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Study Properties of Al-Mg-Si (6000) Matrix Composites Reinforced with Alumina Particles Using Powder Metallurgy

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Abstract: In the present research, Aluminum, Magnesium, Silicon with additives of Alumina particles matrix powders were compacted using powder metallurgy method. The green compacts of both alloy (Al-Mg-Si-Cu) and composites (Al-Mg-Si-Cu/Al_2O_3) mixed powders were compacting using hydraulic press uniaxial at 400 MPa. The compacted mixtures Al-alloy and Al-composite were carried out by the sintering treatments at 460°C for 1.5 h. Over all the evolutions of the precipitates and hard second phases of the Al-matrixes P/M after the sintering process were examined using the X-Ray Diffraction-(XRD) and Scanning Electron Microscopy-(SEM). Outcomes of microstructural the compacted Al-PM alloy and composite investigated having a precipitations and second Al_2O_3 hard within the matrix during steps of sintering treatment. The highest Vickers hardness recorded of Al-Mg-Si-Cu/Al_2O_3p composite under sintering at 460°C.

Key words: Aluminium-Mg-Si alloys, sintering process, SEM,Vickers hardness, green compacts sintering treatment

INTRODUCTION

Metal Matrix Composites (MMCs) are combinations of two or more materials (one of which is a metal) where tailored properties are achieved by systematic combinations of different constituents (Naeem *et al*., 2014). Aluminum matrix composites kind of MMCs are being increasingly used in the automotive, aeronautics, aerospace, military and transportation industries where weight reducing result as using of lighter materials with promote mechanical performances combined with significant weight savings over unreinforced alloys (Murugesan *et al*., 2015; Naeem, 2014). The interface between the Aluminum matrix and the reinforcement plays an important role in determination of the properties of the AlMCs. The advantages of particle-reinforced composites over others are their formability with cost advantage (Purohit *et al*., 2017; Naeem *et al*., 2018). Accordingly, there are a wide volume of applications which are undoubtedly dependent on the enhancement of this sort of alloy, particularly in automotive and transport industries (Shankar *et al*., 2018; Unlu, 2008). Al-matrix composites that comprise a uniform dispersion of reinforcements in the size range of nanometers are defined as Aluminum Matrix Nanocomposites (MMNCs) (Purohit *et al*., 2017; Naeem *et al*., 2018; Shankar *et al*., 2018; Unlu, 2008; Naeem, 2014). By decreasing the size of reinforcement particles it is very likely to achieve a finer grain microstructure due to the suppression of grain growth during solidification stage which can result in the enhancement of mechanical properties (Unlu, 2008). The gettable enhancements within the properties are addicted to the intrinsic properties of composite constituents and also the size, shape, orientation, vol. fraction and division of the reinforcing phase introduced in the metal matrix (Naeem *et al*., 2014; Umanath *et al*., 2014). So, it is necessary to develop newer materials with high strength and stiffness without increasing processing cost. In the present work an attempt is being made to process Aluminum 6xxx series alloy-5 wt.% Al_2O_3 particulate reinforced composites by reinforcement mixing by using powder metallurgy technique. In this research the vickers hardness properties and microstructural were evaluated as per ASTM standards and were compared with base AA6061 Aluminum matrix alloy.

MATERIALS AND METHODS

Powders elemental of Al, Mg, Si, Cu, Mn, Cr, Zn, Al_2O_3 have used to produced Al 6xxx matrix Alloys. characteristics of the elemental powders as in Table 1, Particles size distributions were measured by Malvern-Mastersizer powder size analyzer. All composition is expressing in the weight percentages as in Table 2.

The conventional powder metallurgy method was followed in this study, consisted of powder blending, compacted by uni-axial die compaction and then the sintering treatment. At the start, all element powders have been mixed in a tubular mixer for 1 h.

