

STRUCTURE AND PROPERTIES OF MECHANICALLY ALLOYED COMPOSITE MATERIALS FROM HARD-RECYCLING SCRAP OF Al ALLOYS

M. Samoshina, A. Aksenov and E. Kaevitser

Moscow State Institute of Steel and Alloys (Technical University), 4 Leninsky prosp., Moscow, 119049, Russia

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Abstract. The structure and phase composition of dispersion-strengthened composite materials based on the Al–Mg system at various stages of mechanical alloying were studied by the methods of optical and scanning electron microscopies, electron probe microanalysis and X-ray diffraction analysis. A possibility of the efficient use of commercial scrap of Al alloy chips and initially large strengthening ceramic particles as the base of composite materials was shown, as well as a possibility of synthesis of strengthening particles. These materials resulted in a homogeneous dispersed structure after mechanical alloying.

1. INTRODUCTION

Mechanical alloying is one of the most modern and promising techniques for producing metal composite materials (CM). It has an unsurpassed potential of affecting the structure and properties of dispersion-strengthened composite materials produced on various systems [1–3].

One of the major limitations that restrain the propagation of the method is that the process is rather expensive. Based on the analysis of the literature and extensive research done in our earlier works [4,5], we revealed ways of reducing the cost of the mechanical alloying process. The major of them is the use of cheap initial charging materials such as scrap and waste of metal working industry as the matrix. It is known that chips have the largest fraction (about 40%) in industrial aluminium waste. This type of waste recovering by conventional methods (remelting) is not economically advantageous because of high melting loss especially for Mg-containing alloys.

The use of low-grade oxidized and mixed scrap such as turning and cutter chips would make it

possible to return low-grade and hard-to-recycle materials to production. It would also enable reverting its disadvantage – contamination with impurities and oxide formations – into an advantage.

2. EXPERIMENTS

Dispersion-strengthened materials were obtained by mechanical alloying from commercial chips of aluminum alloy Al-6% Mg-0.7%Mn-0.3%Fe. The chips used were free of moisture and grease. Before treatment the chips were previously grinded to particles less 5000 μm in size.

The composite materials were obtained using the following two methods.

The first method included the combined treatment of the large particles of matrix alloy and strengthening particles (20 vol.%) in a Gefest 11-3 planetary mill in sealed containers with quasi-cylindrical milling bodies in an argon atmosphere for 1–2 h. The ratio of the weight of the milling body to that of the mixture was 6:1. Powdered α -SiC (particle size, 10 μm) was used as strengthening particles.

Corresponding author: M. Samoshina, e-mail: samoshina@list.ru

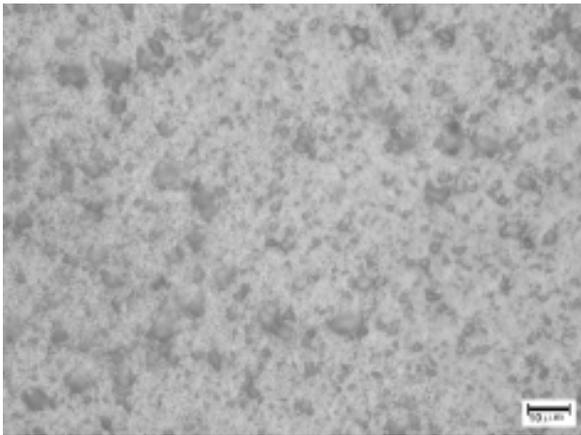


Fig. 1. Structure of compacted specimen (Al-6% Mg-0.7%Mn-0.3%Fe)-20 vol.% SiC after 2 h treatment in planetary mill.

