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Fabrication and Characterization of AA6082 – ZTA Composites by Powder Metallurgy Process

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Abstract

AA6082 alloy and composites was prepared by powder metallurgy process. The AA6082 powder was mixed with 3, 6 and 9 wt.% ZTA and then compacted using uniaxial compression at a pressure of 500 MPa. The green compacts were then sintered at 620°C for 1h in nitrogen atmosphere. The sintering results confirmed that by increasing the compaction pressure the sintered density increases due to more particle bonding. The sintered products were evaluated by analyzing the density before and after sintering, microstructural features, XRD and finally microhardness were studied. The microstructure of polished and etched surfaces of AA6082–ZTA composites samples was studied using scanning electron microscope. It is observed that uniform distribution of ZTA particles over AA6082 matrix. It is noticed that the addition of ZTA particles in the matrix enhance the hardness of the base alloy.

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1. Introduction

There are thousands of materials available to engineers for the design and manufacturing of components for an application. Most of the engineering materials may be classified into one of the following groups: metals, plastics, ceramics and composites [1]. The term “composite” is defined as a group of engineering materials system, in which discrete reinforcements are distributed in a continuous matrix to create a new unique material which offers properties superior to the properties of the conventional material. Generally, the constituent materials such as reinforcements can be fibers, particulates or whiskers and the matrix can be a metal, ceramic, or polymeric material. The superior properties of the composites are often driven from the properties of its constituent materials, from architecture and

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geometry of the constituent materials, from the properties of the boundaries (interfaces) between different constituent materials and also from the processing route [2]

Most advanced technologies need materials with superior properties, where conventional materials fail to meet these properties. Compared with conventional metals, MMCs exhibits superior physical, chemical and mechanical properties [3]. Therefore, these major factors have driven the material designers to create new unique MMCs. Generally, aluminum and its alloys are most widely used as a matrix material because of their favorable properties such as high strength to weight ratio, light weight, improved properties at high temperatures, controlled thermal expansion coefficient, improved abrasion and wear resistance [4,5].

There are several processing routes available for the production of AMCs depending on the state of matrix include liquid, semisolid or solid [6]. Powder Metallurgy (P/M) is the one most advantageous techniques in solid state process to fabricate AMCs because of an isotropic distribution of particles in matrix and good dimensional accuracy in an economical manner. P/M process can also easily formulate various compositions by mixing elemental or premixed powders, followed by the press and sinter process to the net-shape components. Moreover, Aluminum alloy based composite powders are extremely compressible. Typically, green compact densities of more than 90% of theoretical densities can be achieved by applying low compacting pressures when compared to others. Sintering of aluminum alloy based composite parts are more energy efficient than other P/M materials because of the relatively low sintering temperatures [7].

Aluminum 6xxx series are majorly alloyed with magnesium and silicon. Mg excess leads to better corrosion resistance, but lower strength and formability, Si excess produces higher strength without loss of formability and weldability. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. AA6082 is a medium strength alloy with excellent corrosion resistance. It has the highest strength of the 6000 series alloys. The combination of medium strength, formability, corrosion resistance and weldability results in a vast variety of applications [8-10].

Alumina (Al_2O_3) is one of the most cost effective and widely used as reinforcement material in AMCs. Whereas Zirconia (ZrO_2) is an extremely refractory material which exhibits a combination of very low thermal conductivity and high strength properties. Therefore, Zirconia Toughened Alumina (ZTA) is a ceramic material comprising of alumina and zirconia. It is a composite ceramic material with zirconia grains in the alumina matrix. The main advantage of ZTA is the additional strength and toughness over alumina with a lower cost than zirconia. The combination of aluminum oxide and 10-20% zirconium dioxide provides a much higher strength, toughness, hardness and wear resistance than alumina alone [11]

