STRUCTURE AND PROPERTIES OF Al-TM-Ce ALLOYS

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Abstract
Rapidly solidified alloys based on a aluminium - transition metal (TM) system are promising structural materials. They are noted for good mechanical properties and excellent thermal stability, which are caused by very fine nanostructure of these materials and even by a presence of nonequilibrium intermetallic phases. The influence of quenching rate and Ce addition on properties of AlCr5.5Fe3Ti1.5 prepared by melt spinning method were studied in this work. It was proved that at high quenching rate a quasicrystalline phase is formed, at low quenching rate a Al\textsubscript{13}Cr\textsubscript{2} stable phase is formed and middle quenching rates lead to formation of both of these phases. The addition of Ce changes phase composition of the alloy but any influence of Ce addition neither on hardness nor on thermal stability of the alloy was documented.

KEYWORDS: Aluminium alloys, rapid solidification

1. INTRODUCTION

Compact materials prepared from rapidly solidified Al-TM based alloys are very promising structural materials. The main suitable materials are those with more than 80% of aluminium, which is caused by their high strength, good thermal stability and low density. Previous research in Department of Metals and Corrosion Engineering showed good thermal and mechanical properties of Al-5.7 wt.% Cr-2.5 wt.% Fe- 1.3 wt.% Ti alloy prepared by melt atomization by inert gas and consequent hot extrusion [1]. Alloys described in this work have analogous chemical composition but they were manufactured by melt spinning.

Utilization of rapid solidification methods (e.g. atomization by inert gas, melt spinning) can lead to an increase of solubility of alloying elements in matrix, improving materials homogeneity and significantly refining of the materials structure. It is possible to prepare amorphous or quasicrystalline material by these methods, when extremely high quenching rates are used [2]. Above mentioned structural changes are accompanied by many materials properties improvements. Increase of thermal stability is caused by higher solubility of transition metals with low diffusion coefficient in aluminium matrix. Mechanical properties are ameliorated by homogenization and refinement of structure. The last but not least fact is, that presence of quasicrystalline phases prevent grain coarsening in subsequent thermal treatment [3].

It was proven, that adding of few percent of Ce into Al-TM alloy increases the rapid solidification effect and supports formation of ultrafine structure composed of aluminium matrix and quasicrystals [4, 5].
2. EXPERIMENTAL

In this work, alloys with composition of Al-5.5 wt. % Cr-3 wt. % Fe-1.5 wt. % Ti-x wt. % Ce (x = 0; 1.5; 3) were studied. The alloys were prepared by melting of appropriate amounts of master alloys and pure metals (Al-11 wt. % Cr, Al-4 wt. % Ti, Al, Fe and Ce) in induction furnace. Consequently, rapidly solidified ribbons were prepared by melt spinning at cooling wheel velocities of 1000 rpm, 1800 rpm, which correspond to cooling wheel circumferential speeds of 17 m/s, 28 m/s respectively. Microstructure of ribbons was observed in cross section using scanning electron microscope SEM Hitachi S 4700. Phase composition of all materials was determined by X-ray diffraction (XRD) on PAN analytical X Pert PRO + High Score Plus. Intermetallic phases were observed by transmission electron Jeol 3010 (300 kV) equipped by EDS analyser. These phases were extracted from material by selective dissolution of aluminium matrix in reagent composed of 250 g methanol, 25 g tartaric acid and 10 g iodine [13]. Vickers hardness HV 0.005 was measured on the cross section of ribbons.

3. RESULTS AND DISCUSSION

A structural gradient is observed on cross section of rapidly solidified ribbons. No structural constituents can be seen by scanning electron microscope in the ultra-rapidly quenched area, which was in contact with cooling wheel, and this area seems to be homogeneous. This area is placed in the bottom part of Fig. 1 and 2. Increasing distance from cooling wheel causes coarsening of the structure.

In agreement with theoretical expectations, Ce addition resulted in extension of ultra-rapidly quenched area from approximately 5 µm in alloy without Ce, which structure is shown in Fig. 1, to approximately 20 µm in alloy with 3 wt. % Ce, as it is illustrated in Fig. 2. Both these ribbons were prepared at cooling wheel circumferential speed of 28 m/s. The Ce addition lead also to significant refinement of structure in slowly cooled areas of ribbon.

