

PREPARATION AND PROPERTIES OF Al - Fe AND Al - Fe - Cr ALLOYS

Petra HANUSOVÁ^a, Pavel NOVÁK^b

^a Brno University of Technology, Faculty of Mechanical Engineering, Institute of Material Science and Engineering, NETME centre, Brno, Czech Republic, EU, hanusova@fme.vutbr.cz

^b Institute of Chemical Technology, Prague, Faculty of Chemical Technology, Department of Metals and Corrosion Engineering, Prague, Czech Republic, EU, panovak@vscht.cz

Abstract

Aluminum alloys are frequently used structural materials. Their properties can be affected by manufacturing method. Melt spinning is very promising method, enabling to obtain finer structure and increased hardness. In this work, (in wt.%) Al - 11 Fe and Al - 7 Fe - 4 Cr alloys were investigated. They were prepared by conventional casting, melt spinning method, and hot pressing, respectively. Subsequently the microstructure was investigated using scanning electron microscopy (SEM), the hardness was measured by Vickers method and thermal stability was analyzed by long-term annealing. By comparing the alloy of Al - Fe with Cr doped Al - Fe alloy it was found that the method of production strongly affects the microstructure; the hardness of the alloy has been increased. The alloying element used shown an additional positive effect on properties improved by production technology.

Keywords: Aluminum alloys, melt spinning, thermal stability, microstructure

1. INTRODUCTION

Aluminum alloys with their low density are very commonly used materials. They can be used in the aerospace and automotive industries to produce e.g. engine blocks and pistons for combustion engines. The Al - Si alloy is often used for its increased wear resistance, high tensile strength and higher thermal stability [1]. Nowadays there are many methods to produce aluminum alloy. One way use of the conventional casting methods and the other way is application of the methods of rapid solidification. The properties of materials that were produced by foundry technologies have been thoroughly investigated in past decades [2]. Rapid solidification is a very attractive method, especially for aluminum alloys, because of limited equilibrium solubility of some alloying elements in solid solution in the aluminum lattice, which can be extended during rapid solidification [3]. The levels of undercooling reached at such high cooling rates lead to significant structure changes in comparison with those that were prepared by the classical way. These include refinement of solidified microstructure [1], creating new metastable crystalline and amorphous phases [4] or the grain size reduction. It was shown that the increase in thermal stability can be achieved for example by the addition of Fe [5, 6], Ni [7], Cr [7] and other transition metals. Particularly, formation of iron-containing intermetallic compounds contributes to the thermal stability via precipitation strengthening [8].

In this work alloys based on Al - Fe and Al - Fe - Cr were prepared by melt spinning method. The microstructure and properties of the prepared alloys were then compared to the same compounds prepared by conventional casting. To study the microstructure and properties of the alloys, Scanning Electron Microscopy (SEM), X-ray diffraction, Vickers hardness testing were used and the thermal stability was verified by the means of long term annealing.

2. EXPERIMENTAL

As an experimental material, the Al - 11 Fe and Al - 7 Fe - 4 Cr alloys were used. For the production of both alloys three different methods were used. As a basic method, conventional mold casting was chosen. Furthermore the method of melt spinning was utilized. The alloy of desired composition was inserted into a

nozzle made of quartz glass, placed in an apparatus for melt spinning, inductively melted and heated up to 1200 °C. Subsequently, the melt was ejected by flow of argon on a cooling copper wheel that rotated at 1420 rpm. This corresponds to the peripheral speed of 38 m/s. Finally, the third sample was fabricated by hot pressing of the rapidly solidified material. At first it was necessary to crush the rapidly solidified ribbons in a planetary ball mill to obtain a powder with a particle size 100 - 140 µm. Ribbons were immersed in liquid nitrogen and the milling vessel was immediately sealed and placed in the mill. Liquid nitrogen was added to the ribbons in order to reduce the temperature during the grinding, in order to reduce grain coarsening and to increase the brittleness of the ribbons. Milling was carried out for 10 min at 400 rpm. The metal powder was then cold pressed by the load of 70 kN into a preform of 19 mm in diameter and approximately 30 mm in height. Thereafter hot pressing followed. The furnace which is a part of a universal mechanical testing machine was first preheated to 500 °C. After that the pressing mold was inserted and heated to a temperature of the furnace. Subsequently the preform was inserted into a mold and held for five minutes. Hot pressing followed to form a cylindrical sample with a height of about 10 mm.