Every industry is now vying with each other to make the best use of AMCs. One can now notice the application of AMCs in many disciplines starting from sports products to space vehicle components. This worldwide interest during the last few decades has led to the prolific advancement in the field of AMCs. Moreover, production of AMCs has already started in several industries include DWA aluminum composites currently utilizing Al2009, AA6092 and Al7050 as a matrix material with the addition of silicon carbide (SiC) as a reinforcement material with different weight fractions. These AMCs are available in different forms include billets, sheets, plates, extrusion and forgings [12]. A series of Al-SiC MMCs have been developed by MC-21 Inc finding exotic applications in IGBT baseplates, metal backed printed circuit boards, heat sinks, semiconductors, thermal spreaders, brake rotors, connecting rods, cylinder liners, bed plates and few armor applications [13]. Ceramtec is currently utilizing Alsi9MgMn/40Al_2O_3 composites for cylinder sleeves in engines. Apart from being fairly inexpensive in comparison with other light metals (Al, Mg and Ti), it has delivered outstanding results in many automotive and aerospace applications and is noted for its uncomplicated processing properties [14]. Materion Corporation have been developed high quality aerospace grade supremex 215XK with Al2009 as a matrix material reinforced with 15 Vol%. SiC and another grade supremex 620XF AA6061 as a matrix material reinforced with 20 Vol%. SiC produced via a P/M process and these composites are available in several forms include product forms, billets and extrusions [15]. Talon Composites have developed several AMCs, Talbor is a patented MMCs composed of an aluminum base alloy and B_4C reinforcement produced by PM route [16].

In this study, fabrication of AA6082–ZTA with different weight percentages was carried out using powder metallurgy route. Then, the densities, microstructure, XRD and hardness of the fabricated composite including base material were studied.

2. Experimental Procedure

In the present study, AA6082 powders were used as matrix material and ZTA particulates were used as reinforcing material. Table 1 and Table 2 summarizes the chemical composition of respective powders. The size of AA6082 matrix powders were measured in dry mode by using Malvern Mastersizer 2000 apparatus. Furthermore, particle size of ZTA powders were measured in wet mode by using Malvern Zetasizer Nano S90 apparatus. The morphological characteristics of the matrix and reinforcing powders were examined using SEM. The SEM micrograph of AA6082 powders was predominantly irregular shape and ZTA powders was predominantly in angular shape as shown in Fig. 1 (a) – (b). The AA6082 – ZTA composites were prepared by mixing AA6082 powders with varying amounts of ZTA in wt.% (3, 6, and 9) in turbular mixer (Bachofen, Switzerland) for 30 min. A single acting hydraulic press (SVS Hydraulics, Model: 50TC) was used for compaction of powders. The matrix powders were pressed at pressures in the range of 200-600 MPa to study the compaction characteristics and to establish the optimum compaction pressure as shown in Fig. 2 (a). Die wall is brushed with zinc stearate powder for easy ejection of pallet and to reduce the friction between them. The AA6082 – ZTA powder mixtures exhibit uniform die filling and provides good reproduction of part configuration. The green density was determined by weight and dimensional measurements [17].

Table 1. Chemical Composition (wt.%) of the Matrix Material (AA6082)

	Composition (wt.%)				
AA6082	Si	Mg	Mn	Cu	Al
	1.0	0.9	0.7	0.1	Bal.

Table 2. Chemical composition (wt.%) of the reinforcement Material (ZTA)

	Composition (wt.%)					
ZTA	SiO_2	Fe_2O_3	ZrO_2 (HfO_2)	Al_2O_3	TiO_2	MgO
	< 40 ppm	<40 ppm	19.20	Bal.	0.49	0.29 Max

(a) (b)