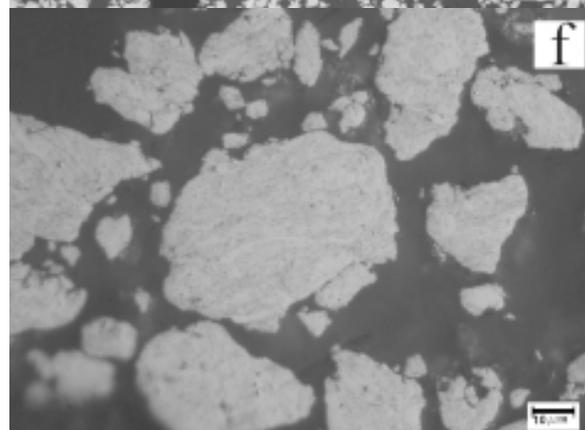
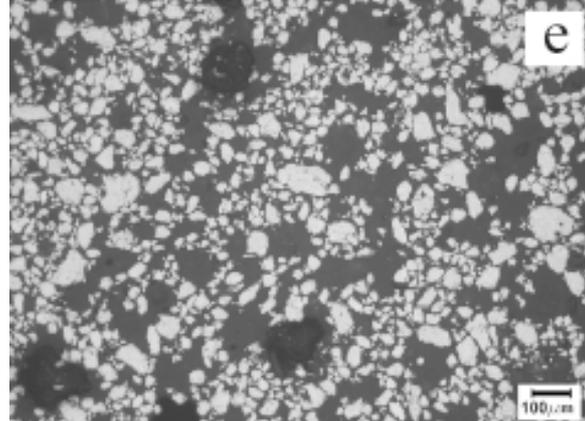
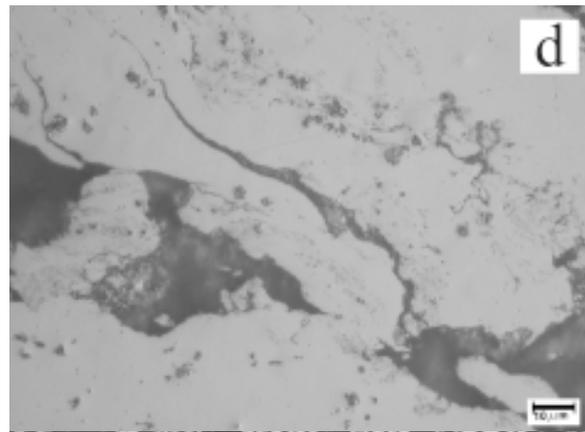
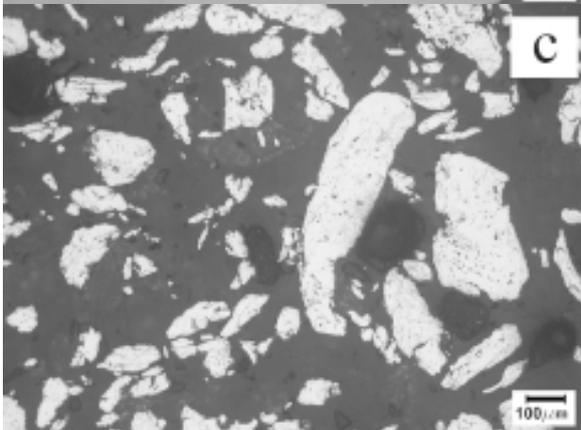
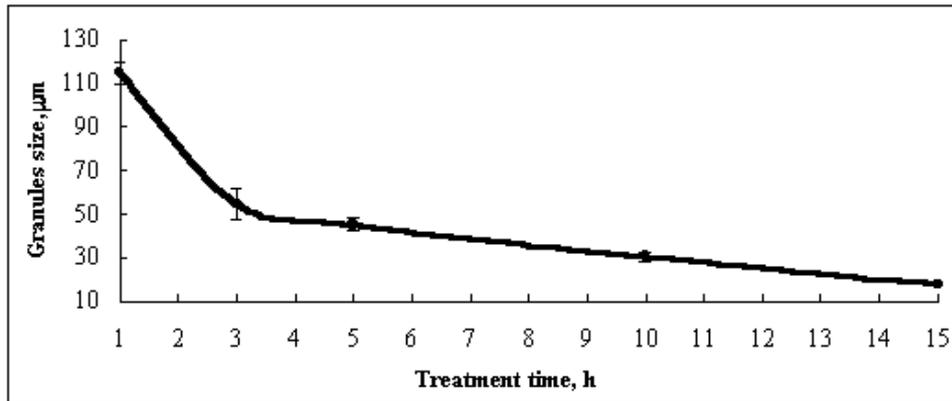
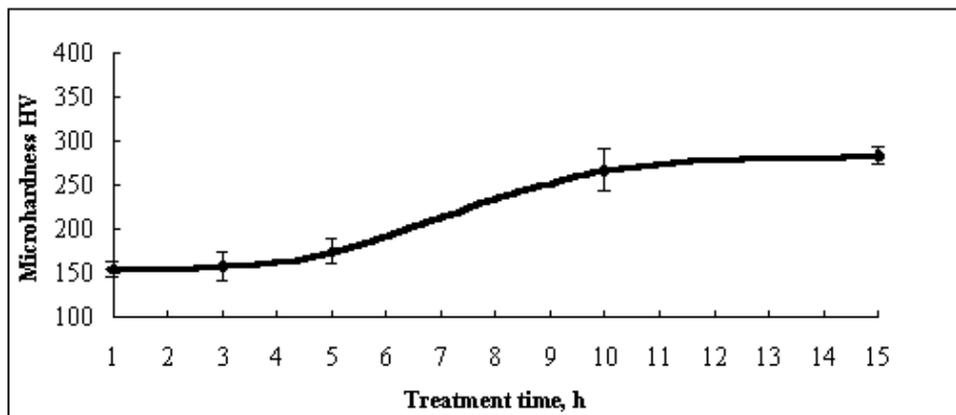


