Processing and characterization of Al-Mg-Si based Composites Reinforced with Steel

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Abstract The aim of this paper was to experimental study of obtaining composites with Al-Mg-Si alloy as matrix reinforced with steel in two versions: steel strip of 0.3 mm thick and steel wire (Φ 0.8 mm). The composites was prepared in an induction furnace at 700-740^{o}C. The casting semi-products composites were than hot-rolled (plastic deformation temperature was 460^{o}C) and heat treated (solution treated at 500^{o}C for 60 minutes and quenched in water (30-50^{o}C) followed by artificial ageing at 175^{o}C for 300 minutes. The obtained composite materials were analyzed in terms of optical microstructure, the mechanical characteristics (R_m, $Rp_{0.2}$, A_{10}) .After optical microstructural analysis we didn't observe any inclusions or oxides at matrix-reinforcement interface or any cracking after plastic deformation. The best mechanical characteristics was obtained for Al-Mg-Si/ steel wire composites (we registered an improvement of $Rp_{0.2}$ with 38% and of Rm by 23% in comparison with un-reinforced matrix).

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1. Introduction

Early in 1880's, the copper was the first metal used for transmission of electrial power or in the other electrical application. The higher price of copper materials required replacing of it with a metal or alloys which have in principal a good conductivity. These materials were and still are aluminum and its alloys, which have about 60 % from copper conductivity. The lower electrical conductivity of the aluminium in comparison with copper it is compensated by the lower density and cost. [1-4].

But these electrical characteristics can be also improved from especially mechanical point of view by reinforcing the aluminum alloy with steel, B, SIC, C, etc., and obtaining a non-conventional material, known with the name composite[5]. The performances of a composite material depend on the quality of matrix and reinforcing elements and also depend on very good adhesion/bonding at reinforcement-matrix interface. These required properties of new material are given by good selection of components (matrix, reinforcement elements) and selection of fabrication technique in correlation with material destination [5].

The good electrical and thermal conductivity associated with good mechanical stability and corrosion resistance, characteristics of Al-Mg-Si system, make it a good candidate as matrix for aluminum based composites used in electrical industry. At selection of reinforcement, we took into account the specific characteristics /cost ratio. Due to the plasticity of steel [6], and his good price (in comparison with silicon carbide or carbon fibre), steel was choused as reinforcement.

The Al based composite reinforced with steel wire can be used for electrical equipment of underground and rapid trains, or as overhead conductors for power transmission and distribution [3, 4, 7].

A particularity of this composite is that can be achieved by all known methods of composites processing route, methods classified in function of aggregation state of matrix in the processing route: the solid-phase fabrication methods (diffusion bonding, hot rolling, extrusion, explosive welding, [8, 9], Powder Metallurgy (P/M) route [10, 11], the liquid-phase fabrication methods (liquid-metal infiltration, squeeze casting, compocasting, pressure casting, spray co-deposition, stir casting, continuous casting etc. [12-15] and two phase (solid/liquid) processes (Rheocasting [16] and Spray atomization [17]).

2. Experimental works

2.1 The fabrication of Al-Mg-Si alloy used as matrix

The manufacturing processing of Aluminum Matrix Composites was made by liquid-phase fabrication methods and in this case we use as matrix, the Al-Mg-Si foundry alloys, due to the high fluidity, shrinkage and small tendency to cracking. For most aluminum alloys, at manufacturing we follow obtaining a higher energy efficiency, an effective protection against gases and metal contamination during casting to be as small as you can. Raw materials used: primary technical aluminum (basic component), according to Romanian standard STAS 7607-1/80, technical magnesium, Al-24.2Si prealloy and the fluxing agents, called GAL2, with the roll of reducing the viscosity of the slag, which the composition is following: 75% $Cl_6C_6H_6$, 10% KBF_4, 13% H_3BO_3.