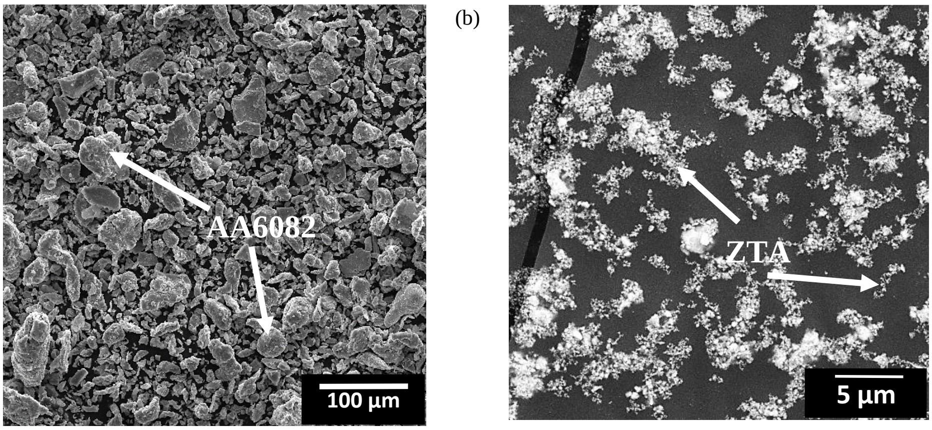

Fig. 1. Scanning electron micrograph of (a) AA6082 powder and (b) ZTA powder

The sintering curves of AA6082 is shown in Fig. 2 (b). Green compacts were subjected to a 60 min sintering soak at various temperatures. AA6082 alloy were sintered between 580 to 640°C for 1h in a protective nitrogen atmosphere and then furnace cooled in a tube furnace. The sintered density of compacts was determined by dimensional measurements as well as through archimedes principle method. The theoretical density of the alloy was calculated using the inverse rule of mixtures which accounts for closed porosity. Metallographic preparation involving grinding on emery paper, polishing using series of alumina suspension (1µm, 0.3 µm and 0.05 µm) and final cloth polishing using 0.02 µm colloidal silica solution. Keller's reagent was used as etchant to reveal the grain boundaries and micro constituents. The scanning electron microscopy (model: Wega3, Tescan) techniques were used to obtain the microstructures of etched samples. PANalytical B.V, XPert^3 Powder XRD is used to determine the phase structure of the sintered samples. Microhardness of alloy and composite were measured using (Make: Chennai Metco, Model: Economet VH 1MD) microhardness tester. The indentation was produced using 136 square based Vickers diamond pyramid at the impact load of 100g for 15 Sec [4]. For hardness measurement, the samples were polished in such ways that opposite sides are parallel to each other. In each sample, 10 indentations were taken and the average hardness value is reported.

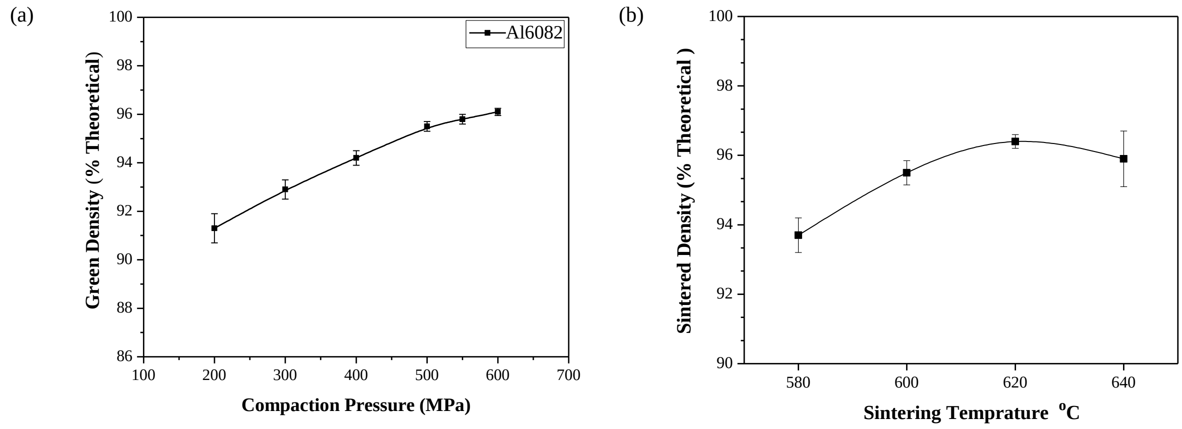

Fig. 2. (a) Compressibility curves of AA6082 alloy and (b) Sinter density versus sintering temperature of AA6082 alloy

