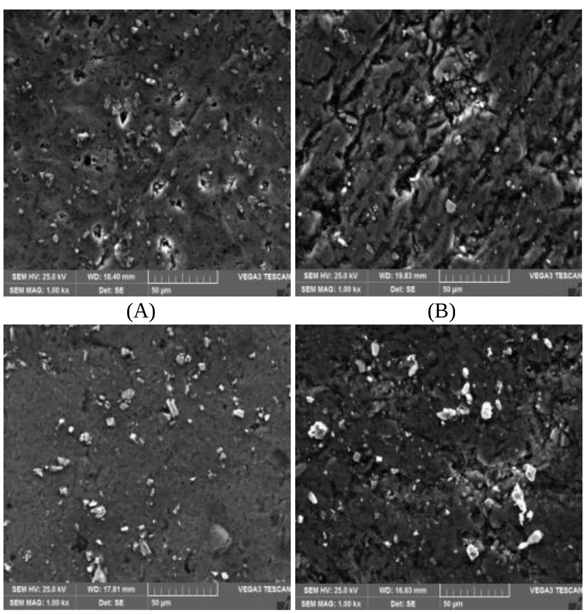


Fig 8: Scanning electron micrograph of (a) pure Al and composites reinforced with TiC particles having (b) 5, (c) 10 and (d) 15 wt% TiC particles in pure Al matrix

E. EDAX Analysis

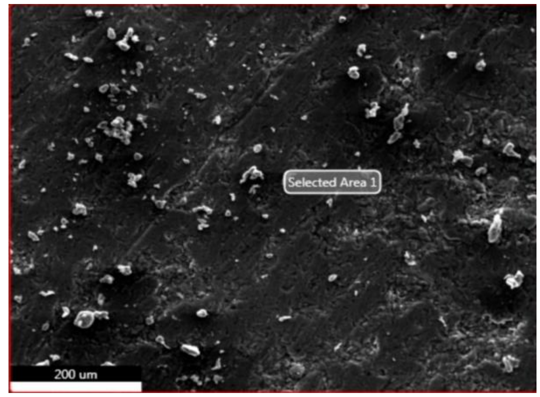


Fig 9: SEM micrograph and EDAX analysis of Al- 5Wt % TiC

Figure 9 and table III depicts the elemental microanalysis of matrix and of various grain boundaries obtained using EDS analysis. It is observed that, the structure contains basically Al, Ti and C. However, it can be seen O is present due to high affinity of Al in the ambient temperature. The EDAX shows that, the presence of grain boundary was almost consistent in all the sintered samples.

TABLE III
EDAX ANALYSIS IN AL -5 WT % TIC COMPACT.

Elements	C	O	Al	Ti
Weight %	25.72	9.24	63.14	1.90

F. Surface Roughness

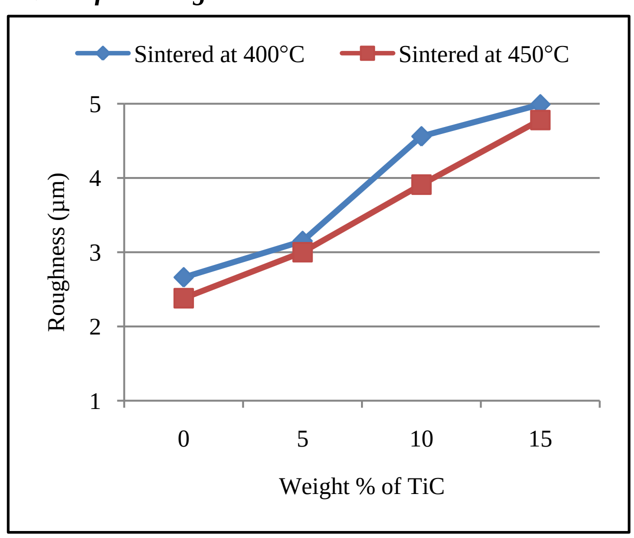


Fig 10: Variation of surface roughness for different weight percentage of TiC reinforced Al composites at various sintering temperature

Surface roughness has been considered as one of the better measurement technique used for determining the performance of a mechanical component as the irregularities on the surface may form nucleation sites for cracks or corrosion. In addition, roughness of surface may promote adhesion. Figure 10 depicts the variation of surface roughness for different weight percentages of TiC reinforced Al composites at various sintering temperature.

