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DEVELOPMENT OF 2024 P/M ALUMINIUM ALLOY – SiCp NANOCOMPOSITES VIA MECHANICAL ALLOYING

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Abstract

Aluminum alloy 2024 is the best known most widely used aircraft structural alloy. Now a days it is also gaining ground in automotive industry. In the present studies, 2024 P/M Al alloy and SiC particulates have been chosen as matrix and reinforcement materials, respectively. Mechanical alloying (MA) was used to obtain uniform SiCp dispersion in the matrix. MA powder was vacuum degassed and consolidated by hot pressing and subsequent hot forging. Thereafter the composites were heat treated to give T-6 temper. Optical and scanning electron microscopy of the composite was carried out and evaluation of mechanical properties was done. The principal objective of the present investigations was to determine how the particulate volume fraction and extent of mechanical alloying affect the microstructure and tensile properties of 2024 P/M Al alloy-SiCp composites. In these efforts it could be possible to develop nano composites of 2024 P/M Al alloy-SiCp having tensile strength of 504 MPa and modulus of elasticity of 105 GPa.

Introduction

Aluminum based metal matrix composites (MMCs) offers excellent combination of properties such as high specific strength, specific stiffness, electrical and thermal conductivities, low coefficient of thermal expansion and wear resistance [1]. Because of their excellent combination of properties, MMCs are being used in varieties of applications in automobile, mining and mineral, aerospace, defense and other related sectors.

For more than two decades, aluminium-matrix composites have been made by different methods including casting, spray atomization, co-deposition, pressure-infiltration of porous ceramic performs, and powder metallurgy techniques like densification of composite powders made by mechanical processing. The mechanical properties of these composites are influenced significantly by the quantity and mode of distribution of the reinforcements and also by the nature of the interfaces between the reinforcements and the matrix.

In this context, the use of mechanically processed composite powders for producing sound aluminium matrix composites or other metal-matrix composites (MMCs) should be considered as a very promising and commercially viable technique since the starting composite powders ensure a uniform distribution of reinforcement particles. Also, this low temperature solid-state process eliminates reactions between the reinforcement particles and the matrix which are indeed an important problem with methods involving molten metal. The use of net and near net shape forming techniques should enable a cost saving in the manufacture. However, the compaction and sintering of aluminium powder have been hindered by technical factors such as the lack of sintering integrity due to the dense and very stable oxide layer covering powder particles. Agglomeration of reinforcement particles is inevitable due to size difference between powders for the matrix and the particles, and the development of static charge on the particles. Different approaches have been suggested to overcome these problems [2]. To achieve homogeneity of particle distribution, several methods have been employed, such as a proper choice of the particle size and the use of polar solvents that neutralize the charge on the surface of the particles [3]. An alternative method to improve particle distribution is to use a mechanical alloying (MA) technique, which enables metallic materials to be coated onto ceramic powder particles [4,5].

The field of material science and engineering is constantly striving to discover new and improved structure-properties-performance relationships among materials. One such change in structure that has peaked much curiosity lately is the field of nanocrystalline materials. It has been shown that materials with nano-sized grains demonstrate many enhanced physical properties. They have been shown to have an increased hardness, strength, ductility, diffusivity and soft magnetic properties to name a few [6].

In the present studies 2024 Al alloy and SiC particulates have been chosen as matrix and reinforcement materials, respectively. 2024 Al alloy has good tensile strength (450 Mpa), modulus of elasticity (E = 72 GPa) and excellent mechanical properties. SiC particles have very low density (3.2 g/cm^3), high hardness (2500 kHN) and modulus of elasticity (E = 450 GPa) and increasingly used in aluminium composites. The 2024 Al alloy is a very important aluminium alloy that can be strengthened by solution and aging treatment, and it is widely used under T6 state for aircraft structures, sheets and truck wheels [7].

The objective of the present investigations was to determine how the microstructural parameters, such as the particulate volume fraction and extent of mechanical alloying affect the microstructure and mechanical properties 2024 Al alloy and SiCp composites. The fabrication process is based on the hot pressing of 2024 Al alloy powder blended with SiCp reinforcement. MA was used to obtain a uniform SiCp dispersion in the matrix. Vacuum degassing, hot pressing and subsequent hot forging and heat treatment (T6) were employed in order to obtain the high density composite, and the microstructure and mechanical properties of the composite specimens were evaluated.

