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Effects of Sintering Temperature on Density and Microstructure of Al-15Si-2,5Cu-0,5Mg/B_4C Composites

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Abstract. In this study, B_4C (5 and 10wt.%) particle-reinforced Al-15Si-2.5Cu-0.5Mg (Ecka Alumix 231®) aluminum matrix composites were produced through cold press/ sintering technique. Sintering process was carried out at three different temperatures (555 °C, 580 °C, 605 °C). The obtained samples were subjected to density measurement, also microstructure analysis and hardness test were examined. Densities of the samples were measured by Archimedes technique according to ASTM B962-08. Optical microscope and scanning electron microscope (SEM) were used in microstructure studies. Macrohardness measurements were performed in terms of Brinell hardness by use of 31.5 kgf load and 2.5 mm ball diameter. The green density of the samples decreased with increasing B_4C wt.%. It was determined that the density decreases in all samples with increasing sintering temperature. It was observed that the porosity increases and the pores become larger with increasing sintering temperature. Al-rich solid solution, primary Si and Cu and Mg-rich phases in the microstructure were determined through SEM and EDS analysis. While the hardness increased in 5wt.% particle reinforced composites, it was observed that the hardness decreased in 10wt.% reinforced composites. Samples produced from Alumix 231 powder was give the highest hardness value at 555 °C.

Keywords: Powder metallurgy, Metal matrix composites, Density, Microstructures, Hardness
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Introduction

Engineering materials with various chemical compositions and mechanical properties are produced using different production techniques. One of these techniques is powder metallurgy (P/M) technique. P/M technique has attracted the attention researchers since 1990s. Mechanical properties of engineering materials have been tried to be improved by P/M techniques. Cold pressing and sintering, one of these P/M techniques, were developed at the University of Sevilla [1].

In recent years, hypereutectic Al-Si P/M alloys have attracted more and more attention as matrix materials because of their properties such as high-wear resistance, high strength and low density [2-6]. Similarly, boron carbide in B_4C composition is an

attractive reinforcer with its properties such as high hardness, wear resistance, and low density [7,8].

In this study, premixed hypereutectic Al-Si P / M alloy powder, with a trademark of Ecka Alumix 231® (nominal composition of Al-15Si-2.5Cu-0.5Mg (wt.%)), was chosen as matrix material for composite sample production. Boron carbide in B_4C composition was used as reinforcement particle. Al/B_4C composites were produced by cold pressing and conventional sintering techniques. The properties of the produced composites were evaluated through microstructure studies, density and hardness tests examinations.

Experimental procedure

B_4C reinforced Al matrix composites were produced through cold pressing and conventional sintering techniques. Hypereutectic Alumix 231® powder, produced by ECKA Granulate Velden GmbH (a German company), with a sintered density of 2.67 g/cm³, was used as matrix material. The chemical composition and average powder size of Alumix 231 powders used in this study are given in Table 1. The reinforcement particle B_4C has a density of 2.52 g/cm³ and the average powder particle size (D_{50}) is 10 µm.

Table 1. The chemical composition (wt.%) and average powder size of Alumix-231 alloy

Composition (wt.%)					
Alumix 231®	Al	Si	Cu	Mg	Lubr.
Nominal	Bal.	14–16	2.4–2,8	0.5–0.8	1.5
Average powder size (µm)					
D_{50}		D_{10}		D_{90}	
~75		~22		~190	

Prepared Alumix231 / (5-10wt.%) B_4C powders were mixed in a triaxial mixer. Pure Alumix 231 and Alumix231/(5-10wt.%) B_4C mixture powders were compressed with cold pressing technique by applying 620 MPa pressure. The obtained green samples were conventionally sintered in N_2 atmosphere at 555 °C, 580 °C and 605 °C. The pressed samples were subjected to the eliminate the lubricant at 400 °C for 20 minutes before sintering temperature.

The densities of the samples were measured through the Archimedes' technique according to ASTM B962-08. The densities were expressed as % of the theoretical densities (% TD). The theoretical density values were calculated via the rule of mixtures using the material composition. Optical microscope and scanning electron microscope (SEM) were used in microstructure examinations. Macrohardness measurements were performed using the Brinell hardness test with 31,5 kgf load and 2,5 mm ball diameter.

Results and Discussion

Table 2 illustrated the sample codes and % TD of the produced samples. The CS sample code shown in Table 2 represents conventional sintering. The numbers 0-5-10 next to the CS code indicate the wt% B_4C particle ratio.

