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Rapidly Solidified Al-Cu-Mg Amorphous and Nanocristalline Alloys

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Abstract
Installation for rapidly solidified ribbons was developed. Three types of Al-Cu-Mg ribbons by the Planar Flow Casting (PFC) method from base alloys $Al_{61}Cu_{33}Mg_6$; $Al_{61,61}Cu_{30,43}Mg_{7,96}$ and $Al_{56,8}Cu_{34,4}Mg_{8,8}$ were obtained. The chemical compositions of the ribbons were determined. Data on the amount of amorphous part and on the phase compositions of the crystalline part were determined by XRD analysis. The amorphous part in the ribbons is in the range 75-98%. The microstructure of the alloys was observed by transmission electron microscopy (TEM). The measured microhardness HV is in the range 4620-5370 [MPa].

Keywords: Al-Cu-Mg, amorphous alloys, nanocrystalline alloys, microstructure, microhardness.

1. Introduction

Recent innovations in metal glass led to the emergence of new alloys, based on at least triple systems and can be grouped into two categories. The first category includes alloys whose volumes can be cooled slowly to a glassy state, which means nucleation-controlled synthesis. The other important category is represented by aluminum and iron glasses, which can be produced by rapid quenched processes, such as melt spinning. These glasses are often called limiting molding glasses, which are produced under kinetic conditions with controlled growth. Glass from both categories of alloys can also be produced by intensive deformation of crystalline multilayer arrays. These developments represent a basic level of control over the microstructure, which affects the structural characteristics and stability [1].
An important characteristic of aluminum and iron-based alloys that can be glazed is that they contain> 80 at.% of the main component and do not have a deep eutectic, which is a common prerequisite for easy glass formation [2]. Factors favoring the formation of glass are large differences in the size of the atom (ie> 12%) [3] of the alloy components and the negative heat of mixing. For amorphous aluminum alloys favorable for the glass formation are multicomponent compositions in which aluminum is (80-92 at.%), rare earth element (RE) (3-20 at.%) and transition metal (TM) (1-15 at.%). It was observed that aluminum alloys often devitrify by nanocrystallization [4]. During this crystallization process, high density (> 1022 m-3) cubic (fcc) Al can form nanocrystals [5]. The formation of nanocrystals can be associated with "hardened" nuclei with an fcc-like structure.
Traditional amorphous aluminum alloys are expensive and this limits their application. The main challenge for scientists today is to obtain new aluminum alloys without rare earth elements with high glass-forming ability (GFA).
The Al-Cu-Mg system was chosen in our research as a base system for obtaining relatively new, not so well-studied alloys, because this system contains used and affordable metals. It is expected that Al-Cu-Mg system will have high GFA and their study will contribute to the in-depth study of the structural relaxation and kinetics of the glass transition.

The aim of the present work is to obtain amorphous or nanocrystalline alloys from the Al-Cu-Mg system and to study their structural and mechanical characteristics.

2. Experiments

2.1. Test materials

Base alloys from the Al-Cu-Mg system – 2a, 3a and 4a, synthesized and described in our other publications, were used to obtain rapidly solidified ribbons. The used base Al-Cu-Mg alloys have a composition close to the composition of the alloys E5, U8 and U9 from the ternary Al-Cu-Mg diagram (Fig. 1, Table 1) [6]. They easily get amorphized and their aluminum-copper ligature contain from 33% to 50% copper.

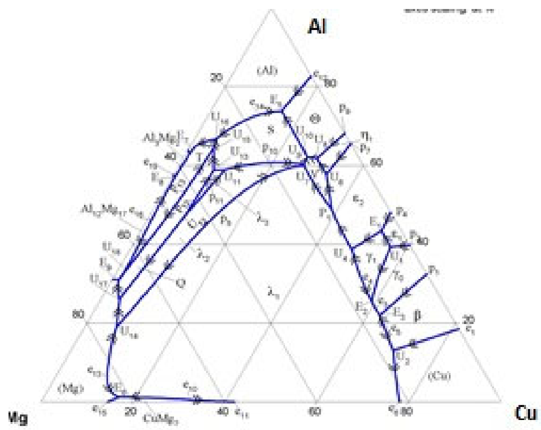


Figure 1. Ternary Al-Cu-Mg diagram

The planar flow casting (PFC) method was used to obtain the rapidly solidified ribbons. The installation scheme of PFC equipment is shown in fig. 2, and figure 3 shows the laboratory installation for rapidly solidification by melt, established in IMSETHA-BAS.