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Experimental

In the present investigations 2024 Al alloy powder having particle size < 75 µm, supplied by ECKA granules, GmbH & Co. Germany was used as matrix. The chemical composition of the powder is given in the Table 1. SiC particles of < 33 µm size were used for the reinforcement purpose. To get blended powders, required amount of Al 2024 alloy and SiC powders were mixed in a laboratory double cone mixer for one hour. Mechanical alloying was carried out in a laboratory attrition mill having stainless steel chamber with a water jacket around it to keep the attritor cool during operation. 2.0 wt % stearic acid was added to each batch as process control agent (PCA) .The alloying was carried out in inert atmosphere of purified nitrogen gas to protect the powder from oxidation. The attritor medium was 8mm hardened steel balls (charge to ball ratio = 1:10), the speed of attritor shaft was maintained at 330 rpm. All the mechanically alloyed powder samples were degassed for a period of one hour in a vacuum of 10^{-2} torr at 200°C.

Table 1. Chemical composition of 2024 Al alloy powder

Elements	Si	Fe	Cu	Mn	Mg	Cr
Weight %	0.50 max	0.50 max	3.8-4.9	0.3-0.9	1.2-1.8	0.10 max
Elements	Ni	Zn	Ti+Zr	Sn	Pb	Al
Weight %	0.05 max	0.20 max	0.20 max	0.05 max	0.05 max	Rest

Consolidation of all the sample powders was carried out by hot pressing at 500 ^{0}C, under a pressure of 140 MPa. All the specimens prepared were of the size 40 mm (L) × 10 mm (B) × 2 mm (H). These specimens were then hot forged at 400^0 C. T_6 temper was given to hot forged compacts. This was done in two steps: (i) Natural aging (T_4 temper): hot forged compacts were heated in furnace at 493 ^{0}C for 45 minutes. After heating compacts were water quenched; and (ii) Artificial aging (T_6 temper): natural aged compacts were than reheated at 191 ^{0}C for 8 hours and allowed to cool in the furnace. After reaching the room temperature, compacts were removed.

A flow chart depicting the complete procedure followed to prepare the specimens is given in the Fig. 1.

Figure 1. Flow sheet for preparation of the 2024 P/M Al alloy SiC composites

Optical microscopy of the specimens was done using LEICA image analyzer. Scanning electron micrographs of the specimens were taken with Leo 440 PC based digital SEM. Hounsfield tensometer was used for evaluating tensile properties of the composite.

Results and Discussion

Details of all the specimens prepared are shown in Table 2. Optical micrographs of these specimens are shown in Fig. 2. Optical micrographs of hot pressed specimens show that all specimens are free from pores and have homogeneous distribution of SiC particles in the matrix. Most of the SiC particles are embedded in the matrix grains while some segregates at the grain boundaries. Precipitate particles present have been identified as Al_2CuMg in the unreinforced one, and $CuAl_2$ and Mg_2Si in the 2024 Al alloy- SiC_p composites [7].

Table 2. Details of the specimens prepared

Specimen no.	Details
1	2024Al/ 0%wt.SiC_p/ 0 hr. MA
2	2024Al/ 0%wt.SiC_p/ 5 hr. MA
3	2024Al/ 5%wt.SiC_p/ 5 hr. MA
4	2024Al/ 10%wt.SiC_p/ 5 hr. MA
5	2024Al/ 15%wt.SiC_p/ 5 hr. MA
6	2024Al/ 10%wt.SiC_p/ 10 hr. MA
6 (a)	2024Al/ 10%wt.SiC_p/ 10 hr. MA, (only hot pressed)