Table 2. The specimen codes and % density values

Sample code	Particle Rate (%)	Density (%TD)			
		Green	T=555°C	T=580°C	T=605°C
CS-0	0	92,127	90,483	88,187	84,827
CS-5	5	91,793	89,618	88,214	87,162
CS-10	10	91,197	88,719	88,361	87,811

The green density of the samples decreased with the addition of increasing particle ratios. Green density decreases due to increasing porosity with increasing particle ratio. This decrease is attributed to the porosity that occurs at the particle/matrix interface.

Sintering process caused a decrease in density in all samples. A decrease in density was determined with increasing sintering temperature (Table 2). It has been found that densification of Ecka Alumix 231® largely depended on the amount of liquid phase presented. Researchers using Alumix 231® as matrix material have reported similar results [11-13]. In studies conducted with Alumix 231® powders, liquid phase formation was mentioned at sintering temperatures above 500 °C [6,10-13]. Studies have indicated that the amount of liquid phase increases with increasing sintering temperature [6,11-13].

The decrease in density observed in sintering operations above 555 °C was attributed to the accumulation of the formed liquid phase in one region and sudden dimensional change. As a result, large pores have been reported to form [11,12]. It was determined that the liquid phase formed due to sintering temperature had an effect on density. This result is attributed to the formation of Al-Si liquid phases above 557 °C eutectic temperature [9,10].

Alumix 231® is a premixed alloy powder that is composed of a mixture of elemental aluminum and master alloy (Al-Si-Cu-Mg) powders. Fig.1 presents the SEM micrograph of the CS-0 (555°C sintered). Table 3 gives the EDS analysis results. Different regions were identified in the microstructure of the Alumix 231® alloy: elemental Al matrix, master alloy,

primary Si particles, Cu and Mg-rich secondary phases.

Table 3. EDS analysis (wt.%) corresponding to the point locations as shown in Fig.1

Sample	Point	Al	Si	Cu	Mg
CS-0	Point 1	95,237	0,76	3,66	0,343
	Point 2	12,224	87,288	0,441	0,048
	Point 3	93,375	3,789	2,46	0,376

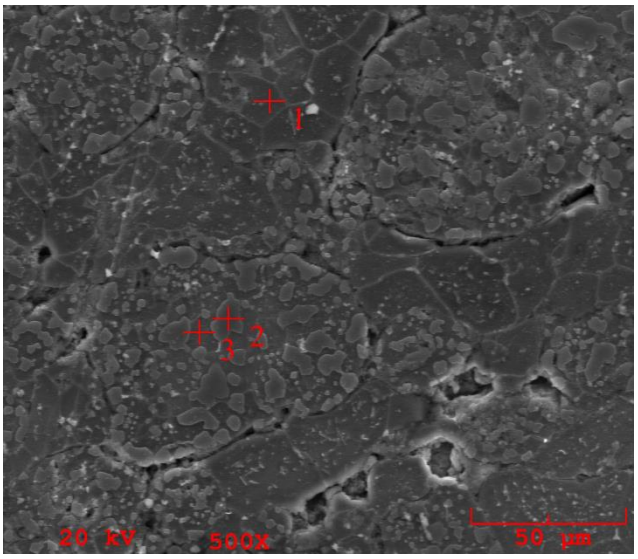


***Figure 1**. The SEM micrograph of the CS-0 (Sintering temperature 555 °C)*

According to EDS analysis, the region where the point 1 is located is the elemental Al containing small amounts of Si, Cu and Mg, and the region where the points 2 and 3 are located is the original master alloy consisting of Al-Si-Cu-Mg component. Point 2 corresponds to the primary Si particles. The primary Si particles have grown from the master alloy powder. Most primary Si phases were still clustered within the original master alloyed powder. It has been stated in the literature that the phases with a bright appearance seen throughout the microstructure are Cu-rich phases (fine white phase) [11,14,16,17].

SEM micrographs of the CS-5 and CS-10 samples are shown in Fig 2. The master alloy, pure aluminum regions and B_4C particles are summarized on micrographs. Micrographs show that B_4C clustered the grain boundaries. In addition, there are regions where there is no coalescence between the master alloy and pure aluminum grains, and it has been determined that B_4C particles are pushed into these vacancies where there is no coalescence during sintering.