3. Results And Discussion

3.1. Particle size analysis

Particle size and size distribution have a significant effect on the behavior of metal powders during processing. The particle size and shape of powders will have a strong influence on flow and compaction properties in PM process. Larger, more spherical particles will typically flow more easily than smaller or high aspect ratio particles. Therefore, the characterization of such properties is essential. Hence, particle size distribution was determined by laser diffraction technique for determination of matrix and reinforcement particle size distribution [4,18]. The particle size distribution of AA6082 matrix powders is shown in Fig. 3 (a). It was determined that the D_{10}, D_{50}, and D_{90} passing sizes of AA6082 alloy are 6.3, 22.1 and 55.4μm. The average particle size of ZTA is 0.4μm as shown in Fig. 3 (b).

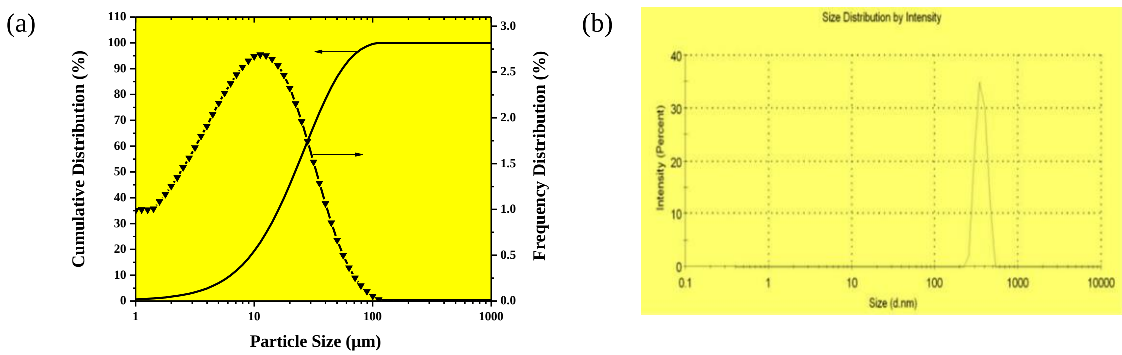

Fig. 3. Particle size distribution of (a) AA6082 and (b) ZTA

3.2. Density

Theoretical density is an ideal density of a composite which accounts zero porosity. The theoretical density is obtained by rule of mixture [19]. Fig. 4 (a) shows the theoretical densities of AA6082 alloy and ZTA composites. The lowest theoretical density is obtained for AA6082 alloy and highest theoretical density is obtained for AA6082 9wt.% ZTA. This is due to the high theoretical density of elemental ZTA incorporated in AA6082 alloy. As the reinforcement content increased from 3wt.% to 9wt.% theoretical density is also increased.