The microstructure of the samples was observed using scanning electron microscope (SEM) TESCAN VEGA 3 LMU equipped with EDS analyzer Oxford Instruments INCA 350. Thermal stability was studied by annealing at 300 °C for 250 h. The samples were taken out at an interval of 50 hours and cooled down to a room temperature. The Vickers hardness was measured. After the hardness measurement, the samples were returned to the furnace and the process was repeated after 50 hours.

3. RESULTS

3.1 Microstructure

Microstructure of the Al - 7Fe alloy in the as-cast state is presented in **Fig. 1a**. The alloy is composed of a solid solution of alloying elements in aluminum (marked as „Al“) and coarse particles of Al₁₃Fe₄.

The same alloy prepared by melt spinning (see **Fig. 1b**) contains Al - based solid solution and metastable phase Al₆Fe and stable phase Al₁₃Fe₄ (marked as „stable and metastable intermetallics“). The metastable phase Al₆Fe appeared exclusively during rapid solidification. This side of the ribbon was in contact with an air during melt spinning and thus solidified more slowly. On the other side of the ribbon the maximum cooling rate was reached. The microstructure consists of a supersaturated solid solution and a very fine intermetallic phase (marked as "Rapidly solidified zone").

Fig. 2 shows the microstructure of the alloy Al - Fe produced by hot pressing. The microstructure consists of large particles which are formed by Al₁₃Fe₄ phases and solid solution of iron in aluminum.

The microstructure of the Al - Fe - Cr alloy in the as-cast state is presented in **Fig. 3a**. A large part of the alloy is formed by solid solution alloying elements in aluminum (marked as "Al"). Another phase Al₁₃Cr₂ is present in a form of white particles of various shapes. **Fig. 3b** represents the microstructure of rapidly solidified ribbon Al - Fe - Cr. At first sight the microstructure is almost the same as that in the case of the alloy Al - Fe. The ribbon is apparently divided into two areas. Rapidly solidified zone is much narrower and between the two regions there is sharp and very noticeable transition. Wider area of the ribbon is composed of stable and metastable intermetallic (Al₁₃Fe₄ and Al₁₃Cr₂ phases). On the side adjacent to the cooling roll a ribbon is mainly composed of a solid solution α-Al and fine intermetallic phases.

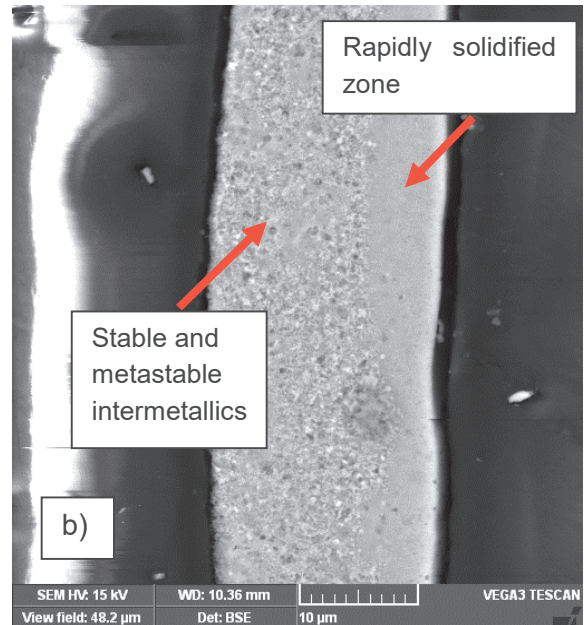
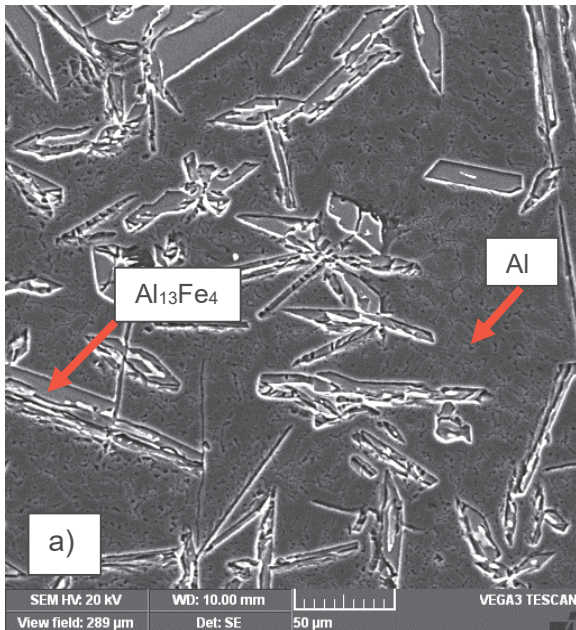