Fig. 2. Structure of granules of (Al-6% Mg-0.7%Mn-0.3%Fe)-O after treatment in vibration mill: a, b – after 1 hour; c, d - after 5 hours; e, f – after 15 hours. Optical microscopy.

Table 1. The data of X-ray photoelectron spectroscopy.

Treatment time, h	Al-O/Al, %	Al ₂ O ₃ , at. %	Mg-O/Mg, %	O, at. %
1	20	25	80	29,1
15	38	50	100	38,8

**Fig. 3.** Dependence of the size of granules of the composite material (Al-6% Mg-0.7%Mn-0.3 %Fe)-O vs the time of treatment in a vibration mill.**Fig. 4.** Dependence of the microhardness of granules of the composite material (Al-6% Mg-0.7%Mn-0.3%Fe)-O vs the time of treatment in a vibration mill.

The second method of producing a composite material with the same aluminium matrix is that the strengthening particles were not put into the initial charge mixture, but were formed as a result of spontaneous and intensive oxidation of aluminium and magnesium of the matrix alloy in contact with air. In this case, the treatment was performed in an SmV-0.005 vibration mill with constantly replenished air for 1–15 h. The charge was milled by steel balls 12.5 mm in diameter; the ratio of the weights

of the balls to those of the charge was 30:1; vibration frequency, 30 Hz.

Granules of the composite materials (Al-6% Mg-0.7%Mn-0.3%Fe)-20 vol.% SiC and (Al-6% Mg-0.7%Mn-0.3%Fe)-O were used to produce consolidated cylindrical specimens 15 mm in diameter and 10 mm in height by double-action compaction at 400 °C. Metallographic studies were carried out at an optical (NEOPHOT-30) and scanning electron (JSM-35CF) microscopes. Electron probe mi-

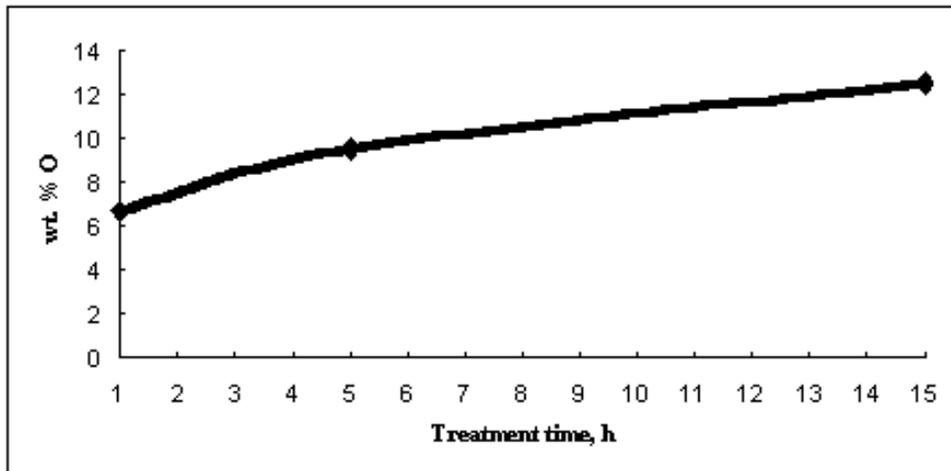


Fig. 5. Dependence of the oxygen content in the composite material (Al-6% Mg-0.7%Mn-0.3%Fe)-O vs the time of treatment in a vibration mill in an air atmosphere (data by electron probe microanalysis).