Technological characteristics of the used Al-24.2Si prealloy are: 12-25% and input temperature of alloying elements: 800-900°C, the casting temperature is 750-800°C and the melting point: 650-700°C. The calculation of the charged load was done from chemical composition prescribed and from composition charged load.

Al-Mg-Si alloy was obtained in the crucible induction furnace with graphite crucible at 700-740°C temperature. Temperature was controlled with a "cromel – alumel" thermocouple. The charged weight was 6.522 Kg.

After elaboration of matrix materials these was chemical analyzed. The chemical composition was determined using Optical Emission Spectrometers equipment in the Ferrous and Non-ferrous Alloys Laboratory, Faculty of Materials and Mechnical Engineering, Valahia University of Targoviste.

Chemical compositions after preparation of the alloy Al-Mg-Si was 1% Mg, 0.6% Si and Al balance, according to standardization values.

Two metallurgical charges were prepared:

- Aluminum alloy reinforced with steel wire;
- Aluminum alloy reinforced with the steel sheet.

2.2 Elaboration of Al-Mg-Si/steel composite

We used a steel wire with ϕ 0.8 mm in diameter and a sheet steel 0.3 x185x270 mm size.

Chemical compositions of wire and sheet steel are given in Table 1.

Table 1. Chemical compositions of wire and sheet steel

Material Type / Chemical Compozition, %	Steel Wire	Steel Sheet
C	0.21	0.86
S	0.045	0.013
Mn	0.33	0.41
Si	0.054	0.21
P	0.052	0.018
Fe	balance	balance

In steel band were practiced holes with ϕ10mm in diameter and degreased with acetone (Fig. 1). Steel wire was performed by cutting support in the middle of a steel table. Were made holes, with 3 mm in diameter, on two sides of the support, in order to introduce steel wires. The number of wires (reinforcement in the longitudinal direction) was 18 (9 pairs). Execution and settlement support wire is shown schematically in the Fig. 1 b).

The mold cavity (10x155x250 mm dimensions) was painted inside with a graphite emulsion and heated to cca.200°C. The two wire supports and the three sheets were degreased with acetone in the assembly before casting their device).

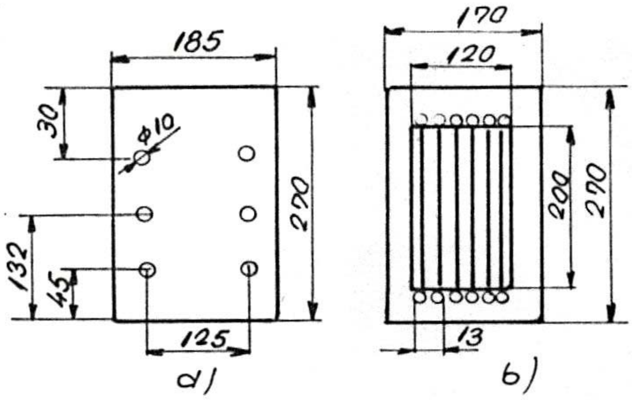


Fig. 1 Schematic presentation of reinforcement a) steel sheet; b) support with steel wires.

2.3 Casting processing of semi-finished composite

For casting were prepared two charges: Al-Mg-Si / steel wire with dimensions 20.5x155x250mm and the second one, Al-Mg-Si / steel sheet, with 21x155x250mm in size.

The two composite charges were pouring at about 720°C temperature. Were cut the excess metal with defects of obtained semi-finished parts and were sampled from each type of composite in order to characterize them. After these operations the composite materials reached at following dimensions: 20x90x110mm for the composite reinforced steel wire and respectively 20x45x130mm for the composite reinforced with steel sheet. Semi-finished composite obtained were heated in a furnace room (180 x 380 x 120mm) with bars (EKL – SIC type) at installed power of 3KW. Heating temperature was 470°C and maintenance during the heating was 90 min.

