Alloy 5083 (AlMg4.5Mn0.7Cr0.15) obtained using rapidly solidified master alloys

G. V. GHICA[a], M. BUZATU[a], I. M. PETRESCU[a], G. IACOB[a,*],
[a]*University "Politehnica" of Bucharest, Materials Science and Engineering Faculty, Bucharest, 060042, Splaiul Independentei Blvd., no. 313, Romania.*

In order to increase the homogeneity, grain finishing and physic-mechanical characteristics of the AlMg4.5Mn0.7Cr0.15 (5083) alloy have been used in the development stage and treatment in the liquid phase: conventional solidified AlMg20 master alloy; solidified conventional and rapidly AlMn10, AlCr4 master alloys (which contains fusible heavy elements); solidified conventional and rapidly AlTi5B1 master alloy (for grain finishing). Rapid cooling performed on copper disk has allowed obtaining bands (splatters) with a thickness of 200...300 μm and about 1.5...3 mm wide. Solidification rate was estimated between 10^{-2}...10^{-3}C/s. The rapid cooling on copper disk of the master alloys ensured uniform dispersion leading to increased homogeneity and grain finishing alloy. Structural analyzes performed (SEI and X-ray diffraction), allowed to establish the main phases present in the master alloys and alloys solidified conventional and rapidly. The effect of rapid solidification was materialized in considerable improvement of the mechanical properties of alloy AlMg4.5Mn0.7Cr0.15 (5083).

(Received April 15, 2015; accepted May 7, 2015)

Keywords: Master alloys; Grain finishing; Rapid solidification; Morphology; Structure

1. Introduction

The properties of aluminium and its alloys (low density, good corrosion resistance and good processability) make that they can be rolled, extruded or forged into useful forms [1, 2]. Aluminium alloys used in practice are divided into: foundry alloys and wrought alloys. In the category of wrought alloys belong also the Al-Mg-Mn systems. Al-Mg-Mn alloys for processing by deformation were introduced in industrial practice to obtain thin plates, sheets and other products achieved through deformation [3]. AlMg4.5Mn0.7Cr0.15 (5083) alloy finds various applications in: steel construction for aeronautical, naval, rail and automotive; mining equipment; tanks; pressure vessels; scaffolding; equipment components exposed to medium stresses; civil engineering; bridges; refrigeration equipments [4-10]. AlMg4.5Mn0.7Cr0.15 (5083) alloy is the most resistant of heat-treated aluminium alloys. It possesses excellent weldability and appropriate corrosion resistance in chemical environments or with sea water (salty). Micro-alloying with master alloys containing modifying elements. This method of finishing the structure of Al alloys is very important to achieve the most advanced structures [11].

Metallic materials may be structurally modified by the introduction in the molten metal of small additions of carefully selected elements (Cr and Mn to improve their resistance and Ti and B to finish the structure). The action of these additives is much diversified and it can manifest over the shape and size of structural constituents, respective on their phases, and on the uniform distribution of basic metal mass [2, 3, 11, 12].

It is known that properties of the metal product depend on the grain structure. The processing by rapid solidification technique is widely accepted and applied in processing industry of fine-grained materials. Rapid solidification by melt-spinning method is widely used for obtaining new classes of materials or to improve material properties. The method of rapid solidification from the melt consists in the pouring of a thin stream of molten alloy on a cooled rotating drum. On contact with the drum surface, the molten alloy passes rapidly from liquid to solid state resulting in freezing of his structure [5,13-15].

Rapid solidification method is known for the production of important structural changes in the phase alloys (grain refinement, solid solubility expansion, the formation of new intermetallic compounds, and suppression of crystallization in favour of amorphization during solidification) [16]. These effects can be highlighted by electron microscope examining and X-ray diffraction investigations.

To obtain a clearer result of the effect obtained by introducing AlCr4, AlMn10, AlTi5B1 master alloys in the development of the AlMg4.5Mn0.7Cr0.15 (5083) alloy, experiments were performed to obtain the master alloys and also the 5083 alloy by two casting process, namely gravitational casting (conventional) resulting samples in cylindrical form and by rapid solidification casting resulting samples as strips.

The master alloys obtained have been structurally characterized by SEM analysis and the Al-4.5Mg-0.7Mn-0.15Cr (5083) alloy has been structurally characterized by optical microscopy, X-ray diffraction and by determining the mechanical properties (microhardness and tensile strength).