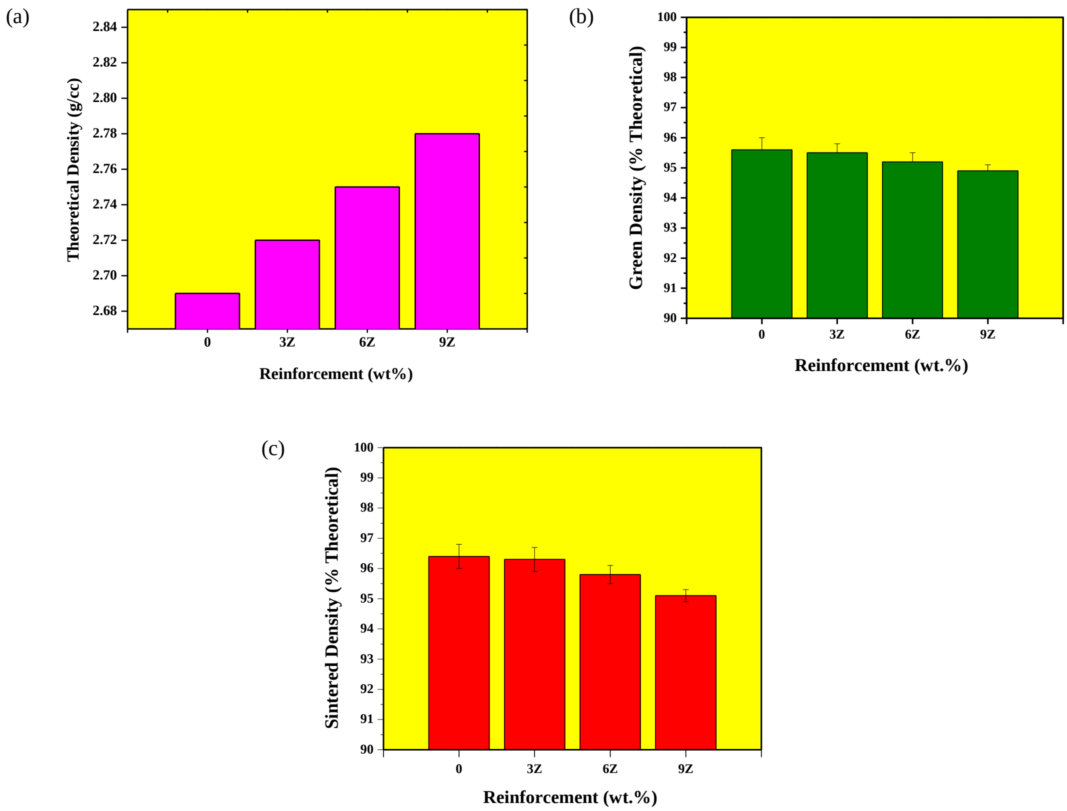

Fig. 4. (a) Theoretical Densities (b) Green Densities (c) Sintered Densities of AA6082 and its composites

Fig. 4 (b) shows the effect of ZTA content on compressibility of AA6082 alloy. It is evident that green density of compact decreases with increasing ZTA content. This attributes to hard and non-deforming nature of the ZTA reinforcements, which constricts Al-particle deformation, sliding and rearrangement during compaction. However, sintered densities of the composites are increased with respect to green densities as shown in Fig. 4 (c) [4,17].

3.3. Microstructure

Fig. 5 shows the SEM micrograph of sintered AA6082-9wt.% ZTA composite. These composites were pressed at 500 MPa and sintered at 620°C for 60 min. It is can be observed that the ZTA particles are uniformly distributed in al matrix [20]. Moreover, it appears to be a good bonding between the Al matrix and ZTA particles without evidence of surface pull out or cracking of these particles during sample preparation. A good degree of sintering is achieved, still there is some evidence of fine grain boundary pores and some bulk porosity distributed almost uniformly within the structure. The sintering results show that by increasing the compaction pressure the sintered density increases due to more particle bonding and presence of less void.

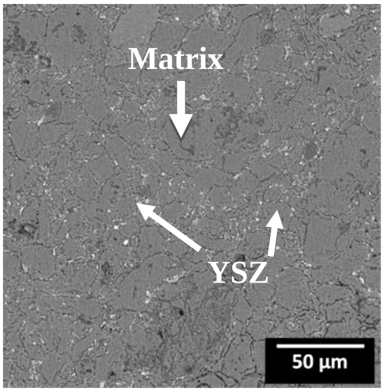

Fig. 5. Microstructure of sintered ZTA composites with 9 wt.% ZTA pressed at 500 MPa and sintered at 560ºC for 60 min.

3.4. Microhardness

Vickers microhardness tests were conducted to measure the hardness of composites under the applied load of 100 g for 10s. For hardness measurement, the samples were polished in such ways that opposite sides are parallel to each other. In each sample, 10 indentations were taken and the average hardness value along with standard deviations reported. The results were shown in Fig. 6. The variation of hardness with weight fraction of the ZTA content is observed. Increasing the wt.% of ZTA in the composite, increases hardness because of dispersion hardening effect [4,17].