Fig. 1 Microstructure (SEM) of the Al - Fe alloy prepared by a) casting, b) melt spinning

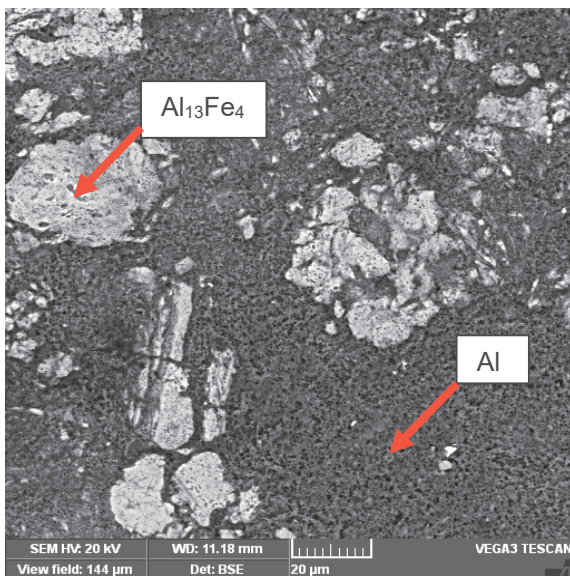


Fig. 2 Microstructure (SEM) of the Al - Fe alloy prepared by hot pressing

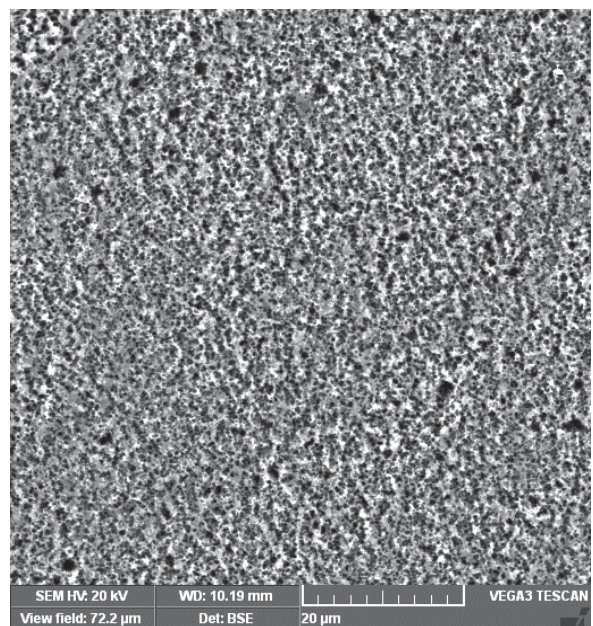


Fig. 4 Microstructure (SEM) of the Al-Fe-Cr prepared by hot pressing

Fig. 4 shows the microstructure of Al - Fe - Cr produced by hot pressing. In comparison with the alloy of Al - Fe the microstructure of Al - Fe - Cr alloy is significantly finer, there are no coarse intermetallic particles. Microstructure is composed of very fine intermetallic phases (bright) in the aluminum matrix (dark grey to black).