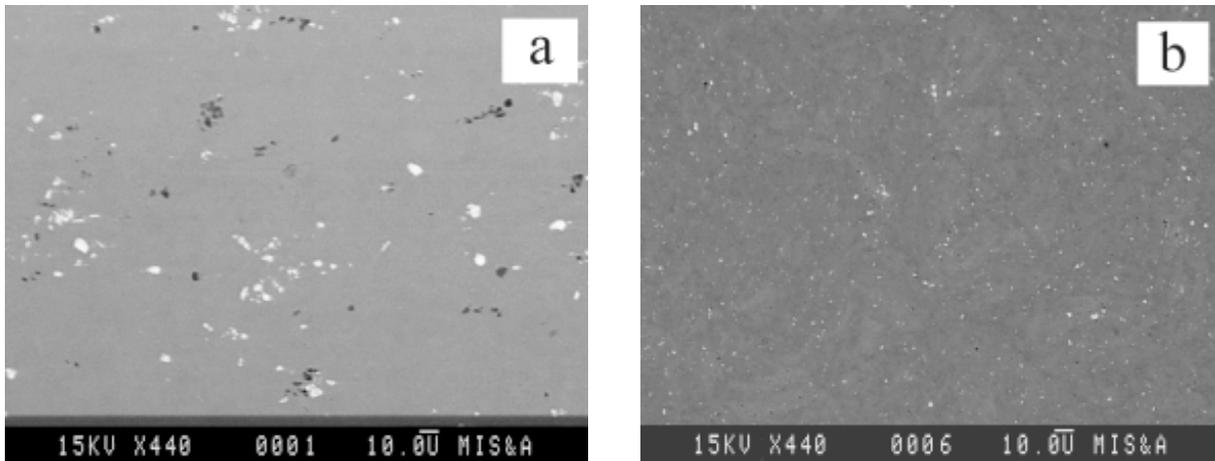


Fig. 6. SEM microstructure of chip particle (a) and compacted specimen of (Al-6% Mg-0.7%Mn-0.3%Fe)-O (b) after 15 h treatment in vibration mill.

croanalysis was done by Camscan-44 scanning electron microscope (Link ISIS-2001L). The phase composition was studied and the size of the coherent scattering regions of CM aluminium solid solution was examined by X-ray diffraction analysis. The analysis was carried out in monochromatized $FeK\alpha$ radiation. Hardness was assessed in the Vickers hardness test.

3. RESULTS AND DISCUSSION

The experiment to produce the composite material by the first method is based on our earlier works which have shown a possibility of using secondary raw materials to obtain quality composite materials [6]. Commercial waste was first used in this work.

Fig. 1 presents the structure of a compacted specimen of the composite material (Al-6% Mg-0.7%Mn-0.3%Fe)-20 vol.% SiC after a 2-h treatment in a planetary mill. After 2 h treatment the uniform distribution of SiC particles was assumed. The average size of strengthening ceramic particles after this treatment was less than 1 μm .

The material (Al-6% Mg-0.7%Mn-0.3%Fe)-O (the second method) was treated in a vibration mill for 1–15 h in a controlled air atmosphere. The consumption of air supplied to the system (V_{air}) was 0.4 m^3/h . The change in shape and size reduction of the granules of the composition material (Al-6% Mg-0.7%Mn-0.3%Fe)-O can be seen in Fig. 2. The particles of the material formed were greatly refined in the course of the treatment resulting in a