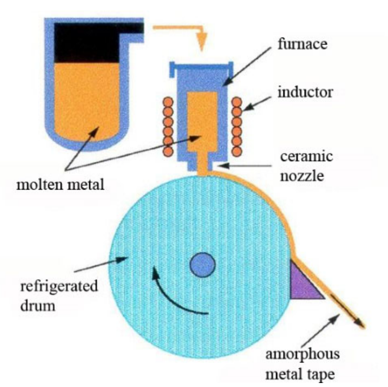


Figure 2. Scheme of PFC equipment.

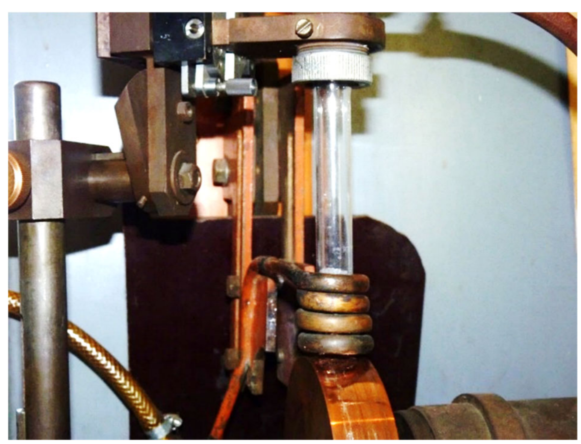


Figure 3. Laboratory installation of PFC.

The base alloys are placed in a quartz nozzle with a tube diameter of 18 mm. The nozzle hole is about 8-10 mm long and 0,5 mm wide. The alloys melting is head in an inductor to a temperature exceeding the melting temperature of the respective eutectic alloy by 20-30ºC. The alloys melt is fired under argon pressure of 0,4-0,5 atm on a copper disk with a diameter 140 mm. The linear speed of the disk was in the range of 31-37 m / s. The resulting ribbons were about 10 mm wide and 110-120 µm thick.
The resulting rapidly solidified ribbons are numbered 2ar, 3ar and 4ar, according to the base alloys 2a, 3a and 4a.

2.2. Test methods

The chemical compositions of the rapidly solidified ribbons were determined by EDS analysis of a scanning electron microscope HIROX 5500 with EDS system BRUCKER at a magnification of 100x in 10 fields with a field area of 2,5 mm^2.
The microhardness measurements were made by TMVS-1 microhardness tester under pressure P =0,025 kg for time τ = 10 s.
X-ray diffraction analysis were performed to characterize the amount of amorphous part and phase composition of the crystalline part of the studied ribbons with a Bruker D8 Advance powder X-ray diffractometer with CuKα radiation (Ni filter) and LynxEye recording in a solid-state position-sensitive detector. The qualitative phase analysis was performed using the PDF-2 (2009) database of the International Data Diffraction Center (ICDD) using the DiffracPlusEVA software package.
The microstructure of Al-Cu-Mg rapidly solidified ribbons was observed by transmission electron microscope JEOL 1011 with accelerated voltage 100kV.

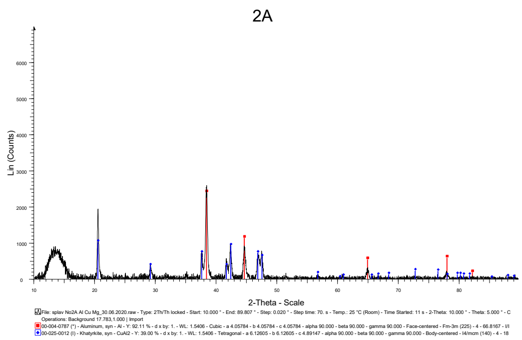
3. Results

The EDS analyzes results of the obtained rapidly solidified ribbons are presented in table 1.

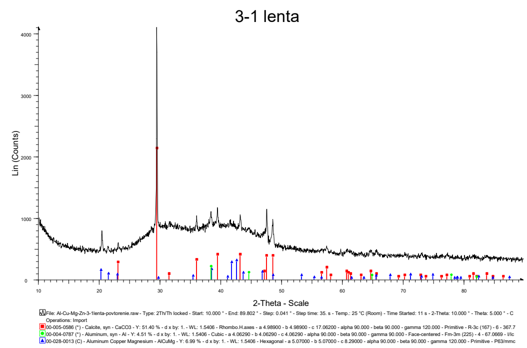
Table 1. Chemical composition of the rapidly solidified Al-Cu-Mg ribbons

	Al [% mass]	Cu [% mass]	Mg [% mass]	Microhardness $HV_{0,025,}$ [MPa]	Linear disk speed [m/s]
Alloy 2a	61	33	6	--	
Ribbon 2ar	46,26	47,99	5,75	4620	34
Alloy 3a	61,61	30,43	7,96	--	
Ribbon 3ar	52,22	41,92	6,86	5370	37
Alloy 4a	56,8	34,4	8,8	--	
Ribbon 4ar	45,55	47,15	7,2	5330	31