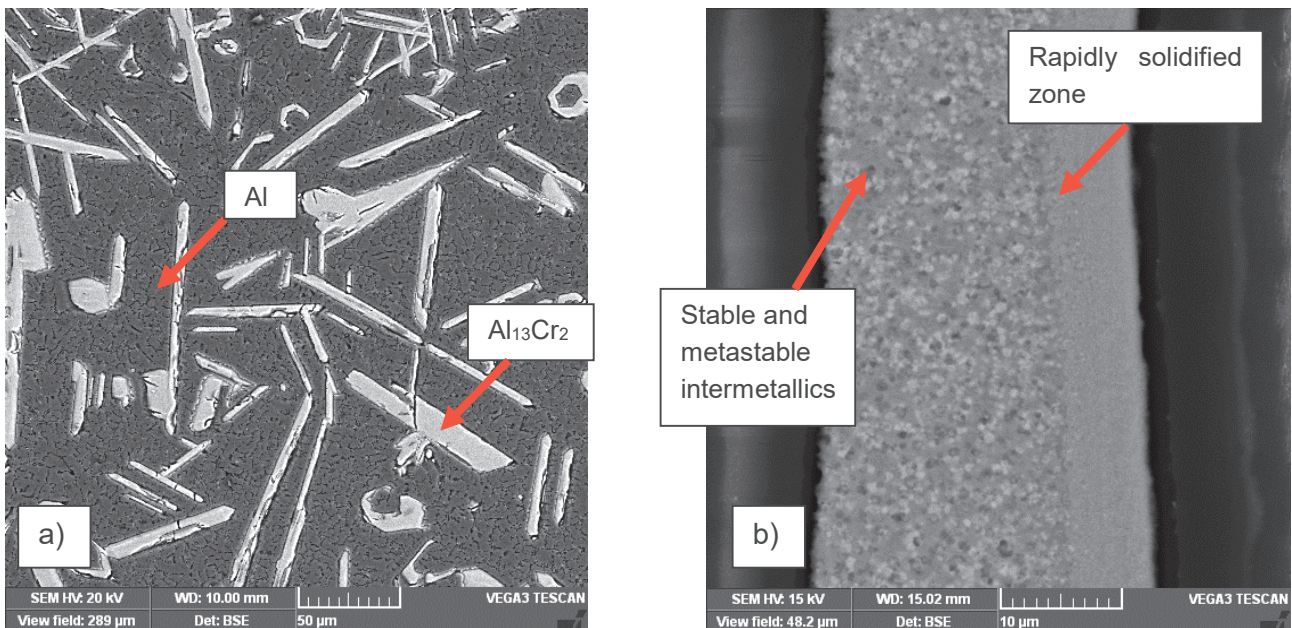


Fig. 3 Microstructure (SEM) of the Al - Fe - Cr alloy prepared by a) casting, b) melt spinning

3.2 Thermal stability

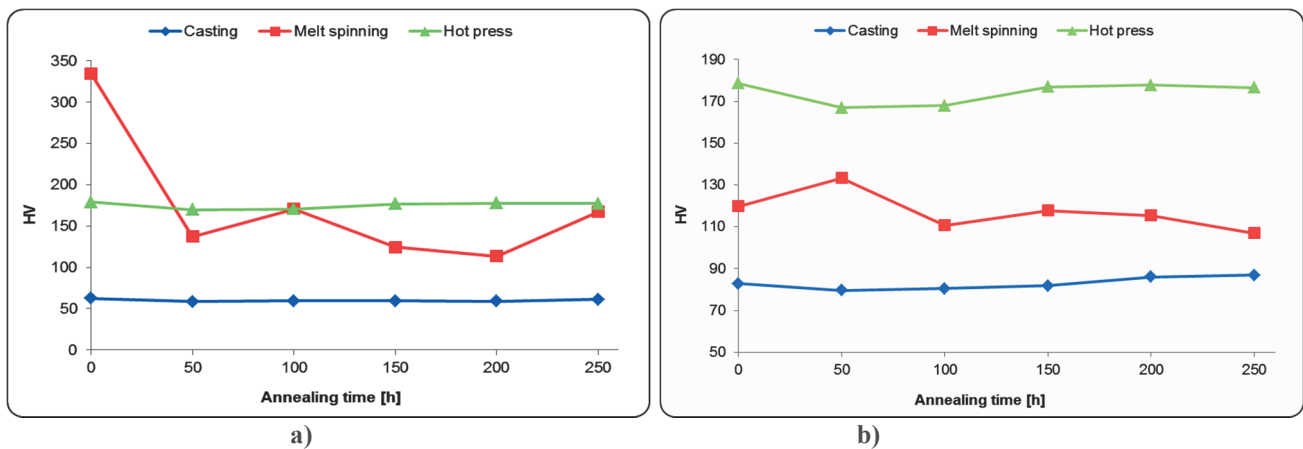


Fig. 5 The dependence of the hardness on the annealing time of the alloy a) Al - Fe, b) Al - Fe - Cr

