CHARACTERIZATION OF AL-FE-X RAPIDLY SOLIDIFIED ALLOYS

Alena MICHALCOVÁa, Dalibor VOJTĚCHA, Pavel NOVÁKA, Milena VODĚROVĀ, Ivo MAREKA, Peter ŠVECb

aICT in Prague, Praha, Czech Republic, michalca@vscht.cz
bInstitute of Physics Slovak Academy of sciences, Bratislava, Slovak Republic, EU

Abstract

Rapidly solidified aluminium alloys are every promising material because of their low specific weight and good thermal stability. Utilization of rapid solidification processing enables to turn waste aluminium material with high iron content into valuable material. The aluminium-iron rapidly solidified alloys are well known. They exhibit good mechanical properties but their thermal stability is very limited. It is possible increase the thermal stability by alloying with third element for example chromium. In this work, the influence of Cr to Fe ration on properties of rapidly solidified alloys was studied. The ribbons of rapidly solidified alloys were prepared by melt spinning method. The structure was also studied in transmission electron microscope. The phase composition was studied by X-ray diffraction and the microhardness of rapidly solidified materials was measured. The formation of quasicrystalline phase Al80(Cr,Fe)20 was observed.

Key words:
Rapid solidification, Aluminium Alloys, Quasicrystals

1. INTRODUCTION

Nanostructured rapidly solidified (RS) aluminum alloys are very promising materials for applications in automotive and aerospace industry. Their main advantage is their superior strain-to-weight ratio. Some of the effects of rapid solidification are an increase of the solubility of alloying elements, a refinement of the microstructure, and improvement material homogeneity. It was shown that the ability of TMs to thermally stabilize the alloys depends on their solid solubilities in Al matrix [1]. Maximum solubility of Fe is very low (0.06 wt.% [2]), but solubilities of Cr and Ti are significantly higher (0.67 wt.% and 1.24 wt.% [2], respectively).

The tendency of Al-Fe system to form quasicrystalline phases is well known [3,4]. It was proved in our previous work [5, 6], that the decagonal quasicrystalline Al80(Cr,Fe)20 phase is formed in Al-Fe-(Cr-Ti-Ce) systems. The change of cooling rate influenced the amount of quasicrystalline phase, while the addition of cerium let to increase of thermal stability of the quasicrystalline phase.

In this paper, the influence of increased amount of iron on structure of rapidly solidified alloy (and quasicrystalline phase) is described.

2. EXPERIMENTAL

The alloys with a composition of Al-7%Fe-4%Cr (concentrations in wt.%, unless otherwise stated), denoted as AlCr4Fe7, was studied. Ingot of the alloy was prepared by melting of the appropriate amounts of master alloys and pure metals (Al, Al-11Cr and Fe) in a vacuum induction furnace. Consequently, rapidly solidified ribbons were prepared by melt spinning. Circumferential speed of cooling wheel was 38 m/s. The microstructure of prepared ribbons was examined using a transmission electron microscope (TEM) Jeol JEM 3010. Vickers hardness HV 0.005 was measured on the cross sectioned ribbons using Neophot 2 light microscope equipped by Hannemann microhardness tester. Phase composition of rapidly solidified alloys
and extracted phases was determined by X-ray diffraction (XRD) (PAN analytical X’Pert PRO + High Score Plus, Cu anode).

Properties of AlCr4Fe7 alloy were compared to properties of previously studied AlCr4Fe3Ti1 rapidly solidified alloy prepared at circumferential speed of cooling wheel of 40 m/s in Helmholtz-Zentrum Berlin für Materialien und Energie GmbH

3. RESULTS AND DISCUSSION

The AlCr4Fe3Ti1 and AlCr4Fe7 alloys were prepared under almost similar conditions. It was proven in our previous research, that Ti is present in small amount in all phases. It does not influence phase composition of rapidly solidified alloys, so the structure and properties of AlCr4Fe3Ti1 and AlCr4Fe7 alloys are able to be compared.