Surprisingly, there were only small differences in materials hardness. The AlCr5.5Fe3Ti1.5 reached the hardness value of 145 HV0.005 and the AlCr5.5Fe3Ti1.5Ce3 alloy has hardness value of 160 HV0.005.
The influence of Ce addition is also evident from XRD patterns. The AlCr5.5Fe3Ti1.5 alloy cooled at 17 m/s contained only Al and Al$_{13}$Cr$_2$ phases. Increasing the cooling velocity up to 28 m/s resulted in occurrence of new quasicrystalline phase as it is documented in Fig. 3. From all recently described phases, this phase exhibits similar structure as a Al$_{80}$Cr$_{20}$ phase.

As it is shown in diffraction pattern in Fig. 4, this phase is formed in AlCr5.5Fe3Ti1.5Ce3 alloy even at lower cooling rate.

In case of this alloy, the increase of cooling rate does not cause any change in phase composition and changes only the phase contents. The Ce was in AlCr5.5Fe3Ti1.5Ce3 alloy present in CeAl$_2$ phase, although in literature is it presence documented in Al$_4$Ce phase [7, 8]. A small amount of Ce stayed not melted. The utilization of Al-Ce master alloys is complicated because of low content of alloying elements in them.

Intermetallic phase, extracted from ribbons prepared at cooling wheel circumferential speed 28 m/s, were observed by transmission electron microscope.

![Fig. 3: XRD pattern of AlCr5.5Fe3Ti1.5 alloy](image1)

![Fig. 4: XRD pattern of AlCr5.5Fe3Ti1.5Ce3 alloy](image2)
Fig. 5 shows irregularly shaped $\text{Al}_{13}\text{Cr}_2$ phase and spherical-shaped quasicrystalline phases extracted from $\text{AlCr}_{5.5}\text{Fe}_3\text{Ti}_{1.5}$ alloy. In the top left corner of Fig. 5, there is selected area diffraction pattern (SAED) of one quasicrystal. The SAED is distinguished by ten-fold symmetry axis, so it is a decagonal quasicrystal. Chemical composition of this quasicrystal is given in Tab. 1. Observed symmetry and chemical composition were in initial expectations that the quasicrystalline phase is close to $\text{Al}_{80}\text{Cr}_{20}$ quasicrystals in which a part of Cr atoms is replaced by Fe atoms. With regard to very close atom ratios of Cr and Fe, the substitution is noted only on intensity of diffraction peaks but not on their position. Accurate structure determination is aim of following research.

### Table 1: Chemical composition of quasicrystalline phases

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Al [at. %]</th>
<th>Ti [at. %]</th>
<th>Cr [at. %]</th>
<th>Fe [at. %]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{AlCr}_{5.5}\text{Fe}<em>3\text{Ti}</em>{1.5}$</td>
<td>84</td>
<td>1</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>$\text{AlCr}_{5.5}\text{Fe}<em>3\text{Ti}</em>{1.5}\text{Ce}_3$</td>
<td>84.5</td>
<td>1</td>
<td>9.5</td>
<td>5</td>
</tr>
</tbody>
</table>

It was also possible to observe $\text{Al}_{13}\text{Cr}_2$ and quasicrystalline phases in the $\text{AlCr}_{5.5}\text{Fe}_3\text{Ti}_{1.5}\text{Ce}_3$ alloy. The other phases were considerably damaged by dissolution of aluminium matrix. To observe these phases, it will be necessary to use samples prepared from the whole alloy.

Transmission electron microscope observations and chemical analyses confirmed the initial idea established on XRD, that quasicrystalline phases in alloy without and with Ce are similar.

### 4. CONCLUSION

The Ce addition into $\text{AlCr}_{5.5}\text{Fe}_3\text{Ti}_{1.5}$ alloy has a significant influence on the refinement of materials structure. It also leads to stabilization of metastable phases. This can be seen as extension of ultra-rapidly quenched area in rapidly solidified ribbons and it causes a formation of quasicrystalline phases at cooling rates which do
not leads to their formation without Ce addition. The influence of Ce addition on materials hardness is negligible.

5. AKNOWLEDGEMENT

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LITERATURE