Table 1: Starting powder characteristics

Powder	Description	Powder sizes (μm)	Purity (%)	Source
Aluminum	Flake	D50 of 51	98.0	Merck K-GaA
Alumina	Rounded	D50 of 6	98.5	Merck K-GaA
Magnesium	Rounded	D50 of 115	98.5	Merck K-GaA
Silicon	Rounded	D50 of 87	98.5	Merck K-GaA
Copper	Irregular	D50 of 37	98.5	Merck K-GaA
Manganese	Rounded	D50 of 191	99.5	Merck K-GaA
Chrome	Irregular	D50 of 157	99.5	Merck K-GaA
Zinc	Rounded	D50 of 19	96.5	Merck K-GaA

Table 2: The chemical compositions of Al-matrix and composites

	Weight (wt.%)							
Elements	Al_2O_3	Mg	Si	Cu	Mn	Cr	Zn	Al
Alloy-1	-	1	1.5	0.5	0.3	0.2	0.5	96
Alloy-2	5	1	0.8	0.5	0.3	0.2	0.5	91

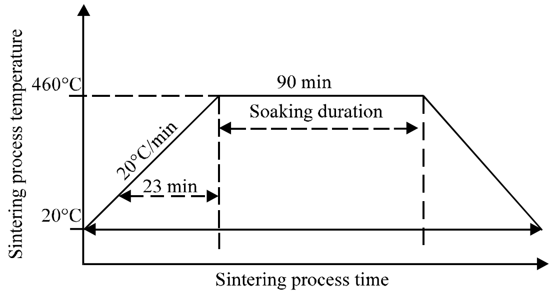

Fig. 1: Sintering diagram

The mixed powders were inserted into cylindrical mold to produce samples of 15 mm in diameter and 10 mm high were compacted at 400 MPa in a floating uniaxial die using a hand-operated hydraulic press. Green compacts were undergone the sintering treatment in the LT electric furnace. The sintering process was carried out at temperature of 460°C for 90 min (Fig. 1). The densities of green the sintered samples have determined from the weight mass and the dimensions while the densities and porosities of the sintered samples determined using the Archimedes principle based to ASTM B 312-09 (Ezatpour *et al*., 2017; Nami *et al*., 2011). The heating and cooling rates were set at a constant level be 20°C/min. After sintering all the compacted samples have been quenching in cool water directly. The steps ground and polished for the sintered specimens according to ASTM E3-01 have been done. Microstructural evolutions of the sintered compactshave been analyzed by the Optical Microscopy (OM), Scanning Electron Microscopy (SEM) and X-Ray Diffraction analysis. Vickers Hardness test was carried out for sintered samples according to ASTM E92-82.

RESULTS AND DISCUSSION

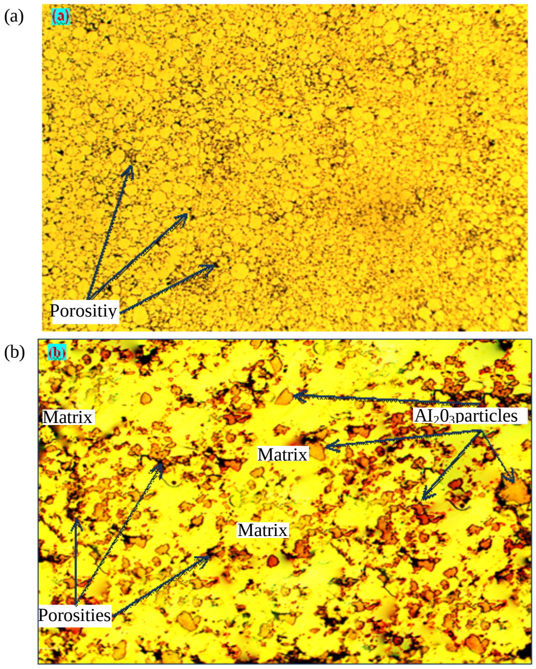

Fig. 2a: Optical Microstructure of Al-Mg-Si matrix alloy (Alloy-1) underwent sintering process (460°C/1.5 h) and b) Optical micrograph of matrix of Al-Mg-Si/Alumina after sintering process

The matrix microstructural of the Aluminum-Mg-Si (6000) alloy is given in Fig. 2a after sintering treatment (460°C/90 min). However, the percentages of apparent porosity in the sintered samples were determined to be 3% that reveals to the presence of the pores. The cause to that is the wide difference to the melting point of the constituents of alloying elements.