2. Materials and methods

2.1. Master alloys used in the elaboration of Al-Mg-Mn-Cr (5083) alloy

The specimens of conventional and rapidly solidified master alloys AlCr4, AlMn10, and AlTi5B1 were prepared on laboratory scale, using induction furnace and graphite crucibles. A chrome/alumel thermocouple and a control panel provided with adjustment devices of the metal bath temperature has been used to measure and control the temperature. In the first stage the specimens of master alloys were conventionally cast into cylindrical steel moulds (30 mm diameter, 10 mm wall thickness, 100 mm height), as follows:

Elaboration of AlCr4 master alloys: For obtaining the AlCr4 master alloys, was used metallic chromium brand X1 in the form of pieces, with a maximum content of impurities of Al - max. 0.7%, Si - max. 0.5%, Fe - max. 0.8%. In the direct melting of Al and Cr was considered the fact that the latter dissolves very slowly in molten aluminium. Cr was introduced in preheated Al at T = 1000...1100°C.

Elaboration of AlMn10 master alloys: In the developing of master alloy was used metallic manganese in the form of pieces, the brand used was Mn2 with impurities content of Si - max. 1.8%, Fe - max. 2.8%, C - max. 0.2% and S - max. 0.1%. Temperature needed to elaboration is not very high (780°C) and the dissolution of intermetallic compounds type $MnAl_4$ and $MnAl_6$ in Al was performed quite fast.

Elaboration of AlTi5B1 master alloys: AlTi5B1 master alloy was obtained by metallothermic reduction of salts (potassium fluoroborate). The technology used to obtain master alloys consists in introducing the titanium sponge and potassium fluoroborate in the molten Al. Elaboration was performed as follows: Al was loaded in furnace and heated to 1000°C. Then the surface of the molten Al was coated with a liquid layer of potassium chloride having a thickness of 60...70 mm. The potassium fluoroborate and the titanium sponge were introduced after the total melting of the potassium chloride. Potassium fluoroborate was introduced using a jacket, under intense mixing of the melt.

In the second stage the master alloys were rapidly solidified from the melt using a rotating cooper wheel of 200 mm in diameter. The melt is ejected through an orifice (0.8 mm) on the rotating cooper wheel (max. 1500 rpm) by means of an overpressure of argon to form rapidly solidified ribbons (10^{-2}...10^{-3} C/s). The rapidly solidified ribbons had a no uniform thickness varying in the range of 200 to 300 µm and about 1.5...3 mm wide.

2.2. Elaboration of Al-Mg-Mn-Cr (5083) alloy

Elaboration experiments were carried out under laboratory conditions. For the elaboration of the Al-Mg-Mn-Cr (5083) alloy were used: primary Aluminium (99.95%) and AlCr4; AlMn10; AlMg20; AlTi5B1 master alloys; protection, cleaning, degassing and deoxidation fluxes.

Conventional solidification:

Elaboration of AlMg4.5Mn0.7Cr0.15 alloy included the following technological:

- Heating the furnace with the empty crucible, to approx. 800^0C.
- Introduction of aluminium pieces from batch load, with approx. 0.2% (~5g) of coating - refining flux.
- The melting of aluminium and heating at approx. 800^0C.
- Introduction of master alloys with heavy fusible elements: AlCr4 and AlMn10.
- Mixing of melt and removing the slag.
- Surface protection with coating - refining flux.
- Introduction into portions of AlMg20 master alloys, under graphite jacket.
- Maintaining for approx. 20 minutes, then gradually reducing the temperature to 720^0C.
- Introduction of finishing AlTi5B1.
- Mixing of melt and removing the slag.
- Maintaining for approx. 10 minutes, then gradually reducing the temperature to 720^0C.
- Successive casting of samples in permanent metal forms.

Rapid solidification:

Experimental rapid solidification installation of melt-spinning type consists of: frequency converter, crucible, inductor, copper disk, and control panel.

Technological stages of the rapid solidification process of melt-spinning consist of: preparing the installation by introducing the material into the quartz tube - graphite crucible; induction melting (900...1300°C) with maintaining at the temperature of the material high fluidity; approximation of the nozzle to rotating drum (Φ116cm) at the predetermined distance (1...2 mm); casting (ejection) of the molten alloy by the creation of an overpressure of gas in the quartz tube, and forming the ribbons, through contact with the copper drum. The ribbons of solidified material are collected in a specially designed chamber.

