Surface modification of aluminium alloys using hybrid treatment techniques

P Petrov
Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences,
72, Tsarigradsko Chaussee, 1784 Sofia, Bulgaria
E-mail: pitiv@ie.bas.bg

Abstract. The application of electron and laser beams to the modification of metal and alloys opens up new possibilities of improving the materials properties. In recent years, the studies aimed at developing new materials have brought about the development of hybrid treatment techniques. These techniques perform an additional alloying in the zone treated, which has a substantial effect on the physical and mechanical properties of the materials processed. In this work we report results on the microstructural changes and mechanical properties of heat-treated AlSi12CuNiMg alloys resulting from additional alloying with Fe, Co, Ni, Cr by hybrid electron-beam techniques. It is established that the mechanical properties of Al-Si alloys can be improved by means of additional alloying with Fe, Co, Ni, Cr by hybrid electron-beam techniques. The specimens’ properties practically do not change after heat-treatment (aging) for up to 200 hours at 250 °C.

1. Introduction
Using electron beams to modify metals and alloys offers new possibilities of improving the materials properties [1-2]. The processes of surface modification of metals and alloys can be roughly divided into two groups depending on whether the electron beam acts on the material in a solid or in a liquid phase. Both types of techniques have found practical applications. In recent years, the studies aimed at developing new materials have resulted in the development hybrid treatment (HEB) techniques that perform an additional alloying in the zone treated, thus affecting substantially the physical and mechanical properties of the materials processed [3-7].

In this work we report results on the changes of the microstructure and the mechanical characteristics of heat-treated Al-Si alloys resulting from additional alloying with Fe, Co, Ni, Cr by HEB techniques.

2. The process of electron-beam hybrid treatment techniques
The experiment on applying electron-beam hybrid treatment techniques is shown schematically in figure 1. The alloying elements were deposited on the specimens’ surface by plasma spraying in argon atmosphere with the thickness of the layer formed being about 0.1 mm. The experiments were performed on Leybold Hereaus EWS300-15/60 equipment. Electron beam remelting was achieved by scanning electron beam with power $P = 1.5 - 3$ kW, frequency $f = 0.5 - 10$ kHz, amplitude $A = 2 - 5$ mm and sample motion speed $V = 0.5 - 2.5$ cm/sec.
The heat-treated Al-Si alloys used in the experiments reported were AlSi12CuNiMg (wt% - 11.45% Si, 1.25% Cu, 0.96% Mg, 1.41% Ni, 0.38% Mn). The alloying was done using Fe-Cr-Ni-Co powders, Table 1.

Table 1. Chemical composition of the Fe-Cr-Ni-Co powders, wt%.

| Composition | Ni   | Fe   | Co  | Cr  | Si  | B   | C  |
|-------------|------|------|-----|-----|-----|-----|----|
| Ni-Cr       | base | 11.76| -   | 16.30| 3.27| 3.20| 0.23|
| Fe-Cr       | 2.34 | base | -   | 21.69| 3.63| 2.10| 0.88|
| Co-Cr       | 3.33 | 1.2  | base| 22.16| -   | -   | -  |

The starting specimens with dimension of 50×50×18 mm were prepared by bulk thermal processing in the following sequence: (i) homogenization at 505 °C for 4 h and at 515 °C for another 4 h; (ii) water quenching; (iii) aging at 200 °C for 15 h. Prior to the analyses by optical and electron microscopy, the specimens were cut into appropriate pieces and a standard procedure was carried out, which included developing in Keller’s solution and electrode etching. The samples’ microhardness was assessed using a LEITZ measuring instrument with loading force of 1 N. X-ray structural analysis was conducted by DRON-1 facilities with Co-Kα emission. The strength measurements were performed after hybrid electron beam processing, as well as after a furnace heat treatment at 250 °C for up to 200 h.