Hot rolling was performed on duo reversible rolling mill, with rolls of 80mm diameter and 200mm length work surface. Hot plastic deformation temperature was 460°C. Hot rolling scheme of semi-finished cast composite is given in Table 2.

Final dimensions obtained were 3 x 95 x 975 mm for semi-finished composite reinforced with steel wire, and final dimension for composite reinforced with steel sheet was 3 x 45 x 1180 mm.

From each type of these composite materials were taken sampled in order to characterize them to characterize them in rolled state. We applied specific heat treatments on aluminum based composites. There were made two lots of samples for both types of composite materials.

The first lot of samples has underwent an annealing temperature T = 400°C with maintenance for 180 min and cooling in air. The second lot was solution treated at 500±5°C for 60 minutes, quenched in water (30-50°C) and followed by artificial aging at 175oC for 300 minutes. The annealing and heat treatment samples were performed in a heat treatment furnace and aging was carried out in oven.

Table 2. Hot rolling scheme of semi-finished cast composite.

No. of switches for rolling	Entry thickness[mm] in mill of the semi-finished composite		Exit thickness[mm] in mill of the semi-finished composite	
	steel wire	steel sheet	steel wire	steel sheet
1	20.5	21	12	13
2	12	13	7	8
3	8	8	3.7	3
1-3	20.5	21	3.7	3

No. of switches for rolling	Section reduction rolling mil			
	[mm]		[%]	
	steel wire	steel sheet	steel wire	steel sheet
1	8.5	7	41.5	38
2	5	7	41.6	38.5
3	4.3	4,3	53.8	62.5
1-3	16.8	18	82	85.7

3. Experimental results and interpretation

3.1 Metallographic investigation

We have analyzed at the optical microscope NEOPHOT 2 type six samples in cast state (three samples of each type of composite) and a total of 17 samples in rolled state from which 11were from the composite reinforced with wire and 6 samples from composite reinforced with steel sheets (Figs. 2-5). The preparation of specimens was classical made: a) abrasive cutting at 2-3 cm height with cooling liquid for minimize damage and no alter the microstructure; b) planar grinding with different granulations of very brittle materials (on silicon paper with 70µm, 15µm and 9 µm grit size), required to planarize the specimen and to reduce the damage created by cutting. After each grinding the specimens was ultrasonic cleaning in ethylic alcohol 4-5 minutes; c) polishing with Pellon Pads in Al_2O_3 suspension and finally, when we want to analyze the structure in etching conditions: d) chemical etching with reactive Tucker (15% HF, 45% HCl, 15%HNO3, 25%H2O).

In Fig. 2 we observed the oxide at the interface. In Fig. 4b at high magnification (x 800) we observed the presence of very fine oxide film. In figure 5, we see specific compounds of Al-Mg-Si alloy (for example Mg_2Si, Mg_5Al_8) and good contact aluminium alloy and steel at the interface.