Investigations on AlCr4, AlMn10, AlTi5B1 master alloys and Al-Mg-Mn-Cr (5083) alloy samples, conventional and rapidly solidified, were performed by: secondary electron image analysis – SEI; X-ray diffraction; testing the mechanical properties (Vickers micro-hardness with hardness tester M-400-G model, according to SR ISO 3878: 1992, and tensile strength using a Walter-Bay testing machine).

3. Results and discussions

Microscopic characterization of samples taken from the AlCr4, AlMn20, AlTi5B1 master alloys after conventional casting and rapid solidification are shown in Fig. 1-3. The microstructure of master alloy AlMn10 conventionally cast exhibited coarse particles phase (Fig. 1a). The microstructure of the master alloy AlMn10 which was rapidly solidified in form of ribbons, show a radial increase of dendrites of intermetallic metastable phase of $Al_{12}Mn$ (Fig. 1b).

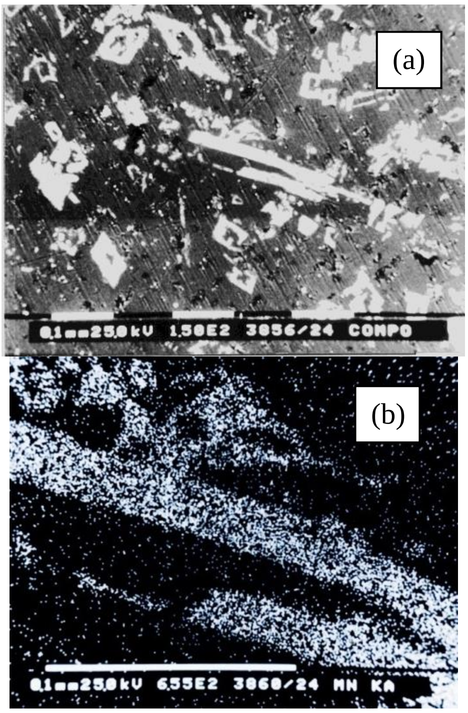

Fig. 1(a). SEI image of the conventional cast AlMn10 master alloy (a) and Mn distribution in the micro-zone analyzed (b).

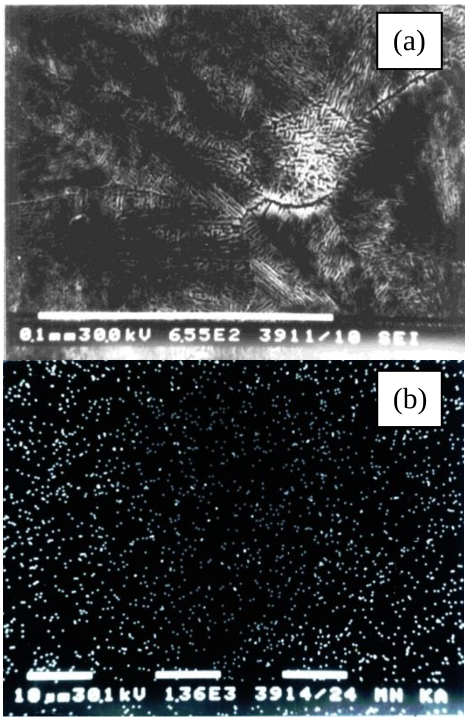

Fig. 1(b). SEI image of the rapidly solidified AlMn10 master alloy (a) and Mn distribution in the micro-zone analyzed (b).

The microstructure of master alloy AlTi5B1 conventionally cast exhibited primary Al_3Ti particles phase which segregates generally at the cell or grain boundaries (Fig. 2a). The microstructure of the AlTi5B1 master alloy which was rapidly solidified shows a very uniform distribution of titanium (Fig. 2b). It is a confirmation that rapid-freezing of alloy melts can result in progressive departure from the microstructures produced by conventional casting, generally in the direction of increased refinement and chemical homogeneity.

