Applied Mechanics and Materials Vol. 232 (2012) pp 39-44
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doi:10.4028/www.scientific.net/AMM.232.39

The Microstructure and Hardness of Al2O3 Particle Reinforced Composite

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Keywords: Al2014 alloy; Al2124 alloy; Al_2O_3; Powder metallurgy; Metal matrix composite; Hardness.

Abstract: Aluminium alloys (Al2014 and Al2124 alloy) and their composites containing 10wt.% Al_2O_3 with 3 μm and 43 μm sizes of particles have been produced by powder metallurgy (PM) method and the microstructure and hardness were investigated. Scanning electron microscopy (SEM) investigation showed a nearly uniform distribution of the Al_2O_3 particles within the Al2124 alloy matrix although some porosities were found in the Al2014 alloy matrix. Furthermore, it was found that the macrohardness of Al2124 alloy composite improved highly in comparison to that of Al2014 alloy due to fine of microstructure and increased hardness. The hardnesses of both MMCs increased with increasing the particle sizes.

Introduction

Particle-reinforced metal matrix composites (MMCs) have developed to reduce the weight of components in structural applications such as helicopter parts, rotor vanes in compressors in aerospace industry over conventional alloys, recently [1,2]. In order to obtain the desired mechanical and physical properties, there is an increasing trend in the worldwide for advanced materials because a single material can not meet the requirements of harsh engineering environments, in general. Among the ceramic particles used for manufacturing the MMCs, Al_2O_3 is favorable since it does not react with the matrix at high temperature and does not create the undesired phases [3-7].

Solid state processes are generally used to obtain the best mechanical properties in aluminium alloy composites. A solid state process viz.PM and MA are simple methods and these processes exhibit excellent finished performance due to the ability to obtain uniform distribution of reinforcement and near-net shape formability although production costs of the method are relatively higher than usual liquid casting processes [8-9]. This method is widely used to synthesize a variety of materials such as intermetallic compounds, oxides, carbide, amorphous alloys, composites and nanocristalline materials. Wear is one of the most commonly encountered industrial problems, leading to frequent replacement of components. Wear resistance, is not an intrinsic property of the material but depends on the tribosystem itself such as properties of materials tested, test condition, counterface, equipment and environment [4, 5,10]. Adhesive behaviours of SiCp/Al composites have been investigated experimentally by several investigators. There has been a number of studies in the fabrication of Al/SiCp or Al/Al_2O_3 reinforced composites [11-21]. However, there was a few reports on effect of matrix type on microstructure of Al_2O_3/Al alloy composites [5,13-15]. The purpose of the current study, therefore, is to produce MMCs with different matrix by PM method and evaluate the effect of matrix type on the hardness of MMCs. Moreover, scanning electron microscope (SEM) investigation is carried out to determine the distribution of Al_2O_3 particles in the matrix structure and its matrix.

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Experimental procedure

Materials. Aluminium alloys (Al2014 and Al2124) were fabricated by powder metallurgy as an unreinforced materials. The chemical composition of the both alloy (wt.%) is Fe0.26, Cu4.5, Mg1, balance Al, and Cu3.9, Mg1.5, 0.6Mn and 0.5Si, respectively. In order to produce Al_2O_3-Al based composites, aluminium powders with an average particle size of 45 μm with 99.5% purity were chosen while Al_2O_3 particles with 3μm and 43μm sizes were used as the reinforcement materials for the manufacturing MMCs. The average particle sizes of 3μm and 43μm was evaluated, hereafter denoted as 3μm-Al_2O_3/Al composites, 43μm-Al_2O_3/Al composites, containing 10wt.% of Al_2O_3 particles. The mixture of pre-alloyed and alloyed powders were uniaxially cold compacted using a cylindrical die of 10 mm diameter and 20 mm height at a pressure of 650 MPa using a single action press. The compacts were then sintered in a rapid heating pipe type of furnace under a control of N_2 gas. By adjusting the auto-controlled power of the induction heat system, the mixed powders were sintered at 610 ^oC for 2 hours. The heating rate was about 200 ^oC/h. After consolidation, the specimen was allowed to furnace cool down. A similar subsequent experiment was conducted for the development of Al alloy-powder specimens-only for comparison purposes. The samples were sectioned and examined by SEM. Specimens for metallographic observation were prepared by grinding through 800 grit papers, followed by polishing with 6 μm diamond paste. Hardnesses of composites and matrix alloy were measured by Rockwell hardness (HRB) method after polishing to a 3 μm finish, and the mean of at least five readings was taken.

