UDK 669.715:620.18:620.17
Professional article/Strokovni članek

ISSN 1580-2949
MTAEC9, 47(2)239(2013)

INFLUENCE OF ALUMINIUM-ALLOY REMELTING ON THE STRUCTURE AND MECHANICAL PROPERTIES

VPLIV VEČKRATNEGA PRETALJEVANJA ALUMINIJEVIH ZLITIN NA STRUKTURO IN MEHANSKE LASTNOSTI

Michal Cagala, Marek Břuska, Petr Lichý, Jaroslav Beňo, Nikol Špirutová

VŠB-Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Department of Metallurgy and Foundry, 17. Listopadu 15/2172, Ostrava – Poruba, Czech Republic
michal.cagala@vsb.cz

prejem rokopisa – received: 2012-08-31; sprejem za objavo – accepted for publication: 2012-10-02

The aim of this work was to assess the repeated-remelting influence upon the mechanical properties, thermomechanical properties, chemical composition and structure changes of the selected material. An Al-Cu-type aluminum alloy was chosen on the basis of the ever increasing experiments with non-ferrous metals in the industry. The technical nomenclature of the selected alloy is RR.350 according to the German standard ALUFOND 60. The RR.350 alloy is known for its poor foundry properties which deteriorate due to remelting and affect mechanical properties and the cast-material structure. This negative influence upon the structure and usable properties of a re-melted alloy is further confirmed in the submitted paper. The samples for tensile-strength determination were cast into a metal mould. The gating system and the riser, which served as a charge for the second melt, were removed from the casting. In this way we re-melted the material four times. The samples were machined and ruptured within the temperature range between 20 °C and 350 °C. A sample for metallography and hardness determination (HBS) was taken from the cast material. It can be seen in the tensile-strength diagram that the mechanical properties of the first melt are higher, by 11 % at the temperature of 20 °C, than the properties of the third melt. This difference is evident up to 100 °C. At the temperatures of above 100 °C the cast-material strength characteristics are the same. This tendency shows itself on all the materials tested so far. The hardness and microhardness evaluations show that the material reaches the highest values with the fourth melt. This phenomenon is attributed to the repeated reoxidation and exclusion of oxide membranes. Further, the material structure properties and chemical-composition change were evaluated. The results of this study confirmed a negative influence of alloy remelting upon the material properties and structure.

Keywords: aluminium alloys, metallographic analysis, microstructures, thermomechanical properties, remelting, mechanical properties

Namen tega dela je bil oceniti ponavljanje pretaljevanja na mehanske lastnosti, termomehanske lastnosti, kemijsko sestavo in spremembe mikrostrukture izbranega materiala. Izbrana je bila vrsta aluminijeve zlitine Al-Cu na podlagi naraščanja preizkusov na neželeznih kovinah v industriji. Tehnična oznaka izbrane zlitine, skladno z nemškim standardom ALUFOND 60, je RR.350. Zlitina RR.350 je poznana zaradi slabih livarskih lastnosti, ki se s pretaljevanjem poslabšujejo in vplivajo na spremembe mehanskih lastnosti in mikrostrukture v litem stanju. V predstavljenem članku je potrjen negativni vpliv pretaljevanja na uporabne lastnosti. Vzorci za natezne preizkuse so bili uliti v kovinsko kokilo. Ulivni in napajalni sistem, ki se je uporabljal za sekundarno napajanje, je bil odstranjen iz ulitka. Tako je bil material štirikrat pretaljen. Izdelani vzorci so bili porušeni v temperaturnem intervalu med 20 °C in 350 °C. Iz ulitega materiala so bili odrezani vzorci za metalografijo in za meritve trdote (HBS). Iz nateznih diagramov je razvidno, da ima prva talina za okrog 11 % višjo natezno trdnost pri 20 °C v primerjavi s tretjo talino. Ta razlika se opazi do temperature 100 °C. Pri temperaturah nad 100 °C so trdnostne lastnosti materiala v litem stanju enake. Ta tendenca se je pokazala pri vseh do sedaj preizkušenih materialih. Primerjava trdote in mikrotrdote kažeta, da je najvišjo vrednost dosegel material četrte taline. Ta pojav se pripisuje ponovljeni reoksidaciji in odsotnosti oksidnih kožic. Ocenjene so bile tudi značilnosti mikrostrukture in določene kemijske sestave. Rezultati teh preiskav so potrdili negativen vpliv večkratnega pretaljevanja na mikrostrukturo in lastnosti materiala.