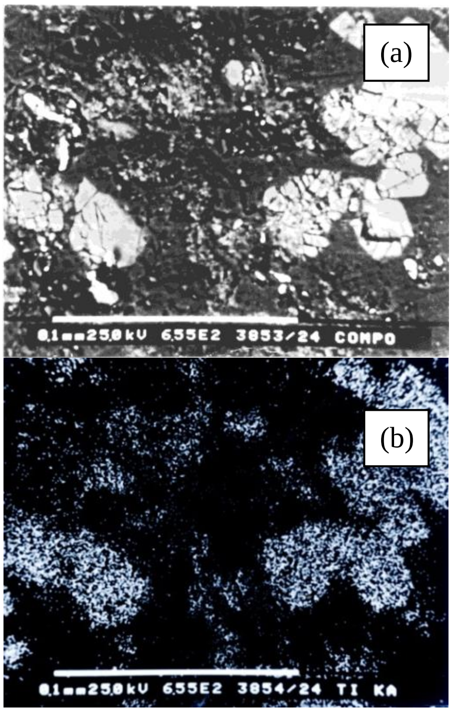

Fig. 2(a). SEI image of the conventional cast AlTi5B1 master alloy (a) and Ti distribution in the micro-zone analyzed (b).

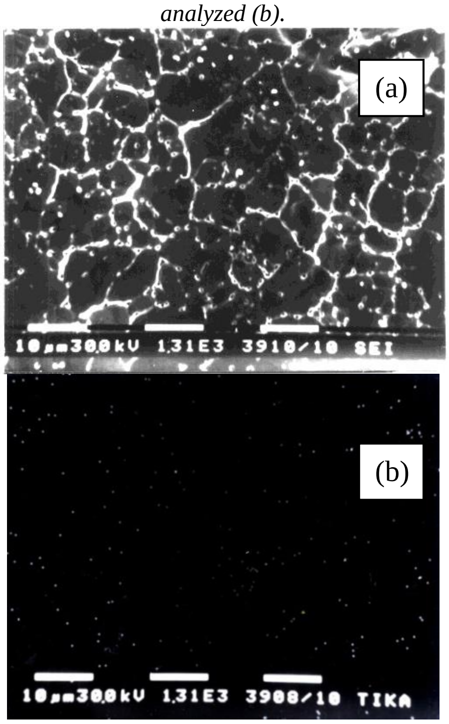

Fig. 2(b). SEI image of the rapidly solidified AlTi5B1 master alloy (a) and Ti distribution in the micro-zone analyzed (b).

The microstructure of master alloy AlCr4 conventionally cast exhibited coarse particles phase (Fig 3a). The microstructure of rapidly solidified AlCr4 ribbon shows a very uniform distribution of chromium in the structure (Fig 3b).

It is a confirmation that rapid solidification of master alloy melts can result in progressive departure from the microstructures produced by conventional casting, generally in the direction of increased refinement and chemical homogeneity of the final alloy.

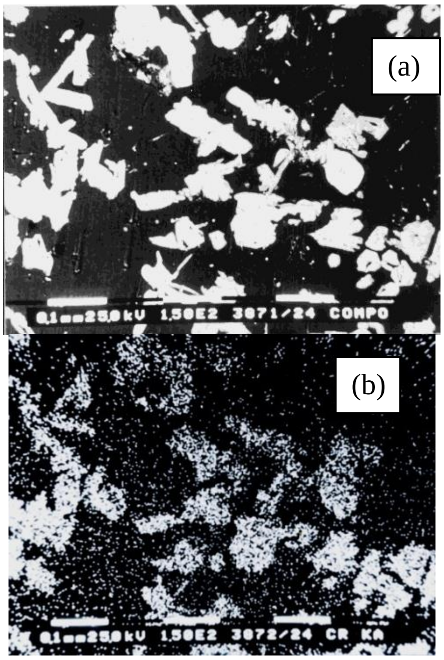

Fig. 3(a). SEI image of the conventional cast AlCr4 master alloy (a) and Cr distribution in the micro-zone analyzed (b).