3. Results and discussion

A transverse cross-section of the samples’ zone treated by the HEB technique at \( P = 3 \text{ kW}, \ V = 2 \text{ cm/s}, \ f = 10 \text{ kHz} \) and \( A = 5 \text{ mm} \) is shown in figure 2a; the longitudinal cross-section is shown in figure 2b. Some defects, such as cracks in the case of alloying with F-Cr powder, are observed in alloyed zone. The microstructure observed is quite different from the initial one, figure 3 and figure 4. Electron beam treatment without alloying results in the formation of an \( \alpha \)-hard solution and a highly dispersed intermetallic compound, as shown in figure 3a, b. The crystallization is of a dendritic nature.

The data of the X-ray diffraction analyses of the layers produced by hybrid electron beam treatment show: (i) Fe-Cr powder - FeSiAl\(_6\), Al\(_3\)Fe, CrAl\(_3\), (CrFe)\(_2\)Si\(_3\)Al\(_13\), (CrFe)\(_2\)Si\(_3\)Al\(_2\) phases; (ii) Ni-Cr powder - NiAl\(_3\), Cu\(_2\)NiAl\(_7\) and (CuFeNi)\(_2\)Al\(_1\) phases and (iii) Co-Cr powder - Co\(_2\)Al\(_9\) and CoCu\(_2\)Al\(_7\), (CoFeNi)\(_2\)Al\(_9\) phases. After heat treatment for 24 h at 250 °C, the alloy’s phase composition in the layer does not change, as proven by X-ray diffraction.

The layer formed following the application of the HEB technique (curves 3, 4, 5 in figure 5) exhibits hardness substantially exceeding that of the base metal (curve 1 in figure 5), as well as that
Figure 2. Transverse cross-section of the alloyed zone (×4) - a; longitudinal cross-section of the alloyed zone (×2) - b.

Figure 3. Microstructure of the treaded zone without alloying (×160): a) near the border with initial material; b) in the remelted zone.

Figure 4. Microstructure of the alloyed zone: with Ni-Cr a)-(×160), b)-(×2500); with Fe-Cr c)-(×160), d)-(×2500).
after electron-beam remelting without alloying (curve 2 in figure 5). Aging for up to 200 hours at 250 °C leads to a decrease of the hardness of all types of layers, especially in the first 24 hours. However, the hardness of the layers subjected to HEB treatment (alloying and electron beam remelting) remains the highest.

Figure 6 shows the variation of the tensile strength $R$ as a function of the type of dopant powder. The highest tensile strength is measured in the treated samples in the case of doping with Co-Cr powders. The results obtained by the microhardness and tensile strength measurements demonstrate the advantages of applying hybrid electron-beam treatment of aluminium alloys as compared with the standard electron-beam remelting. The hardness and the tensile strength at normal and higher temperatures increase due to the higher dispersivity of the structure, the appearance of new structural components and the formation of a stable frame of inter-metallic compounds.

![Figure 5. Microhardness variation during aging for up to 200 hours at 250 °C: curve 1 - base material; curve 2 - after electron-beam remelting; curve 3 - (Ni-Cr), curve 4 - (Fe-Cr), curve 5 - (Co-Cr).](image)

![Figure 6. Tensile strength $R$ after HEB processing: a); RT b) elevated temperature at 250 °C; (1 - base material; 2 – alloying with Ni-Cr; 3 - alloying with Co-Cr, 4 - alloying with Fe-Cr).](image)

**Conclusions**

As a result of the systematic studies carried out, it is established that the mechanical properties of Al-Si alloys can be improved by means of additional alloying with Fe, Co, Ni, Cr by hybrid electron-beam techniques. The specimens’ properties practically do not change after heat-treatment (aging) for up to 200 hours at 250 °C.

**References**

[1] Schiller S and Pancer S 1988 *Ann. Rev. Mater. Sci.* **18** 121
[2] Surla V and Ruzic D 2011 *J. Phys. D: Appl. Phys.* **44** 1740
[3] Petrov P and Dimitrov D 1993 *Vacuum* **44** 857
[4] Petrov P *Vacuum* **1997** 48 49
[5] Zhou Q 2001 *Ordinance Mater. Sci. Eng.* **24** 28
[6] Song R, Zhang K and Chen G 2002 *Surf. Coat. Technol.* **157** 1
[7] Dalke A, Buchwalder A, Zenker R and Biermann H 2009 *Int. Heat Treatm. Surf. Eng.* **3** 147