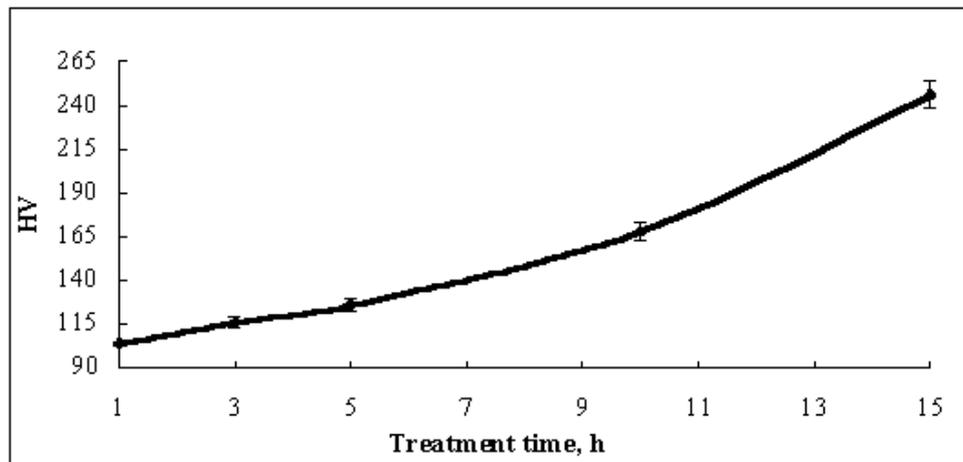


Fig. 7. Vickers hardness of compacted specimens versus milling time.

nearly equiaxial shape. Their microhardness increased with milling time (Figs. 3 and 4). An increase in the microhardness is due to a larger amount of oxide particles in the matrix (see the data of [7]), and also to an increased strain hardening with time of treatment. Compacted specimens of the composite material (Al-6% Mg-0.7%Mn-0.3%Fe)-O were subjected to electron probe microanalysis to determine the content of oxygen. The amount of oxygen was found to increase with milling time (Fig. 5). X-ray analysis failed to reveal oxide particles, showing their amorphous structure as obtained in our earlier works [7]. The investigation of oxygen bond with aluminium and magnesium was carried out by X-ray photoelectron spectroscopy (see Table 1). Aluminium appeared in two chemical states: in unbound state and in oxide after treatment. In specimen treated for 15 h magnesium appeared only in the form of oxide MgO. After 1 h treatment the insignificant amount of magnesium exist in unbound state.

Fig. 6 presents the microstructures of initial material (chip particle) and compacted specimen of the composite material (Al-6% Mg-0.7%Mn-0.3%Fe)-O after final treatment time. After final time treatment the uniformly distributed Fe-containing particles are seen in the microstructure. We estimated the size of the coherent scattering regions of aluminium solid solution, which corresponds to the size of grains or subgrains in the material. The size of coherent scattering regions before compaction was about 30 nm. Heating during the compaction led to an approximately two-

fold increase in the coherent scattering region size, which is due to the recovery processes. Fig. 7 is a plot of the Vickers hardness of compacted specimens versus treatment time. The hardness of the materials increased up to 250 HV with increasing time of treatment. This is, probably, due to the increase in the amount of strengthening oxide particles, reaching the values close to those of the composite material (Al-6% Mg-0.7%Mn-0.3%Fe)-20 vol.% SiC, obtained with a planetary mill. For comparison, the hardness of alloy Al-6% Mg-0.7%Mn-0.3%Fe obtained by conventional methods is about 80 HV. The decrease in the hardness of the compacted specimens as compared with that of the granules (Fig. 4) is explained by the increase of the size of the coherent scattering regions, as well as the decrease of imperfection produced during the compaction.

Both methods of producing dispersion-strengthened composite materials led to obtain the material with uniform distribution of strengthened particles. However, fine oxide particles 40-60 nm in size [7] enable using (Al-6% Mg-0.7%Mn-0.3%Fe)-O material in sliding friction conditions. Thus, mechanical alloying is applicable for recycling system and allows producing new materials with properties different from those of conventional alloys.

4. CONCLUSIONS

1. The possibility of producing the composite material (Al-6% Mg-0.7% Mn-0.3% Fe)-20 vol.% SiC by combined treatment of matrix alloy chip's

particles and SiC particles in a planetary mill in an argon atmosphere was shown. Mechanical alloying led to the formation of the homogenous structure with uniformly distributed SiC particles less than 1 mm in size.

2. The possibility of producing the composite material (Al-6% Mg-0.7% Mn-0.3% Fe)-O by treatment matrix alloy chips in a vibration mill in an air atmosphere with a controlled air supply is shown. The increase of mechanical alloying time results in the increase of the amount of oxygen in CM granules. In accordance with this, the strengthening oxide particles were found to be synthesized in the aluminium matrix. It was found that the full oxidation of magnesium and the partly oxidation of aluminum occur after 15 h treatment

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