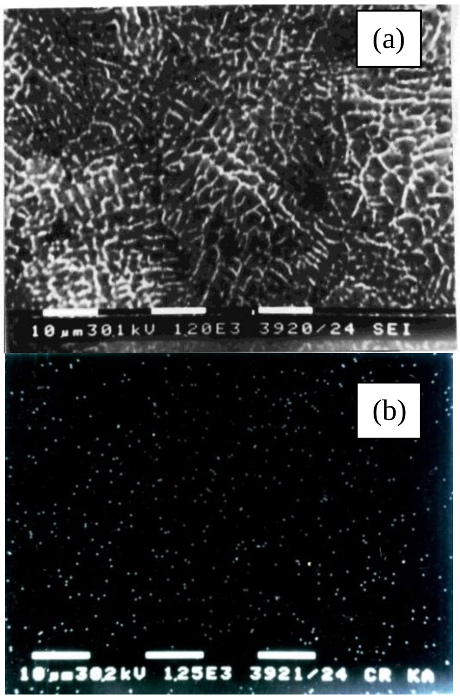

Fig. 3(b). SEI image of the rapidly solidified AlCr4 master alloy (a) and Cr distribution in the micro-zone analyzed (b).

The chemical composition of the Al-Mg-Mn-Cr (5083) alloy is presented in Table 1, compared with its standard composition.

Table 1. Chemical composition of 5083 alloy

ALLOY	Chemical composition, %								
	Al	**Si**	**Mg**	**Mn**	**Cr**	**Ti**	**Cu**	**Fe**	**Zn**
AlMg4,5Mn0,7Cr0,15 (5083) standard	Bal.	0.4	4.0-4.9	0.4-1.0	0.05-0.25	0.15	0.1	0.4	0.25
AlMg4,5Mn0,7Cr0,15 (5083) obtained	Bal.	0.08	4.65	0.66	0.16	0.11	0.007	0.32	0.007

The samples used for mechanical tests of alloy 5083 were obtained as follows:

1. The first set of samples has resulted to the elaboration of alloy 5083 by the conventional method using conventional master alloys (CM);

2. The second set of samples resulted after elaboration of alloy 5083 by the conventional method using rapidly solidified master alloys (CM-RS);

3. And the last set of samples by elaborating by rapid solidification method the alloy 5083 by using rapidly solidified master alloys (RS).

X-ray characterizations of samples taken from the alloy Al-Mg-Mn-Cr (5083) conventionally cast and rapidly solidified are shown in Figs. 4 and 5.

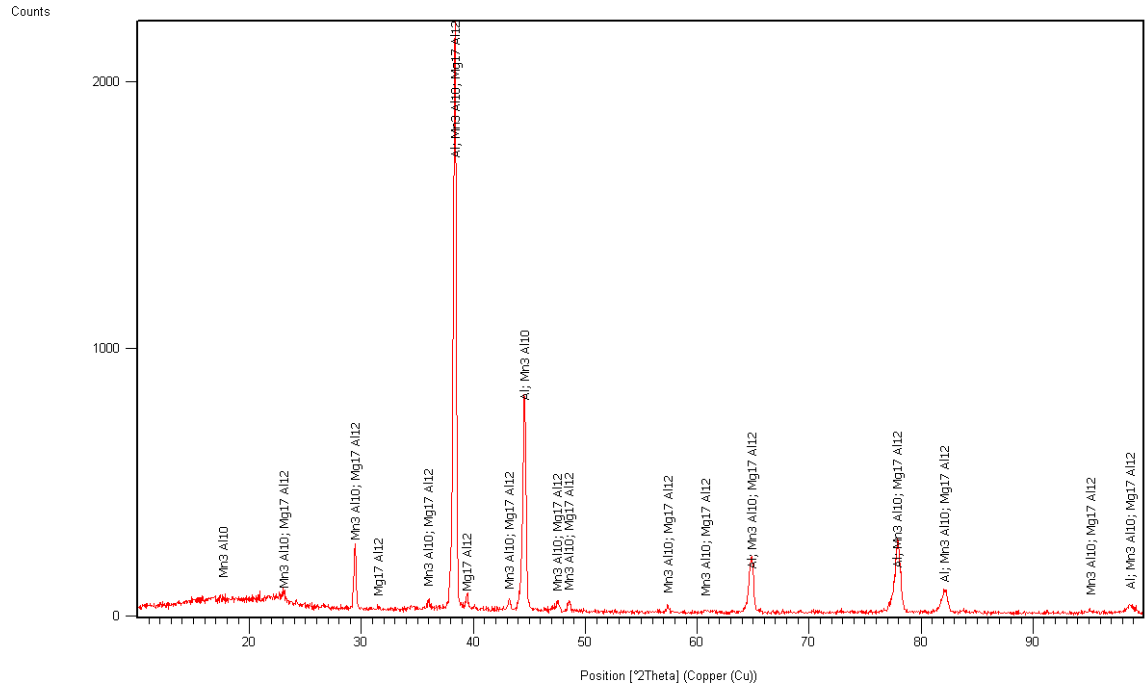

Fig. 4. X-ray diffractogram of Al-Mg-Mn-Cr (5083) alloy, conventionally cast.