![XRD patterns of AlCr4Fe7 and AlCr4Fe3Ti1 alloys](image)

Fig. 1. Phase composition of rapidly solidified AlCr4Fe3Ti1 and AlCr4Fe7 alloys: 1 – fcc Al, 2 – Al_{13}Fe_{4}, Q – quasicrystalline phase Al_{80}(Cr,Fe)_{20}

The rapidly solidified ribbons are formed by fcc-Al matrix and Al_{80}(Cr,Fe)_{20} quasicrystalline phase, as documented in diffraction patterns in Fig. 1. In Fig. 2 and 3, the ball articles are quasicrystalline phases and the light grey matrix belongs to fcc-Al. The AlCr4Fe7 alloy contains also small amount of Al_{13}Fe_{4} phase. This phase is place preferentially along grains boundaries, as can be seen in Fig. 3.
The fcc-Al matrix grain size of AlCr4Fe7 alloy determined by image analysis is shown in Fig. 4. The significant majority of matrix grains have size less than 70 nm.

Fig. 2. Structure of AlCr4Fe3Ti1 alloy (TEM)

Fig. 3. Structure of AlCr4Fe7 alloy (TEM)

Fig. 4. Grain size distribution in AlCr4Fe7 alloy determined by image analyses
The grain size determined by Scherrer calculator from XRD diffraction patterns is given in Tab. 1. The results of grain size by image analysis and by Scherrer calculator are in very good agreement. The fcc-Al matrix grain size of AlCr4Fe3Ti1 alloy cannot be determined by image analyses because of massive quasicrystalline phases particles overlay. The grain size of AlCr4Fe3Ti1 alloy is almost two times smaller than for AlCr4Fe7 alloy. This can be caused by slightly higher cooling rate of this alloy. Surprisingly, the hardness of AlCr4Fe7 alloy is higher, as illustrated in Tab. 1.

**Tab. 1.** Properties of AlCr4Fe3Ti1 and AlCr4Fe7 alloys: average grain size determined by Scherrer calculator, microhardness HV 0.005

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Average grain size / nm</th>
<th>Hardness HV 0.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlCr4Fe3Ti1</td>
<td>37 ± 6</td>
<td>167 ± 6</td>
</tr>
<tr>
<td>AlCr4Fe7</td>
<td>61 ± 11</td>
<td>201 ± 4</td>
</tr>
</tbody>
</table>

The selected area electron diffraction (SAED) patterns of quasicrystalline phases from both alloys are given in Fig. 5 and 6. The patterns are similar (the only difference is rotational). This means that the structure of quasicrystalline phase is similar.

As shown in Tab. 2, also the chemical composition of quasicrystalline phases is comparable. The quasicrystals from AlCr4Fe7 alloy contains higher amount of Fe, which is understandable due to higher Fe amount in the alloy.
Tab. 2. Chemical composition of quasicrystalline phase determined by EDS in TEM, given in wt.%

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cr</th>
<th>Fe</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlCr4Fe3Ti1</td>
<td>78.6 ± 0.2</td>
<td>12.2 ± 0.1</td>
<td>7.6 ± 0.1</td>
<td>0.6 ± 0.1</td>
</tr>
<tr>
<td>AlCr4Fe7</td>
<td>77.1 ± 0.3</td>
<td>12.2 ± 0.1</td>
<td>13.1 ± 0.3</td>
<td>_</td>
</tr>
</tbody>
</table>

CONCLUSION
The rapidly solidified AlCr4Fe7 alloys is formed by fcc-Al, Al80(Cr,Fe)20 quasicrystalline phase and small amount of Al13Fe4 phase localized on grain boundaries. The average fcc-Al matrix grain size is 61 ± 11 nm. It was proven that promising nanostructured material can be prepared from waste aluminium alloys with high Fe content by rapid solidification.

ACKNOWLEDGEMENT
This research was financially supported by Czech Science Foundation, project No. P108/12/G043.

LITERATURE