Results and discussion

Microstructure. Fig.1 shows the SEM micrograph of a pre-alloyed Al2014 alloy sintered at 610^oC for 2 hours, at low magnification. It can be observed. that grain boundary appears more clearly. Its average value is about 150-200μm. Compared to the original Al particles, grain growth phenomenon is observed (Fig.1a). The grain gowth might proceed via solid-state atomic diffusion or formation of Cu/Al oxide since the matrix can not melted at this sintering temperature. Pure Al compacts were sintered at 600$^oC$for 2 h for comparison to Al5Cu and Al5Cu0.5Mg, and grain boundaries of Al5Cu compact are thicker than that of Al compact. The precipitates were finer and grain boundaries were thinner due to effect of Mg addition [4,5]. Fig.2 shows the SEM micrographs of the composites reinforced with a 10 wt.% values of Al_2O_3 composites with 43μm particle sizes. The Al_2O_3 particles (white colour) are observed to be angular in shape. It can be seen that the Al_2O_3 powders has a certain shape viz. polygonal and hexagonal geometry or a combination of others. This figure indicates that the distributions of Al_2O_3 particles in these composites seems to be a not-uniform due to obtaining with a pre-alloyed powder. The composite produced by PM contained a small amount of porosity. This SEM image reveals that some agglomeration and porosity also increase slightly because of selecting the elemental matrix (Fig.2b). The other reason may be the sintering temperature because the sintering temperature significantly affects the consolidation of composites. Increasing the sintering temperature from 500^oC to 550 ^oC increased the hardness from 58 to 62BHN and led to reduced porosity [2]. Optimization of processing parametres for the Al+10%B_4C alloy was investigated [8]. The MA time is about 12h while compaction pressure is 700 MPa for a 30 min sintering time. The best results were obtained at 635 ^oC under Ar atmosphere. The powder metallurgy of SiC/Cu-Al composites was characterized by Wang et al.[11]. Reaction between Al and Cu was detected at above 750 ^oC to form Al_2Cu.The highest microhardness of 80 MPa occurred at 700^oC. The effect of particles concentration on the wear of Al matrix alloy was investigated [20]. The highest hardness for 6060 Al matrix and composite with 30% volume fraction of Al_2O_3 particles were about 46.58HVN and 154.1VHN, respectively

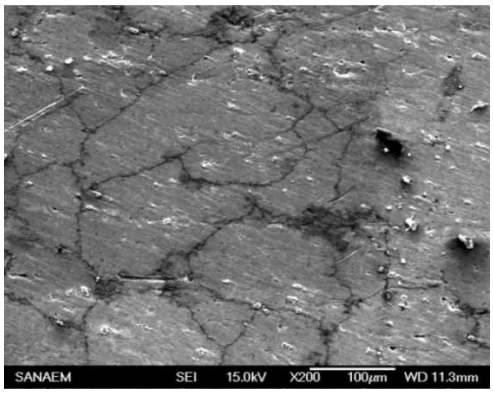


Fig.1. SEM micrograph of a pre-alloyed Al2014 alloy sintered at 610^{o}C for 2 hours, at increased magnification.