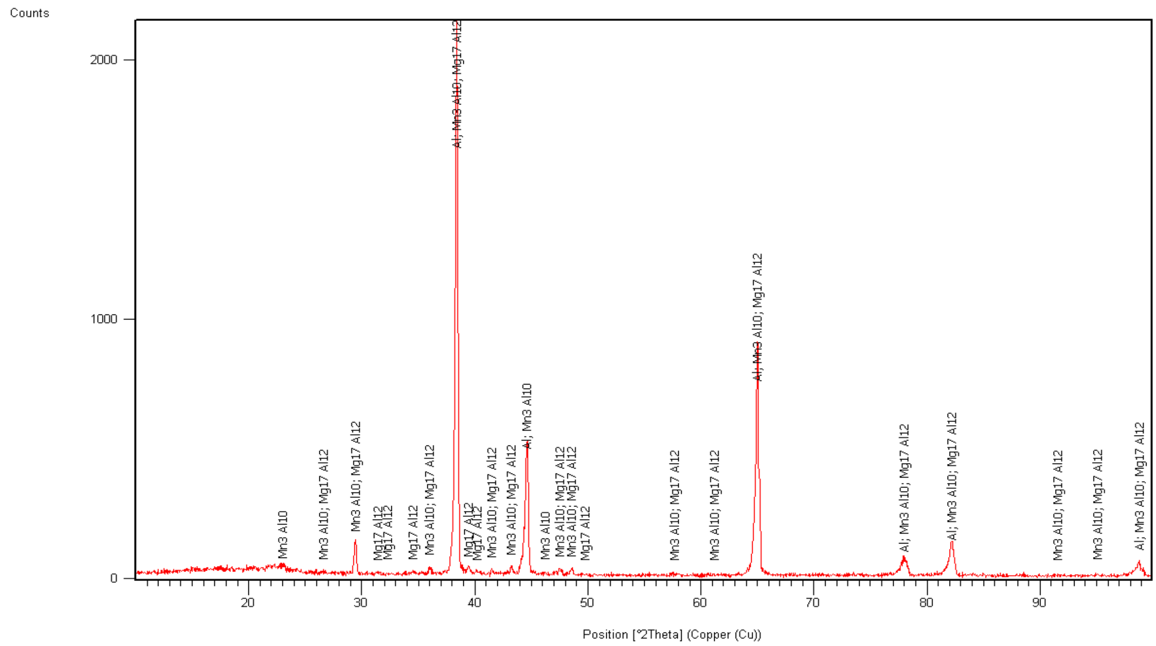

Fig. 5. X-ray diffractogram of rapidly solidified Al-Mg-Mn-Cr (5083) alloy.

Determination of Vickers microhardness of the alloy samples Al-Mg-Mn-Cr (5083) was carried out by performing a number of 7 tests for each sample, starting from the centre of the sample to the outside thereof, and achieving an average of these values. Results obtained from tests of Vickers microhardness are shown in Fig. 6. The Vickers microhardness values show a rising trend of samples obtained by rapid solidification compared to gravitational casting.