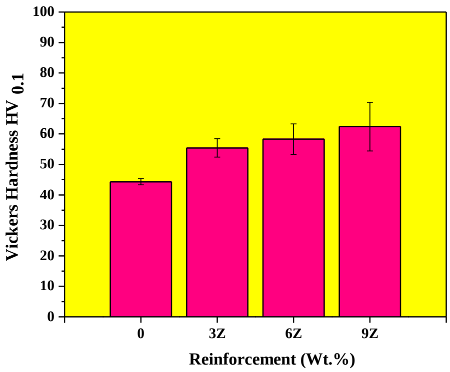

Fig. 3. Effect of ZTA Addition on the Hardness

4. Conclusions

The Powder metallurgy route was successfully employed for the development of AA6082 composites. The effect of ZTA content on densities, microstructure and microhardness of sintered AA6082-ZTA composites were studied. The optimum process parameters of compaction pressure, sintering temperature and time for AA6082 MMCs were found to be 500 MPa at 620ºC for 60 min. AA6082 alloy achieved a sintered density of 96.4% relative density. Furthermore, the addition of reinforcement content to the base alloy had a slightly negative effect on the densification during sintering. The microstructural studies of the composites revealed the uniform distribution of the reinforced particles in the aluminum matrix and good bonding was observed between reinforced particles and aluminum matrix.

The hardness of the composites is found to be increased with the increase in filler content because of dispersion hardening effect. The AA6082-9wt.% ZTA composite exhibited higher hardness values. The results confirmed that the composite exhibits superior hardness to base AA6082.

References

[1] William D. Callister, David G. Rethwisch, Materials Science and Engineering: An Introduction, eight ed., Wiley, 2009.
[2] M. Hayajneh, A.M. Hassan, A. Alrashdan, A.T. Mayyas, J. Alloys Compd. 470 (2009).
[3] V. Umasankar, M. Anthony Xavior, S. Karthikeyan, J. Alloys Compd. 582 (2014) 380–386.
[4] C. Padmavathi, A. Upadhyaya, Sci. Sinter. 42 (2010) 363–382.
[5] M. Youseffi, N. Showaiter, M.T. Martyn, Powder Metall. 49 (2006) 86–95.
[6] I. a. Ibrahim, F. a. Mohamed, E.J. Lavernia, J. Mater. Sci. 26 (1991) 1137–1156.
[7] D. Jeyasimman, R. Narayanasamy, R. Ponalagusamy, V. Anandakrishnan, M. Kamaraj, Mater. Des. 64 (2014) 783–793.
[8] A. J. Knowles, X. Jiang, M. Galano, F. Audebert, J. Alloys Compd. 615 (2014) S401–S405.
[9] A. Arockiasamy, R.M. German, P.T. Wang, M.F. Horstemeyer, W. Morgan, S.J. Park, et al., Powder Metall. 54 (2011) 354–359.
[10] J. B. Fogagnolo, M.H. Robert, E.M. Ruiz-Navas, J.M. Torralba, J. Mater. Sci. 39 (2004) 127–132.
[11] A. Arab, Z.A. Ahmad, R. Ahmad, Int. J. Refract. Met. Hard Mater. 50 (2015) 157–162.
[12] http://www.dwa-usa.com/#!technical-info/c21xi
[13] http://www.mc21inc.com/armor.html
[14] https://www.ceramtec.com/ceramic-materials/metal-matrix-composites/
[15] http://materion.com/ResourceCenter/NewsAndAnnouncements/Aerospace-Metal-Composites/AMS-Spec-Published-for-SupremEX 225XE.aspx.
[16] http://www.taloncomposites.com/New_Technology.html
[17] N. Showaiter, M. Youseffi, Compaction, Mater. Des. 29 (2008) 752–762.
[18] M. Hasanuzzaman, a. Rafferty, a. G. Olabi, T. Prescott, Int. J. Nanoparticles. 1 (2008) 50.
[19] G.B. Veeresh Kumar, C.S.P. Rao, N. Selvaraj, Compos. Part B Eng. 43 (2012) 1185–1191.
[20] H. Abdizadeh, M. Ashuri, P.T. Moghadam, A. Nouribahadory, H.R. Baharvandi, Mater. Des. 32 (2011) 4417–4423.