For the Al-6000 matrix composite (Alloy-2) (fabricated using the Al-Mg-Si matrix the reinforced by Al_2O_3p (6 μm) a sufficiently uniform reinforcement distribution is observed when the particulates of Al_2O_3 content is 5 vol.%. In those cases, clusters of the reinforcement particles are formed. The mean of sintered density for the Al-compacted sample (alloy-2) was determined to be (2.8 g/cm^3) representing 89.5% of the full theoretical density (3.07 g/cm^3).

To evaluate the microstructure of the as-sintered alloy-2 composite, the Scanning Electron Micrograph (SEM) represents in Fig. 3 it indicates that the alpha aluminum (primary solid solution) grains surrounded by a light phases precipitates of alloying elements (Mg, Si, Mn, Cu) which is a remnant of the Mg-enriched sintering liquid that decomposes on solidification to the a-aluminum, (η)-Al_2CuMg, Mg_2Si phases (Ezatpour *et al*., 2017; Nami *et al*., 2011; Jamaludin *et al*., 2015) Additionally, the distribution of Al_2O_3 particles within the matrix is reasonably uniform with the least agglomeration.

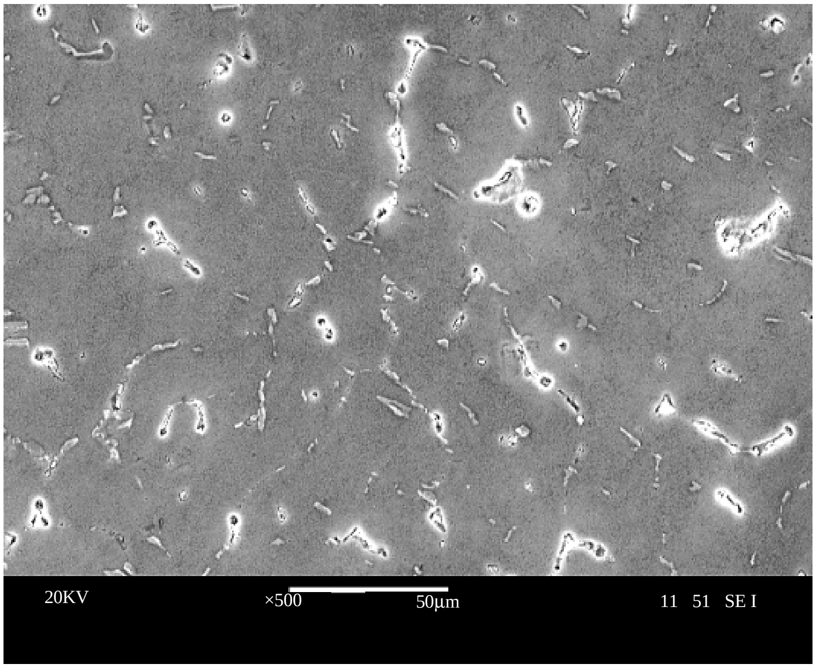

Fig. 3: SEM micrograph of the sintered Al-Mg-Si/Al_2O_3 PM (after applying sintering at 460°C)