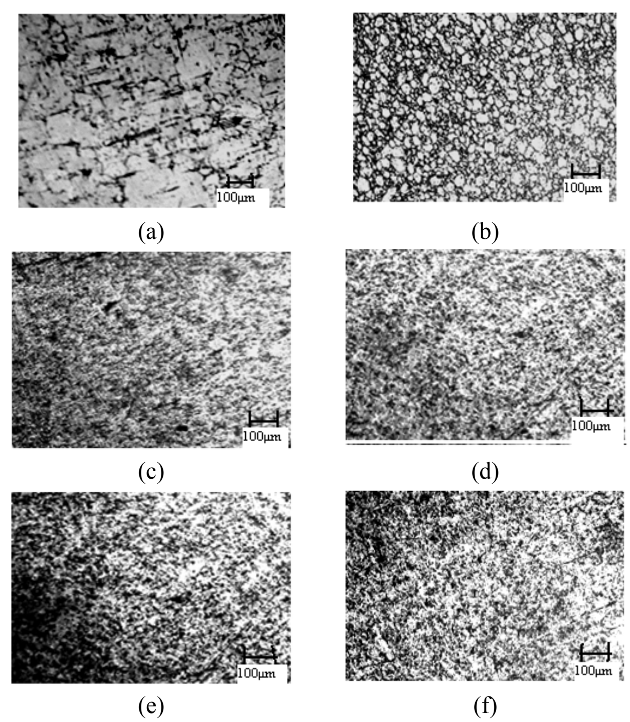

Figure 2. Optical micrographs of specimen no.1-6

Scanning electron micrograph of specimens 6 and 6(a) are shown in Fig. 3 and Fig. 4, respectively. Particle size measurement in specimen 6 shows that white contrast particles size varies between 0.25 μm (250 nm) to 1.5 μm and that of the dark contrast particles between 0.50 μm (500 nm) to 1.5 μm. In specimen 6(a) particle size of the white contrast particles and dark contrast particles was found to very between 0.5 μm (500 nm) to 2.5 μm and 1.5 μm to 3.25 μm, respectively. The white contrast particles are possibly the fine oxides and carbides formed due to interaction of matrix with PCA [8], while the dark contrast particles are SiC. This clearly indicates refinement of the particle size due to forging. However, in both the samples grains with distinct boundaries could not be observed, indicating clearly that matrix grain size in these composites is of nano size. In fact, the presence of nanosized oxide and carbide particles in the matrix stabilize the fine grains and dislocation substructure during the thermo-mechanical processing [9].

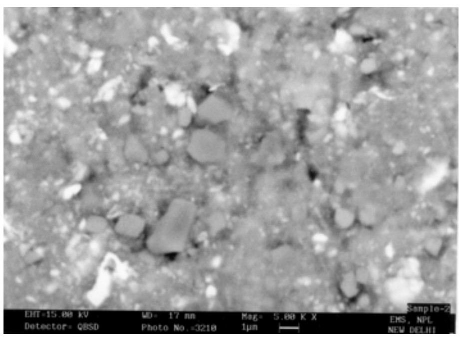

Figure 3.:Scanning electron micrograph of specimen 6

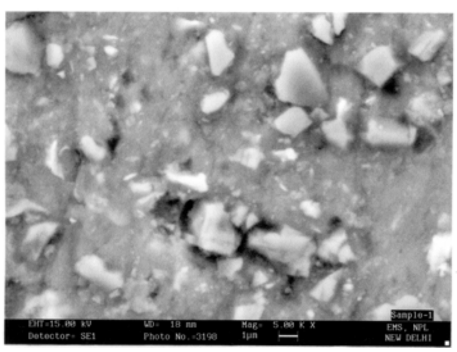

Figure 4. Scanning electron micrograph of specimen 6(a)

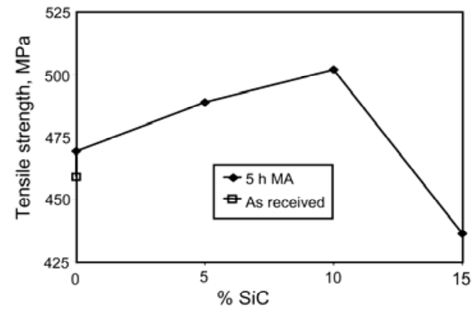

Figure 5. Tensile strength vs. % SiC

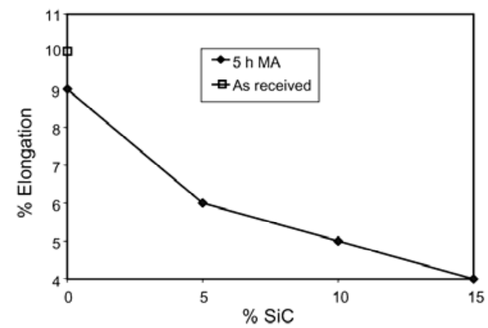

Figure 6. % Elongation vs. % SiC

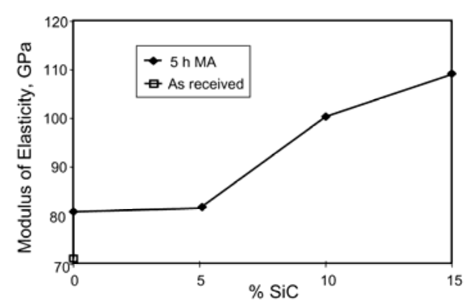

Figure 7. Modulus of elasticity vs. % SiC

Mechanical Properties

(a) Effect of amount of SiC:

Effect of variation of percentage of SiC_p on tensile strength, % elongation and modulus of elasticity are shown in Fig. 5, 6 and 7, respectively**.** These plots show that with the increase in percentage of SiC_p reinforcement, there is a significant increase in tensile strength and modulus of elasticity. It is also evident that percentage elongation decreases drastically.

The improvement in the tensile strength and modulus of elasticity with decrease in percentage elongation can be attributed to the nano sized oxide and carbide dispersion, nano grain size, high dislocation density and substructure in the MA processed composites. As expected, the tensile strength of all the composites has significantly increased for the composite with $SiC_{p\geq}$5wt%. The weight fraction of the SiC particulates was found to have a significant effect on the tensile properties of the composites. Tensile strength started to decrease beyond about 10 wt.% SiC_p. The tensile strength started to decrease at higher SiC_p contents, mostly due to the increased amount of clustering. Also the presence of hard and non-ductile particles limited the deformation to a zone comprised between these particles and resulted in a globally small ductility in the composite.

(b) Effect of variation of mechanical alloying hours:

Effects of variations of mechanical alloying hours on tensile strengths, % elongation and modulus of elasticity are shown in Fig. 8, Fig. 9 and Fig. 10, respectively. These plots clearly show improvement in the tensile strength and modulus of elasticity with decrease in percentage elongation of the composite, with increasing duration of MA. This is mainly due to the addition of increasing amount of contamination from the mill with the increasing processing duration.

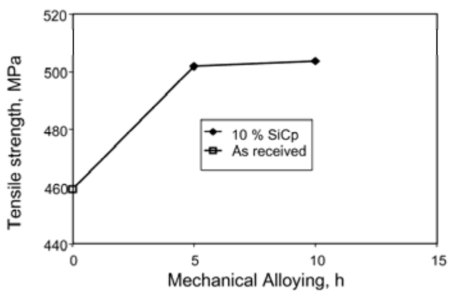

Figure 8. Tensile strength vs. hours of mechanical alloying

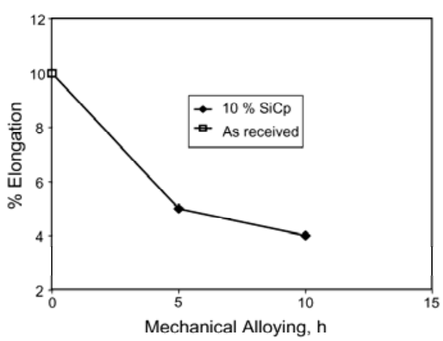

Figure 9. % Elongation vs. hours of mechanical alloying

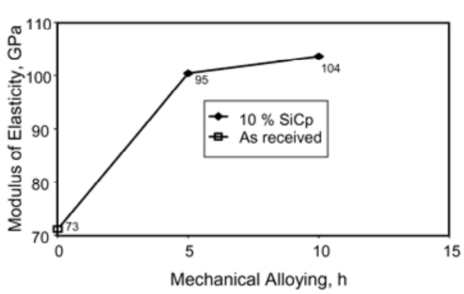

Figure 10. Modulus of elasticity vs. hours of mechanical alloying

Conclusions

1. Mechanical alloying resulted in nanograin structure with a homogeneous distribution of fine SiC particles in 2024 P/M Al alloy matrix.
2. Significant improvement in tensile strength (504MPa) and modulus of elasticity (104MPa) of 2024 P/M Al alloy matrix took place due to dispersion of SiC_p by the MA technique, whereas it significantly decreased the percentage elongation (4%).
3. The addition of 10 wt% SiC_p in 2024 P/M Al alloy and 10 hours of mechanical alloying resulted in the best combination of mechanical properties in the composite.

All these conclusions make 2024 Al alloy-SiC_p composite processed via MA technique a better choice for aircraft and automotive industry.

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