Fig.5a summarizes the effect of the annealing time on the hardness at 300 °C for the alloy Al - Fe. The hardness of the alloys prepared by three used production methods are compared in this plot giving following results: The hardness of the cast alloy is about several tens lower than the hardness using other two methods. The hardness of the alloy prepared by melt spinning is higher, nevertheless within the first 50 hours of annealing it was substantially reduced and following character fluctuates. The initial decrease is caused by the conversion of hard metastable phase Al₆Fe to the stable phase Al₁₃Fe₄ and by coarsening of the grains of solid solution of iron in aluminum. During the first fifty hours, a slight decrease in hardness was observed in the case of hot pressed alloy, after 150 hours of exposure the hardness increased slightly again. The probable reason for such a development of hardness can be found in phase composition changes associated with the dissolution of metastable phases, intermetallics precipitation from supersaturated solid solution and their subsequent coarsening. Fig. 5b represents the dependence of the hardness on the annealing time at 300 °C for the alloy of Al - Fe - Cr. As can be seen the hardness of the alloy was positively influenced by the addition of Cr. The hardness of the alloy produced by casting was about several units higher than the Al - Fe alloy. In

the case of melt spinning the hardness of the alloy was not significantly changed during annealing. The alloy prepared using hot pressing method shown similar behaviour as the alloy of Al - Fe, ie. the slight decrease and subsequent increase in the level of the hardness is due to changes in the phase composition.

CONCLUSION

In this work two types of alloys (Al - Fe, Al - Fe - Cr) were studied and the impact of the manufacturing process on the microstructure and thermal stability was compared. The as-cast alloys exhibit a coarse microstructure with sizable particles of stable intermetallic phases ($Al_{13}Fe_4$, $Al_{13}Cr_2$). Rapid solidification resulted in a significant refinement of the microstructure of the material and the formation of metastable phases (Al_6Fe). Rapidly solidified ribbons partially decomposed into the metastable phases and stable intermetallics were formed during subsequent compaction. In the case of Al - Fe alloy, structure coarsening occurred. It is obvious that the addition of Cr has a significant impact on the formation of finer structures during pressing due to the fact that it prevents coarsening of the grains and intermetallic phases during heating.

Due to the long term annealing of the material in a various processing states it was found that Cr has a significant positive effect on the thermal stability of the material. Based on the results of this work it is advisable to use the alloy in industrial applications, assuming that the temperature does not exceed 300 °C.

ACKNOWLEDGEMENTS

The part of the work done by Pavel Novak was realized with the support of the Czech Science Foundation, project No P108/12/G04. Petra Hanusova gratefully acknowledges the financial support by the project No. 13 - 35890S of the Czech Science Foundation.

REFERENCES

- [1] ÜNLÜ, N., GENÇ, A., ÖVEÇOĞLU, M.L., ERUSLU, N., FROES, F.H. Characterization investigations of melt-spun ternary Al-xSi-3.3Fe (x = 10, 20 wt.%) alloys. *Journal of Alloys and Compounds*, 2001, Vol. 322, No. 1-2, pp. 249-256.
- [2] OKAYASU, M., OTA, K., TAKEUCHI, S., OHFUJI, H., SHIRAIISHI, T. Influence of microstructural characteristics on mechanical properties of ADC12 aluminum alloy. *Materials Science and Engineering: A*, 2014, Vol. 592, pp. 189-200.
- [3] CHEN, Z., LEI, Y., ZHANG, H. Structure and properties of nanostructured A357 alloy produced by melt spinning compared with direct chill ingot. *Journal of Alloys and Compounds*, 2011, Vol. 509, No. 27, pp. 7473-7477.
- [4] ZHANG, Z., WANG, Y., BIAN, X., WANG, W. Orientation of nanocrystals in rapidly solidified Al-based alloys and its correlation to the compound-forming tendency of alloys. *Journal of Crystal Growth*, 2005, Vol. 281, No. 2-4, pp. 646-653.
- [5] ESTRADA, J.L., DUSZCZYK, J. Characteristics of rapidly solidified Al-Si-X powders for high-performance application. *Journal of Materials Science*, 1990, Vol. 25, No. 2A, pp. 886-904.
- [6] VAN MOURIK, P., MITTEMEIJER, E.J., DE KEIJSER, T.H. On precipitation in rapidly solidified aluminum-silicon alloys. *Journal of Materials Science*, 1983, Vol. 18, No. 9, pp. 2706-2720.
- [7] DELHEZ, R., DE KEIJSER, T.H., MITTEMEIJER, E.J., VAN MOURIK, P., VAN DER PERS, N.M. KATGERMAN, L., ZALM, W.E. Structural inhomogeneities of AlSi alloys rapidly quenched from the melt. *Journal of Materials Science*, 1982, Vol. 17, No. 10, pp. 2887-2894.
- [8] RAJABI, M., VAHIDI, M., SIMCHI, A., DAVAMI, P. Effect of rapid solidification on the microstructure and mechanical properties of hot-pressed Al-20Si-5Fe alloys. *Materials Characterization*, 2009, Vol. 60, No. 11, pp. 1370-1381.