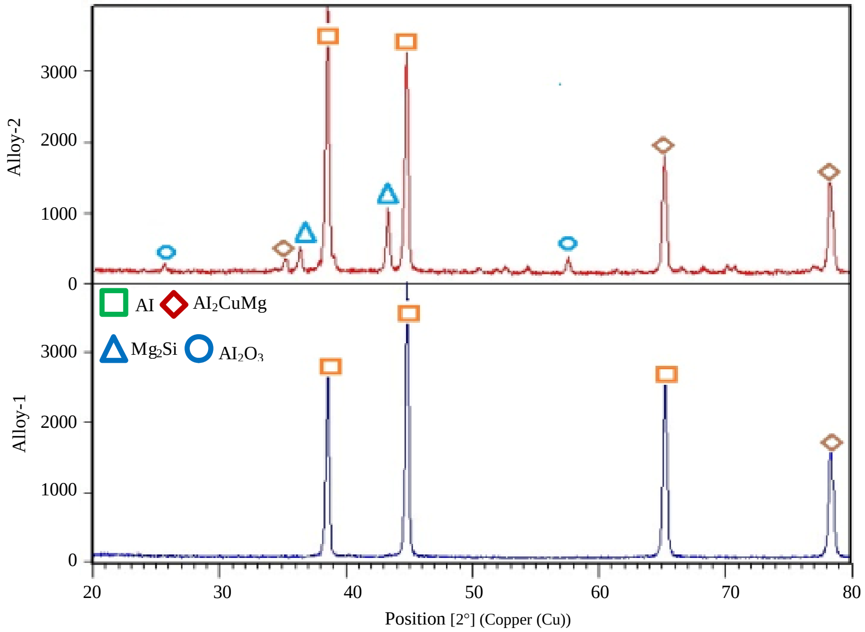

Fig. 4: X-ray diffraction patterns of the Al-alloy 1 and 2 after sintering treatments

Also, indicated that interfacial bonding is achieved between the Al_2O_3p and aluminium matrix due to small Al_2O_3 particles (6 µm) and an advanced sintering at elevated temperatures. Naeem (2014) also, observed this behavior. SEM micrograph in Fig. 3 indicates good distribution of reinforcement's alumina particles within the matrix of alloy-2.

The X-Ray Diffraction (XRD) in Fig. 4 manifests to the patterns of the alloy-1 and -2 after carrying the sintering process. Figure 4b refers as sintered alloy-1 sample which fundamentally consisted of alpha-Al and the S-Al_2CuMg. The XRD results in Fig. 4 a exhibited the Al-matrix alloy-2 after adding (5% of Al_2O_3) under the impact on the sintering process. It detects the new

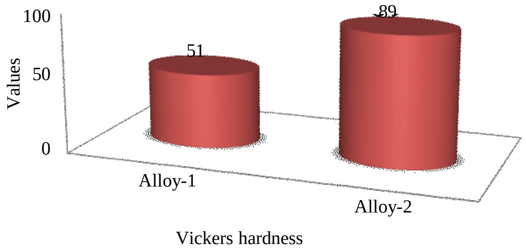

Fig. 5: Vickers's hardness of the Al-Mg-Si P/M alloys compacted at sintering process

creating the Al_2O_3 phase as well as plenty of Mg_2Si phase. The precipitation procedure through the matrix of an Al-Mg-Si alloy after carrying the heat process is more detailed by Ezatpour *et al*. (2017), Nami *et al*. (2011) and Jamaludin *et al*. (2015).

Vickers hardness for the sintered Al-alloy compacts under the 460°C/90 min, sintering condition (Fig. 5). Generally, alloy-2 samples after applying the sintering have significantly increment hardness mores than what was observed in the alloy-1 sample as sintered at same condition. Predominately, values of micro-hardness for the Al-Mg-Si alloy depends on strength mechanisms such the precipitation hardening results as the alloying elements which assumed that the influences of the (Al_2CuMg) with (Mg_2Si) phase are precipitates within the Al-matrix as stated by Naeem *et al*. (2014), Umanath *et al*. (2014), Ezatpour *et al*. (2017), Nami *et al*. (2011), Jamaludin *et al*. (2015), Sonawane and Karnik (2017) and MacAskill *et al*. (2007). These precipitate acts as pin-points which impeded the dislocation movement thus improve the hardness. Additionally effects of the hard second phase Alumina particles were disturbed uniformly dispersion within Aluminum-Magnesium-Silicon matrix. These Al_2O_3 particles cause to rise of hardness through Orowan mechanism (Naeem, 2014; Purohit *et al*., 2017; Naeem *et al*., 2014; 2018; Shankar *et al*., 2018; Unlu, 2008; Umanath *et al*., 2014; Ezatpour *et al*., 2017; Nami *et al*., 2011; Jamaludin *et al*., 2015; Sonawane and Karnik, 2017).

CONCLUSION

Through the experiments of this research that accomplished, it has understood that: The mixed Al-Mg-Si matrix PM alloys were much responding to condition of sintering and it reaches density sintering of about 90% of theoretical. Microstructural observations mentioned that the sintered Al-Mg-Si/Al_2O_3 matrix composite after sintering treatments, to having more precipitations particles with hard second phase of alumina in the sintered Al-matrix. The compacted alloy-2 after doing the sintering at 460°C have the highest Vickers hardness because of the precipitation particles (Al_2CuMg and Mg_2Si) and compounds of (Al_2O_3).

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