Ključne besede: aluminijeve zlitine, metalografska analiza, mikrostrukture, termomehanske lastnosti, pretaljevanje, mehanske lastnosti

1 INTRODUCTION

At present the significance of non-ferrous metal alloys as structural materials is growing thanks to their good mechanical and thermomechanical properties, low specific weight and heat-treatment possibility enhancing usable properties of the alloy. By virtue of the aforementioned properties, non-ferrous metal alloys replace iron-based alloys in various industry branches. Non-ferrous metals utilization in various industry branches will have an increasing trend in the future. Considering the rising prices of the materials, the enterprises engaged in the processing of alloys and in the manufacture of castings seek for a production-cost reduction. This trend has been intensified due to the contemporary economic crisis. One saving way is the utilization of recycled material or remelting of foundry returns.

Some of the most widely used non-ferrous metal alloys are aluminum-based alloys. In this paper we have focused on the Al-Cu alloy RR.350. Due to its favourable properties, low weight, minimal dilatation and capability to resist high temperatures up to 350 °C, the RR.350 alloy is used for the thermally stressed castings and the castings subjected to higher pressures[1]. This alloy has an extensive usability not only in the automotive industry. The RR.350 alloy is used in heat-treatment conditions when its usable properties reach the highest values. This study is focused on an evaluation of the

Figure 1: Test bar
Slika 1: Preizkusna palica

mechanical and thermomechanical properties of the above-mentioned alloy after multiple remelting in casting conditions. After the melting and casting of the samples, a gating system, which then served as a new charge, was cut off. These steps were performed four times and then the material changes after remelting were assessed. The research team focused on the changes in following properties: tensile strength, hardness, micro-hardness, alloy chemical composition and alloy structure after remelting. The research took place in the VŠB – Technical University Ostrava laboratories.

2 MATERIALS AND METHODS

To observe the re-melting of non-ferrous metals, an Al-Cu alloy with the technical nomenclature of RR.350 was chosen. The chemical composition of the alloy used for the experiment is shown in **Table 1**.

Table 1: Chemical composition of the RR.350 alloy (in mass fractions, *w*/%)
Tabela 1: Kemijska sestava zlitine RR.350 (v masnih deležih, *w*/%)

Fe	Cu	Mn	Mg	Ni	Zn
0.368	4.731	0.310	0.034	1.937	0.126
Ti	**Pb**	**Sn**	**Co**	**Cr**	**Al**
0.117	0.011	0.042	0.203	0.007	92.115

The original alloy with the as-delivered chemical composition was melted in an electric resistance furnace in a graphite-fireclay crucible and marked as I. melt. For the casting of the test bars, a metal mould equipped with a silicon sprayed-on coat preventing the sticking of the casting to the mould was used. The mould consists of a gating system with a bottom gate (for the laminar filling of the mould), a test bar and a riser. The riser is over dimensioned to eliminate defects, for instance the shrinkage cavities. After having cast a batch of the test bars marked as I. melt, the gating system with the riser, which served as a charge for the next heat, was removed. In this way we re-melted the original material four times. The test bars (**Figure 1**) were machined and subjected to a tensile test in the temperature range of 20 °C to 350 °C. The measurement was performed on the INOVA PRAHA tensile-testing machine. The heating of the samples was performed in a resistance furnace with an inert atmosphere. At each temperature, three samples were ruptured and the numerical values of their diameters were entered into the diagram.

For the hardness measurement, nine samples were used and each of them was subjected to three incisions. The sample preparation for the hardness testing (HB) was performed in a metallographic laboratory. At first, we cut off a one-centimeter-long cylinder from the cast sample with the help of an emulsion-cooled saw. Then the surface polishing on a horizontal water-cooled grinder followed using the emery cloths with a granularity of 360 up to 1.200. As a test specimen, a hardened ball of 2.5 mm in diameter was used. The test sample was placed on a work plate and adjusted so that the indentor could be pointed to the centre. Now the indentor arm was moved to the vertical position and the arm movement onto the sample was switched on. The machine carried out the loading to the value of 306.5 N, with the holding time of 10 s, followed by a release of the indentor.