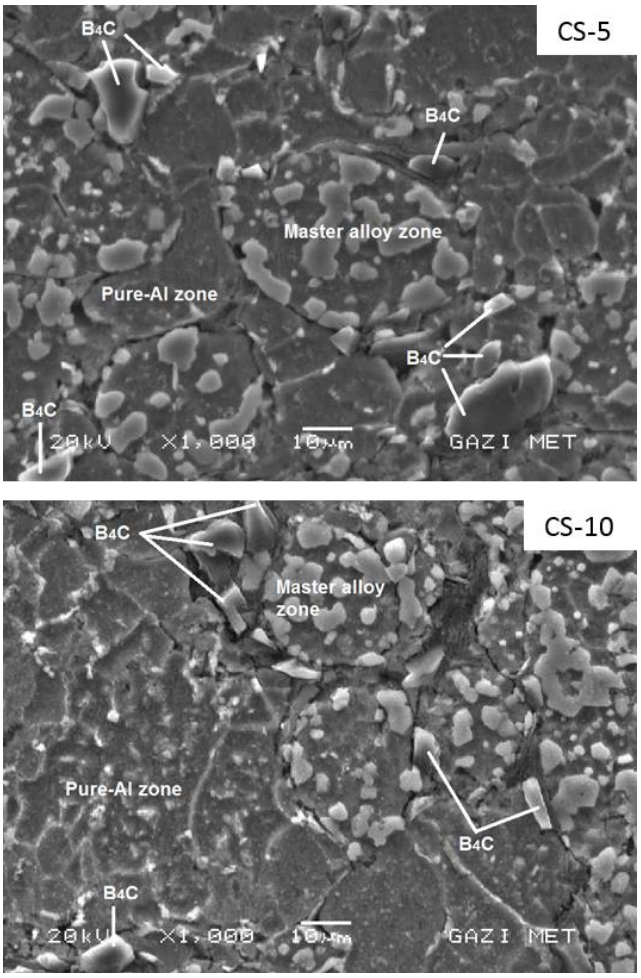


***Figure 2**. The SEM micrographs of the CS-5 and CS-10 (Sintering temperature 555 °C)*

Optical micrographs of Alumix 231® samples sintered at different temperatures are given in Fig. 3. When the micrographs are examined, it was found that the micrograph results are parallel with the density measurement results (Table 2). It was observed that the porosity increases and the pores become larger with increasing sintering temperature. In samples containing 10wt.% B_4C, intergranular vacancies are clearly seen, with increased porosity (Fig.3). The porosity that increases with increasing sintering temperature has been attributed to the increase in the amount of liquid phase with temperature, the accumulation of the liquid phase in a region and the sudden dimensional change during cooling [6,11-13].

Fig.4 shows the hardness curves of the samples produced. At the sintering temperature of 555 °C, no significant effect of B_4C particle addition was observed. An increase in hardness of ≈5,4% was observed in the CS-5 coded sample. In the CS-10 coded sample, a decrease of ≈5,7% was determined. The reason for not achieving a significant change in

hardness is the increased porosity with increasing B_4C addition.

No significant change in hardness was observed in samples containing 5wt.% and 10wt.% B_4C due to increased porosity with increasing sintering temperatures. In the CS-0 coded sample, a decreasing in hardness was observed with increasing sintering temperature. The reason for the decrease in hardness is the increased amount and size of porosity with increasing sintering temperature. In addition, increases and decreases in hardness values show different tendencies according to sintering temperatures. These different trends are reflected in the porosity/wt.% particle relationship.