The surface roughness of samples varies from 5 µm to 2.38 µm. Results indicate the composites sintered at 4500C exhibit better surface finish.

IV. CONCLUSIONS

- Mixing of aluminum and TiC powders in a horizontal mill for 30 minutes resulted in fine and uniform distribution of reinforcements.
- Rockwell hardness, density and compressive strength of composites increases with increase in reinforcement content from 5 to 15 weight percent of TiC.
- Micrograph of Al-TiC composites reveals that uniform distribution if TiC particles within the matrix and also indicates better interfacial metallurgical bonding of aluminum and TiC particles.
- EDAX analysis revels that, the structure contains basically Al, Ti and C. However, it can be seen O is present due to high affinity of Al in the ambient temperature.
- The surface roughness of the composites sintered at 450^0C fall in the range 2.38 to 5 µm.

REFERENCES

[1] Hafeez Ahamed, V. Senthil Kumar, A comparative study on the milling speed for the synthesis of nano structure Al 6063 alloy powder by mechanical alloying, Journal of Minerals and Materials Characterization and Engineering,2011, Vol.10, 507-515.

[2] P.O Babalola, C.A Bolu, A.O Inegbenebor, K.M Odunfa, Development of aluminum matrix composites: A review, Online International Journal of Engineering and Technology Matrix, 2014, Vol.2, 1-11.

[3] Sangita Mohapatra, Anil K. Chaubey, Dilip K.Mishra, Saroj K.Singh, Fabrication of Al-TiC composites by ht consolidation technique: its microstructure and mechanical properties, Journal of Materials Research and Technology, 2014,JMRTEC-175.

[4] Tjong SC, Recent advances in discontinuously reinforced aluminum based metal matrix nano composites, Material Research Progress, 2008, ISBN: 1-60021-994-2, , 275-296.

[5] Senthilkumar V, Omprakash B U, Effect if titanium carbide particle addition in the aluminum composite on EDM process parameters, Journal of Manufacturing Processes, 2011,Vol.13, 60-66.

[6] Kok M, Ozdin K, Wear resistance of aluminum alloy and its composites reinforced by Al2O3 particles, Journal of Materials Process Technology, 2007, Vol.183,301-309.

[7] Rana R S, Rajesh Purohit, Das S, Review of recent studies in Al matrix composites, International Journal Science, Engineering and Research, 2012, Vol.6, 1-16.

[8] Anandkumar R, Almeida A, Vilar R, Microstructure and sliding wear resistance of an Al-12wt%Si/TiC laser clad coating, Wear, 2013, Vol.9, 282-283.

[9] Mazahery A, Shabani M O, Study on microstructure and abrasive wear behavior of sintered Al matrix composites, Ceram Int, 2012, Vol 38(5).

[10] Dikici B, Gavgali M, Bedir F, Synthesis of in situ TiC nano particles in liquid aluminum: the effect of sintering temperature, Journal of composite Materials, Vol.45 (8), 2011, 895-900.

[11] Kennedy A R, Wyatt S M, The effect of processing on the mechanical properties and interfacial strength of aluminum/TiC MMCs, Composite Science and Technology, 2000, Vol.60, 307-314.

[12] F Zhang, W A Kaczmarek, L Lu, M O Lai, Formation of titanium nitrides via wet reaction ball milling, Journal of Alloy Composites, 2000, Vol. 307, 2047-2052.

[13] Tyagi R, Synthesis and tribological characterization of in situ cast Al-TiC composites, Wear, 2005, Vol.259, 569-576.

[14] K Venkateswrlu, Suman Saurabh, V Rajnikanth, Ranjan Kumar Sahu, Ajoy Kumar Ray, Synthesis of TiN reinforced aluminum metal matrix composites through microwave sintering, Journal of Materials Engineering and Performance,2010, Vol.19, 231-236.