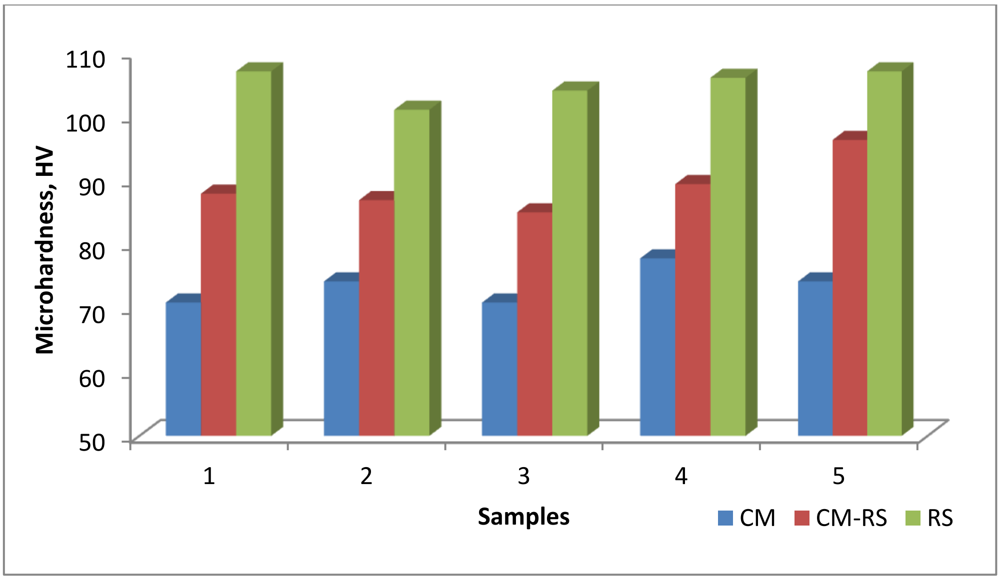

Fig. 6. Variation of Vickers microhardness of alloy samples Al-Mg-Mn-Cr (5083) obtained by conventional casting and rapid solidification.

In Fig. 7 is represented the variation of tensile strength of alloy samples Al-Mg-Mn-Cr (5083) obtained by conventional casting and using conventional master alloys (CM samples) and rapidly solidified master alloys (RS samples). It can observe an increase of tensile strength of RS samples comparative with the CM samples, increase of about 10 – 12%. This can be attributed to the grain finishing effect of the rapidly solidified master alloys on the structure of the 5083 alloy.

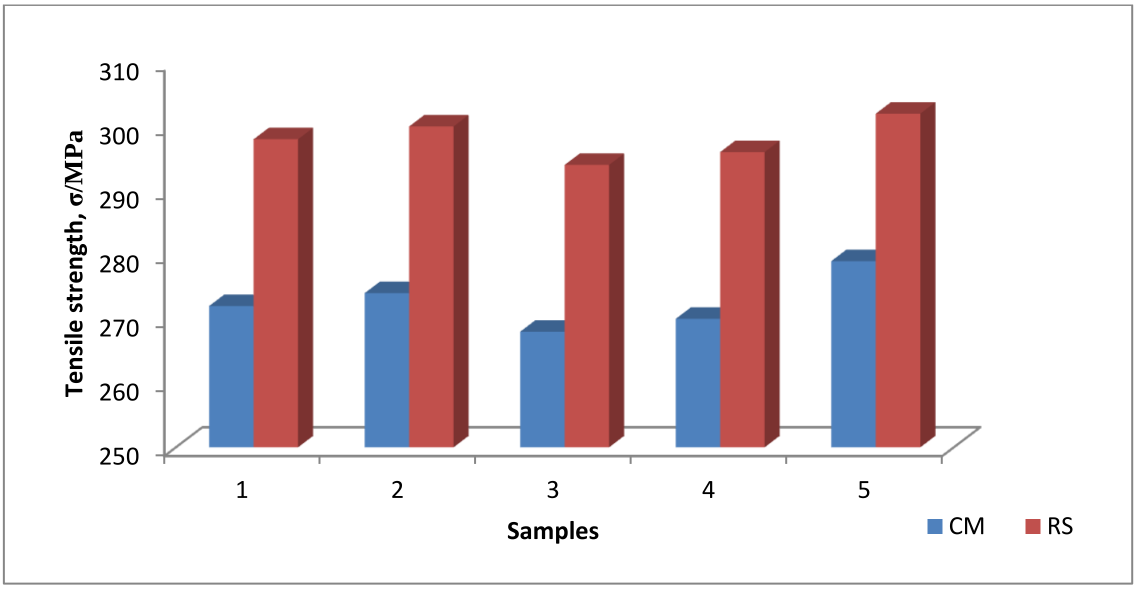

Fig. 7. Variation of tensile strength of alloy samples Al-Mg-Mn-Cr (5083) obtained by conventional casting and using different types of master alloys.

It can be concluded that this type of alloy Al-Mg-Mn-Cr can be developed quite well by using rapidly solidified master alloys, which has a marked effect of finishing the alloy structure, a fact noted by previous analyzes and confirmed by the results of mechanical properties.