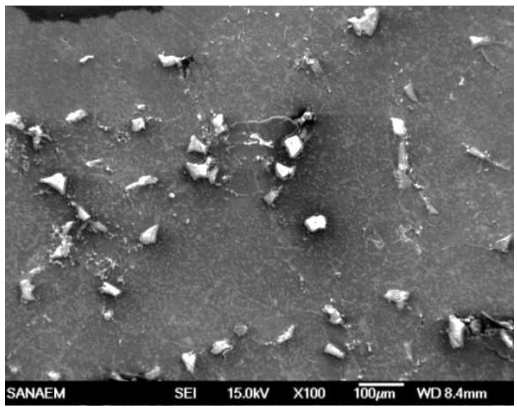


Fig.2. SEM micrograph of an Al2014 alloy /10wt.% Al_2O_3 reinforced aluminium alloy composites with 43 μm sizes of particles at low magnification.

Fig.3 shows the SEM micrograph of a commercial Al2124 alloy sintered at 610^{o}C for 2 hours at low magnification. It can be observed that grain boundaries appears again. Fig.3b is a higher magnification of Fig.3a, indicating the the grain boundary region more clearly. Its average value is found to be very low, which is about 20-40μm. It is the reason for getting a higher hardness values for Al2124 alloy when compared to Fig.1. Fig.4 shows the SEM micrographs of a 10wt.% Al_2O_3 reinforced Al alloy composites with 43μm sizes of particles. In general, the distribution of Al_2O_3 in the composite seems to be uniform for this composite. It seems that no reaction forms between the particle and matrix. It may be an indication of enough bonding between the particles and matrix. A clear interfacial reaction product/layer at Al-SiC interface for composites held for a relatively long processing time (>30 min), but no reaction product was observed at Al-B_4C and Al-Al_2O_3 interfaces [3].

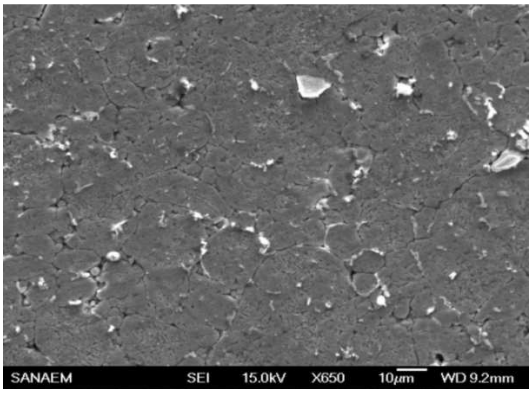


Fig.3. SEM micrograph of an alloyed Al2124 matrix alloy, sintered at 610^{o}C for 2 hours, at low magnification.

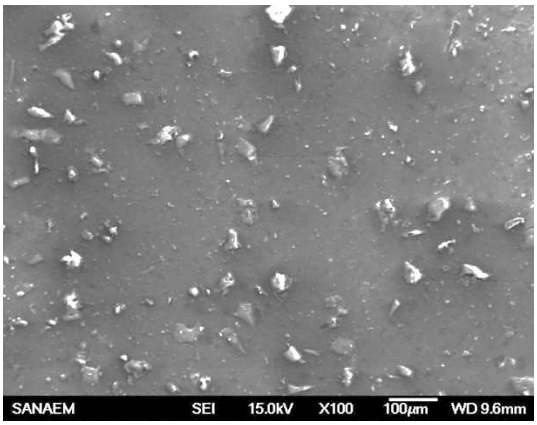


Fig. 4. SEM micrograph of Al2124 alloy and its MMC, showing distributions of 10wt. %Al_2O_3 particles in 2124 Aluminium alloy.

The voids were found to initiate at retained porosity sites at the Al-Al_2O_3 interface or in the matrix close to the interface due to stress concentration [10]. The hardnesses of both MMCs are shown in Figs.5 and 6, respectively. The hardness of the MMCs increased with increasing the size of particles and type of the matrix. Hardness for 2014Al composite is about 49HB, 58.5HB and 61,6HB for the matrix, 3µm and 43µm particle sizes of MMCs (Fig.5). However, these values increased from 58HB, 65,1HB to 73,2HB for the 2124 Al-Al_2O_3 composites due to application of the original trade-alloy including Cu and Mg element, production method and composition (Fig.6). The other reason was the reducing the grain size and fining the microstructure because of compaction pressure, as shown in Fig.3 in comparison to Fig.1. Another study showed that the hardness increased with increasing SiC contents [1, 21].