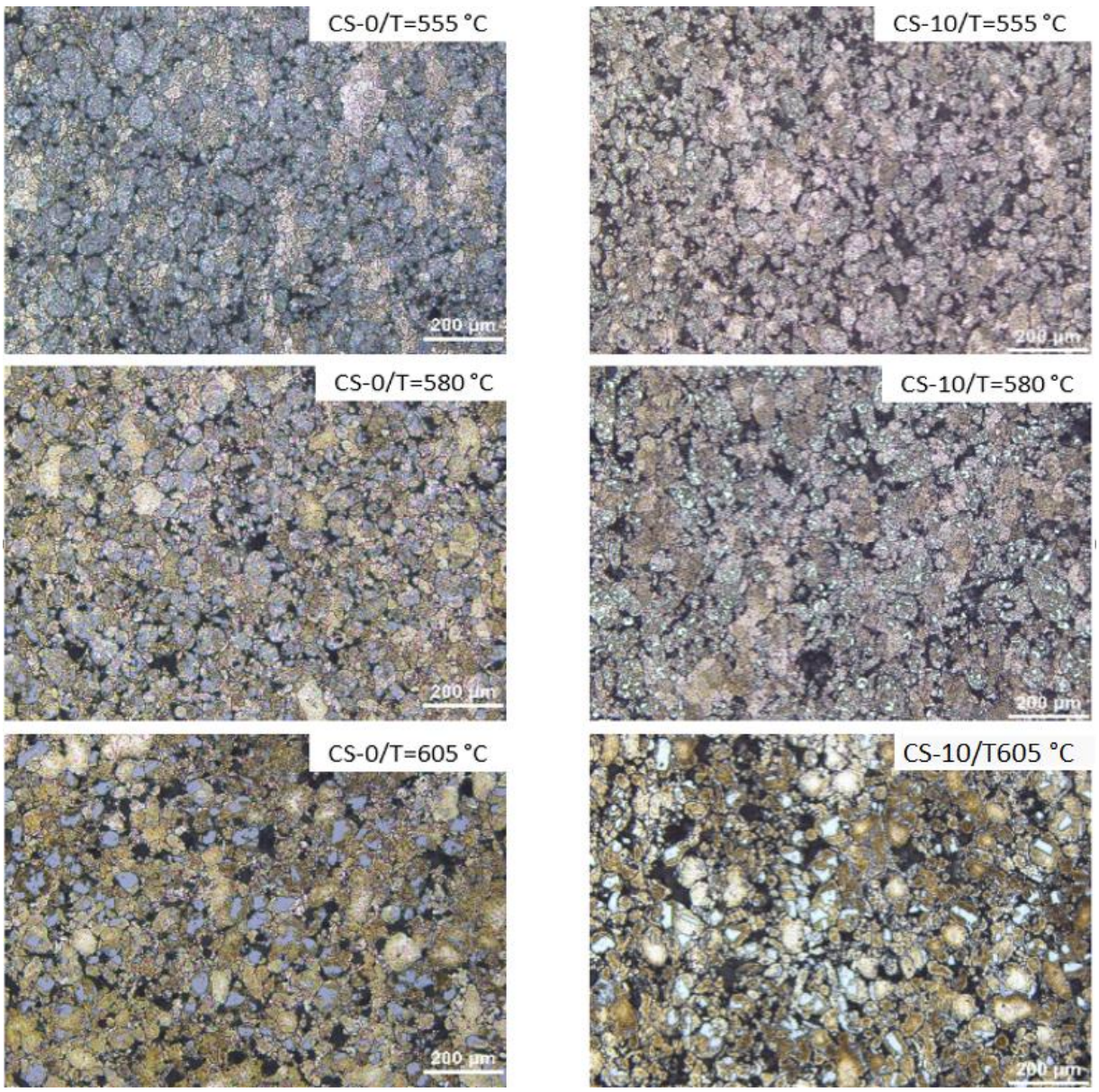


Figure 3. *Optical micrographs of CS-0 and CS-10 samples sintered at different temperatures*

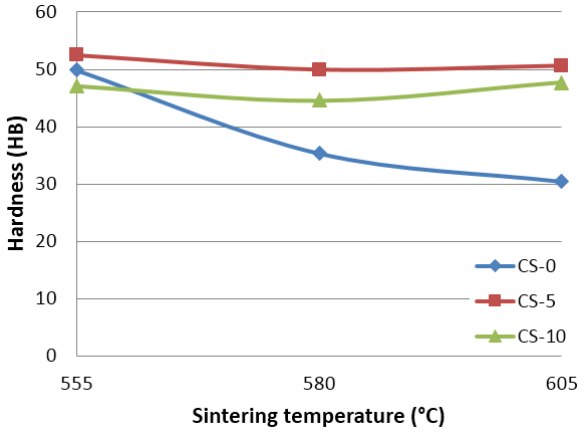


Figure 4. *Hardness change graph according to different sintering temperatures and wt.% particle amount*

Conclusion

The main conclusions for this study are summarized below:

- B_4C (5 and 10wt.%) particle-reinforced Ecka Alumix 231® aluminum composites were produced through the cold press/sintering technique. Sintering process was carried out at three different temperatures (555 °C, 580 °C, 605 °C).
- The green density of the samples decreased with the addition of increasing particles.
- Sintering process caused a decrease in density in all samples. A decrease in density was determined with increasing sintering temperature. It was observed that the porosity increases and the pores become larger with increasing sintering temperature. In samples containing 10wt.% B_4C by weight, intergranular vacancies were formed with increased porosity.
- Different regions were identified in the microstructure of the Alumix 231® alloy: elemental Al matrix, master alloy, primary Si particles, Cu and Mg-rich secondary phases.
- B_4C particles clustered at the grain boundaries. It was observed that there is partial sintering between the master alloy and pure aluminum particles.
- No significant change in hardness was observed in samples containing 5wt.% and 10wt.% B_4C.
- In the Alumix 231 samples, a decrease in hardness was observed with increasing sintering temperature.