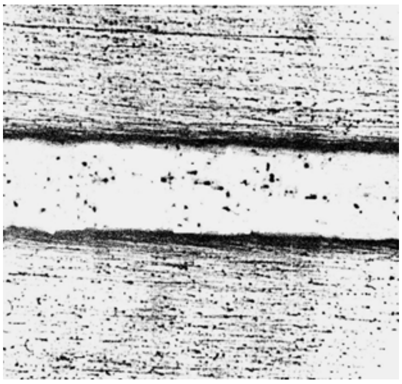
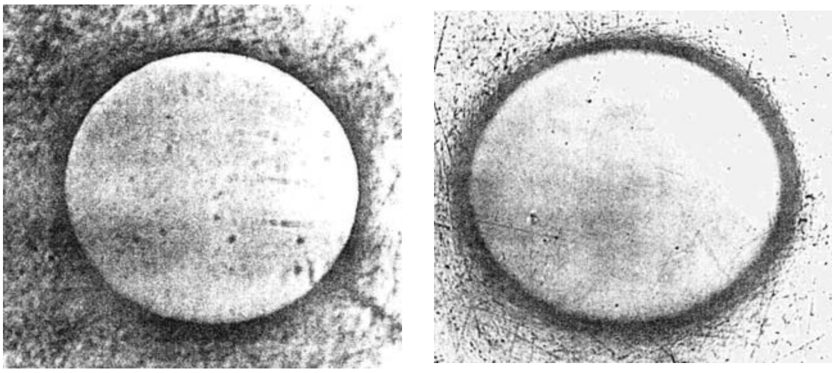
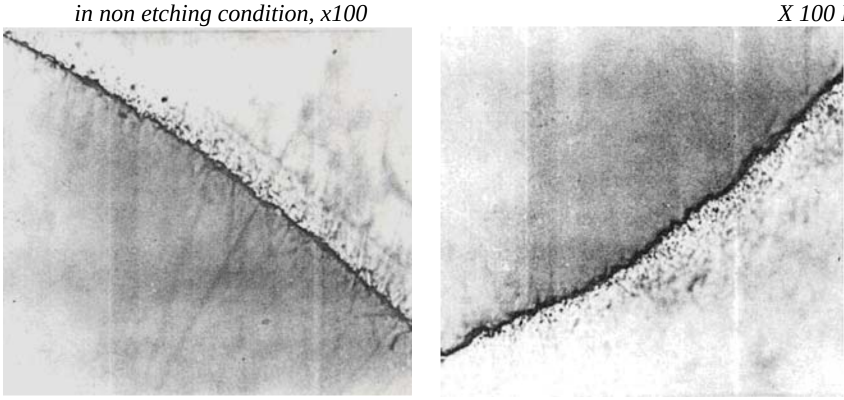


Fig. 2 Characteristic appearance of contact areas between carbon steel sheet and Al-Mg-Si in cast state on samples, in non etching condition, x100



(a) (b)
Fig 3 The characteristic aspect of the contact areas of carbon steel and Al-Mg-Si matrix on not-etched samples: (a) in cast state, (b) laminate state X 100 Magnification



(a) (b)
Fig 4 The magnification of the contact areas of carbon steel wire and Al-Mg-Si matrix on not-etched samples: (a) in cast state, (b) laminate state X 800 Magnification

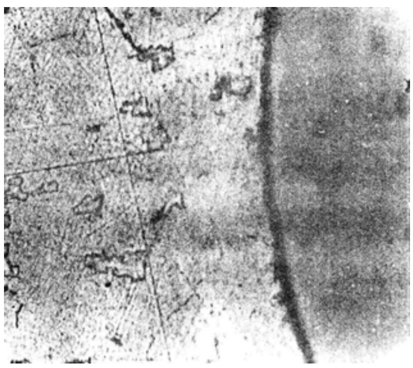


Fig. 5 The evidence of microstructure at etched conditions with reactive Tucker, x 800 Magnification

3.2 Mechanical characteristics

The superiority of composite material properties in comparison with the component elements was revealed by determining the mechanical characteristics of rolled composite in comparison with similar obtained values of the alloy which is constituting the matrix.

Tensile strength Rm, yield Rp0,2 and elongation A10, in annealed state (O) and in heat treated state TF (solution treated, quenched in water + artificial aging) are shown in Fig. 6. We note A- aluminum alloy (AlMgSi) unreinforced, B (AlMgSi/steel sheet), C1-AlMgSi/steel wire no.1, C2-AlMgSi/steel wire no. 2. In Fig. 6 we observed that tensile strength and yield strength increase by reinforcing of AlMgSi alloy with steel wire reinforcement and steel sheets respectively, and elongation decreases.