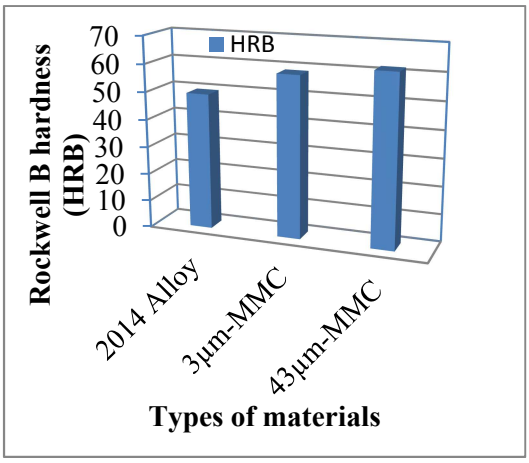


Fig.5. The results of the hardnesses of Al2014 Alloy/Al_2O_3 reinforced composites.

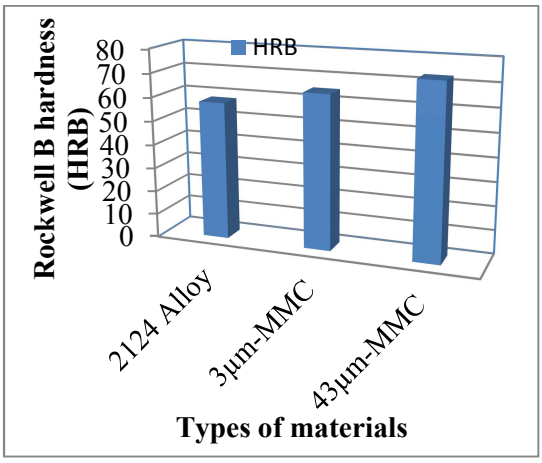


Fig.6. The results of the hardnesses of Al2124 Alloy/Al_2O_3 reinforced composites.

Both hardness and compresive strength increased with addition of Al_2O_3 and Al_4C_3 to pure Al was reported [19]. For example, the hardnesses for pure matrix, Al+1.5%Al_2O_3+4%Al_4C_3 composite and Al+1.5%Al_2O_3+12%Al_4C_3 composite were about 20, 49 and 79 VHN, respectively. They are still lower, especially for the matrix although it consists of ball milled, cold compaction followed by hot extrusion at 500^{o}C. In the present study of manufacturing MMCs, the hardnesses were about 58 HB, 65HB and 73,2HB for the 2124 matrix alloy, 3 μm-10wt.% Al_2O_3 reinforced composite, 43 μm-Al_2O_3 reinforced MMC, respectively. These hardnesses values are comparable to the previous works [2, 3, 20].

Conclusions

Al 2014 alloy, 2124 alloy and its composite were fabricated by PM route. The following results were obtained: Al2014 alloy, Al2124 alloy and their composites containing 10wt.% Al_2O_3 particles with 3μm and 43μm particle sizes were produced successfully. SEM observation of the microstructure showed that dispersion of Al_2O_3 particles for the Al2124 alloy composite was more uniform that of the Al2014 alloy composite. The macrohardness of both types of Al alloy composites improved with increasing particle sizes of Al_2O_3 particles, but hardness of 2124Al alloy composite was higher than that of the 2014 Al alloy composite. The macro hardness of 10wt.% Al_2O_3 reinforced Al2124 alloy increased by 26% compared to that of matrix alloy.

Acknowledgements

This work was financially supported by the National University of Gazi in Ankara (07-2009/38).

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