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References

1. J.J. Fuentes, J.A. Rodriguez, E.J. Herrera, Increasing the ductility and strength of submicrometer-grained P/M aluminium, Journal of Alloys and Compounds 484 (2009), pp.806–811, doi.org/10.1016/j.jallcom.2009.05.045
2. L.F. Mondolfo, Aluminum Alloys: Structure and Properties. Butterworth, 1979.
3. J.R. Davis. Aluminum and Aluminum Alloys. ASM International: Materials Park, 1994.
4. I. Ozdemir, C. Gode, H. Yilmazer, H. Callioğlu, The effect of extrusion and high-pressure torsion on the properties of Alumix-231, Materials Science and Engineering A 532 (2012), pp.573-578, doi.org/10.1016/j.msea.2011.10.123
5. K. Kalaiselvan, I. Dinaharan, N. Murugan, Characterization of friction stir welded boron carbide particulate reinforced AA6061 aluminum alloy stir cast composite, Materials and Design 55 (2014), pp.176-182, doi.org/10.1016/j.matdes.2013.09.067
6. S.S. Su, I.T.H. Chang, W.C.H. Kuo, Effects of processing conditions on the sintering response of hypereutectic Al-Si-Cu-Mg P/M alloys. Materials Chemistry and Physics 139 (2013), pp.775-782, doi.org/10.1016/j.matchemphys.2013.02.031
7. B.V. Ramnath, C. Elanchezhian, M. Jaivignesh, S. Rajesh, C. Parswajinan, A.S.A Ghias, Evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites, Materials and Design 58 (2014), p.332-338, doi:10.1016/j.matdes.2014.01.068
8. A. Tuncer, B. Tasdelen, G. Arslan, Effect of passivation and precipitation hardening on processing and mechanical properties of B_4C–Al composites, Ceramics International 37 (2011), p.2861-2867, doi.org/10.1016/j.ceramint.2011.05.007
9. ASM Handbook, vol. 3, ASM International, Materials Park, OH, 1992.
10. A. Özer, The microstructures and mechanical properties ofAl-15Si-2.5Cu-0.5Mg/(wt%)B_4C composites produced through hotpressing technique and subjected to hot extrusion, Materials Chemistry and Physics 183 (2016) pp. 288-296

11. D.W. Hearda, I.W. Donaldsonb, D.P. Bishop, Metallurgical assessment of a hypereutectic aluminum–silicon P/M alloy, Journal of Materials Processing Technology 209 (2009) pp.5902–5911
12. H. Rudianto , S. Yang, K-W. Nam, Y-J Kim, Mechanical properties of Al-14Si-2.5Cu-0.5Mg aluminum-silicon p/m alloy, Rev. Adv. Mater. Sci. 28 (2011) pp.145-149
13. H. Rudianto, Y.S Sun, K.Y. Jin, N.K. Woo, Sintering behavior of hypereutectic aluminum-silicon metal matiıx composites powder, Advanced Materials Development and Performance (AMDP2011) International Journal of Modern Physics: Conference Series Vol. 6 (2012) pp.628-633, doi.org/10.1142/S2010194512003881
14. S. Rudinsky, J.M. Aguirre, G. Sweet, J. Milligan, D.P. Bishop, M. BrochuSpark plasma sintering of an Al-based powder blend Mat. Sci. Eng. A Struct., 621 (2015), pp. 18-27
15. P. Wanjara, M. BrochuCharacterization of electron beam welded AA2024 Vacuum, 85 (2) (2010), pp. 268-282
16. I. Arribas, J.M. Martin, F. Castro, The initial stage of liquid phase sintering for an Al–14Si–2.5Cu–0.5Mg (wt%) P/M alloy, Materials Science and Engineering A 527 (2010) 3949-3966.
17. A. Manonukul, A. Salee, Relationship between atmospheric dew point and sinterability of Al-Si based alloy, J Mater Sci Technol 29(1) (2013) 70-76.