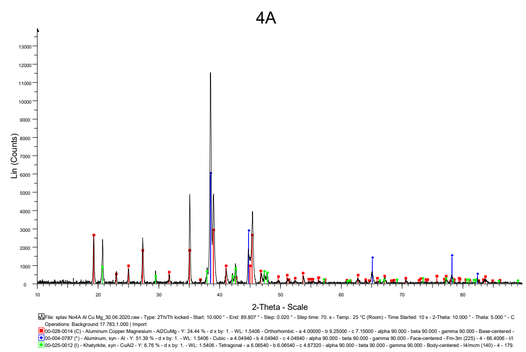
After rapid solidification Al content in all alloys decreases, Cu content increases and the Mg content does not change.
The XRD analyzes results are presented on figure 3 and in the table 2. Figures 3a and 3b clearly show the amorphous halo, which is evidence of the amorphous ribbons structure.



a) Rapidly solidified ribbon 2ar



b) Rapidly solidified ribbon 3ar



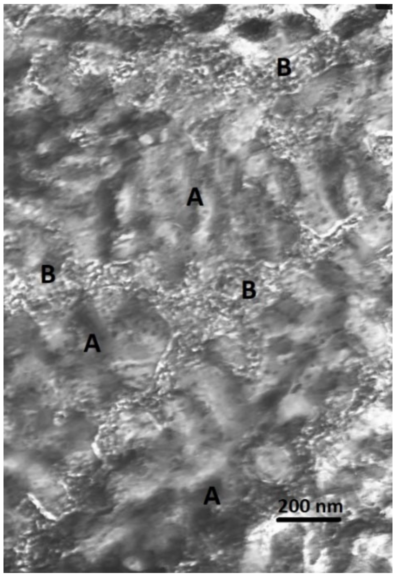
c) Rapidly solidified ribbon 4ar

Figure 3. X-ray diffractograms of 2ar, 3ar and 4ar ribbons.

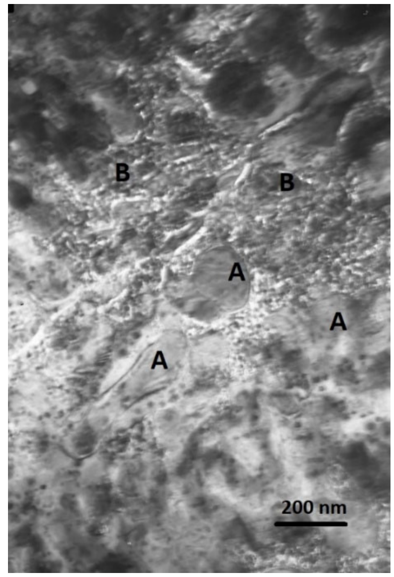
Table 2. XRD analysis of the rapidly solidified Al-Cu-Mg ribbons

Base Alloy/ Ribbon	Amorphous part [%]	Cristal part [%]	Phase /Quantity [%]/ Size [nm]
$Al_{61}Cu_{33}Mg_{6}$ Ribbon 2 ar	90	10	Al / 50 /28 Al_2Cu /50 /28
$Al_{61,61}Cu_{30,43}Mg_{7,96}$ Ribbon 3 ar	98	2	Al traces/1/ cannot be determined AlCuMg traces/1/ cannot be determined
$Al_{56,8}Cu_{34,4}Mg_{8,8}$ Ribbon 4 ar	75	25	Al / 32 / 49 Al_2Cu /11 /55 Al_2CuMg / 56 /54

The separated amorphous (A) and nanocrystalline regions (B) are clearly visible in the presented TEM photographs (fig.4). The obtained images confirm the results obtained by XRD analysis for the coexistence of amorphous structure with nanosized phases regions.



a. Rapidly solidified ribbon 2ar, TEM



b. Rapidly solidified ribbon 4ar, TEM

Figure 4. Microstructure of rapidly solidified ribbons 2ar (a) and 4ar (b) obtained from the Al-Cu-Mg base alloys, TEM

4. Conclusions

- Three ribbons with different chemical compositions by rapid solidification were produced.
- The amorphous part in the rapidly solidified ribbons is in the range 75÷98 %. The phase compositions of the crystalline phases were determined.
- The microstructure of the rapidly solidified ribbons was observed.
- The microhardness of the ribbons is in the range of 2050÷5300 MPa.

Acknowledgements
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