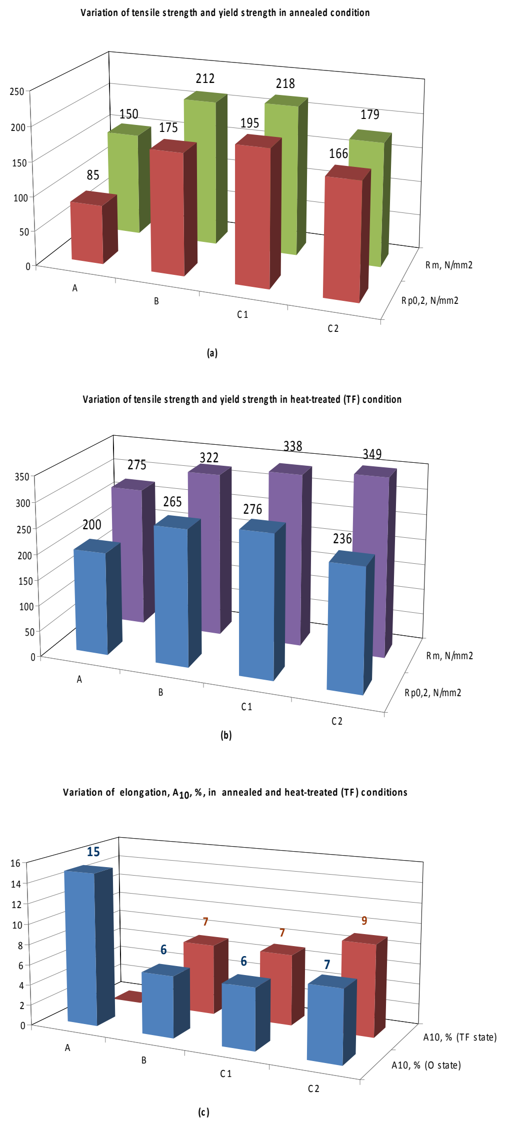


Fig. 6 Mechanical characteristics variation of composites in comparison with un-reinforced matrix: (a) tensile strength and yield strength in annealed (O) condition and (b) tensile strength and yield strength in heat-treated TF condition; (c) variation of elongation in respectively the annealed state and heat treated state.

3.3. Determination of specific adhesion strength of composite material components Al-Mg-Si/ Sheet steel

The specific adherence is one of the primary importance characteristics of laminated composite materials. The best known methods for determining adherence are: bending, tension, shear or bond separation. For Al-Mg-Si composite / steel sheet or band has been used the bending method in laminate state. Composite thickness of 3 mm was bent on a mandrel diameter d = 6 x a.

The minimum diameter that should not happen catching of a plated layer should not exceed 30-50% in bending area. After bending, we have not found separation or bending of the matrix.

4. Conclusions

In the optical microscope analysis were not reported at the interface oxide inclusions or other nature and also we not seen cracking of the matrix during plastic deformation. In general it was found that the composites reinforced with wire, does exist an investigated intimate contact areas steel wire and matrix between (Fig.2-5). The composites reinforced with the sheet after the casting was a partial grip due to the formation of a very small layer of oxide. Rolling adhesion depends to the melting temperature on the components and working conditions during lamination (temperature, pressure and rolling speed).

A good adhesion resulted from the combination of matrix mechanics made by pressing soft surface roughness of hard reinforcement (favored by the fragmentation of oxide film at high pressure rolling) and in combination to grain boundary due to inter-atomic diffusion phenomena occurring in contact areas between the two metals.

These phenomena are explained as follows: there are defects in the peripheral layers of the crystalline structure (vacancies, dislocations, etc.) and cracks, which implies more energy available than in deeper areas and thus a thermodynamic instability in their terms. Decreasing of thermodynamic potential and of free energy occurs during the process of diffusion or at thermal and mechanical influences that accompany the reduction surface. Higher speed on which the rolling process occurs allows a shortly contact and a high temperatures between components of composite, and resulting in high tension and friction forces that favor breaking the tape or wire and thus favoring the reinforcing steel (sheet or wire) breakage.

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