In the treatment of molten aluminium alloys are added elements or master alloys to change the shape or dimensions of the structural constituents of the alloy, which can improve mechanical properties and other properties of the alloy such as casting fluidity, processability, hardening, etc. Depending on the nature of the modifiers introduced into the melt it can be obtained a considerable decrease of the grains of the solid solution which constitute the metallic mass of the alloy, the primary crystals of secondary or eutectic phases.

4. Conclusions

The grain refining of aluminium alloy 5083 by addition of rapidly solidified master alloys is a question of technical interest for the future treatment of aluminium materials. Compared with conventionally solidified master alloys the technique of inoculation of ribbons offers a number of advantages: uniform grain refinement of aluminium alloy 5083 fine well distributed nucleating small particles, no particle agglomeration, optimum refinement. In the case of AlCr4 master alloy after rapid solidification can be observed a uniform distribution of chromium in the structure. After rapid solidification of the AlMn10 master alloy there was a radial growth of metastable intermetallic phase $Al_{12}Mn$ dendrites. In the case of rapid solidification AlTi5B1 master alloy can be observed a separation of the extremely fine particles at grain boundaries probably metastable intermetallic compound Al_xTi. In the case of Al-Mg-Mn-Cr (5083) alloy prepared by rapid solidification at a pouring temperature of 720^{o}C can be observed the formation of microcrystalline fine grains.

Results obtained from tests of Vickers microhardness show that samples obtained by rapid solidification exhibit much better values compared to conventional casting.

Increasing of tensile strength of RS samples comparative with the CM samples is about 10 – 12%. This can be attributed to the grain finishing effect of the rapidly solidified master alloys on the structure of the 5083 alloy.

The Al-Mg-Mn-Cr (5083) alloy can be developed in good conditions by using rapidly solidified master alloys, confirmed by the results. These master alloys, has a marked effect of finishing the alloy structure, a fact noted by previous analyzes and confirmed by the results of mechanical properties.

References

[1] R. Cobden, Aluminium: Physical Properties, Characteristics and Alloys, EAA (European Aluminium Association), (1994).
[2] G.E. Totten and D.S. Mackenzie, Handbook of Aluminum, Ed. M. Dekker Inc. New York, (2003).
[3] J.R. Groza, J.F. Shackelford, E.J. Lavernia, M.T. Powers: Materials Processing Handbook, C.R.C. Press Taylor & Francis Group, Florida, USA 2007.
[4] P. Rogl, J. Bauer and M. Bohn, Annual Raport COST 507 II, Group A, (1994), p. 1-10.
[5] F. Liu, R. Liu, Z. Hou, H. Liu, Z. Tian and L. Zhou, Ann. Phys. **324**, 332 (2008).
[6] L. Arnberg, L. Backerud and H. Klang, Met. Tech. **9**, 1 (1982).
[7] L. Arnberg, L. Backerud and H. Klang, Met. Tech. **9**, 7 (1982).
[8] M.M. Guzowski, G.K. Sigworth, D.A. Sentner, Metall. Trans. A **18**, 603 (1987).
[9] A. Arjuna Rao, Studies on the grain refinement of Al-Cr, Al-Zr and Al-Si alloys using Al-Ti-B master alloys, PhD thesis, IIT Kharagpur, (1997).
[10] X.J. Liu, O.R. Kainuma and K. Ishida, J. Phase Equil. **20**, 1, (1999).
[11] B.S. Murty, S.A. Kori, M. Chakraborty, Int. Mater. Rev. **47**, 1, (2002).
[12] H. Jones, Mat. Sci. Eng. A **413-414**, 15, (2005).
[13] M.J. Kramer, H. Mecco, K.W. Dennis, E. Vargonova, R.W. McCallum, Ralph E. Napolitano, J. Non-Cryst. Solids **353**, 32–40, (2007).
[14] V.I. Tkatch, Alexander I. Limanovskii, Sergey N. Denisenko, Sergey G. Rassolov, Mat. Sci. Eng. A **323**, 1–2, (2002).
[15] D.Y. Maeng, J.H. Lee, S.I. Hong, B.S. Chun, Mat. Sci. Eng. A **311**, 1–2, (2001).
[16] A.-M. Adam, U.P.B. Sci. Bull, Series B **73**, 3, (2011).

*Corresponding author: iacob_gh@yahoo.com