The metallographic analysis was done with the help of a GX 51 microscope, equipped with light polarization, with a magnification of 12.5–1000.

The chemical analysis was performed on a GDS-LECO spectrometer with the aid of the reference-material calibration with guaranteed element content.

3 EXPERIMENTAL RESULTS AND DISCUSSION

The obtained results confirm a negative influence upon the remelted alloy.

The measured results of the tensile tests (**Figure 2**) show that the maximum strength of the original material (I. melt) is reached at the temperatures of 20 °C and 100 °C. During the third remelting, the tensile strength values at the temperatures of 20 °C and 100 °C decreased by approximately 24 MPa, which was 11 %. At the temperatures of over 100 °C, the strength values

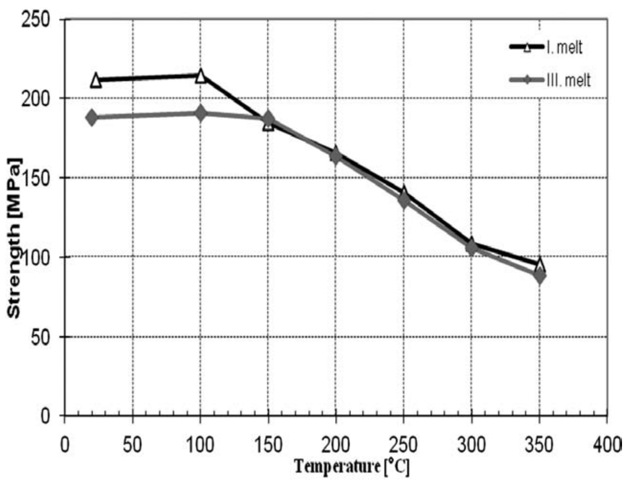

Figure 2: Dependence of tensile strength on temperature for different melts
Slika 2: Odvisnost natezne trdnosti od temperature pri različnih talinah

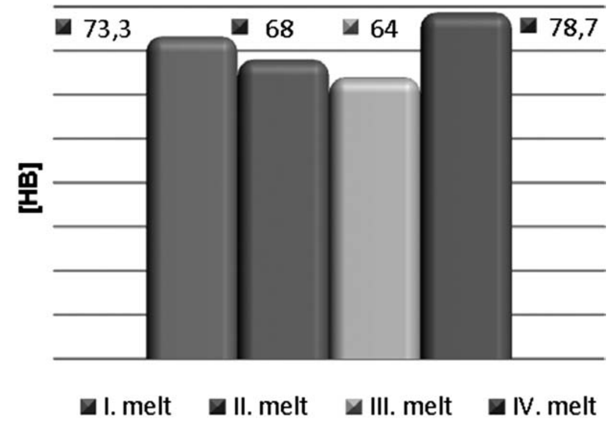

Figure 3: Values of Hardness of individual melts
Slika 3: Trdota materiala posameznih talin

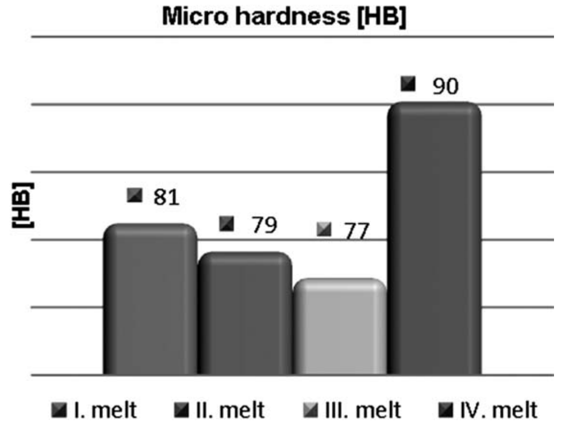

Figure 4: Values of Micro-Hardness of individual melts
Slika 4: Mikrotrdota materiala posameznih talin

of both melts were the same. This tendency was similar for the most of the tested materials[2]. The equation of the values of the tensile strength at elevated temperatures can be explained with the melting of low-melting components in the material which could occur by segregation in the material.

For this paper, the tensile-strength values of I. and III. melts were selected. II. and IV. melts will be finished and published in the next papers.

In both diagrams, the hardness values (**Figure 3**) and the microhardness values (**Figure 4**) are the highest for IV. melt. This tendency can be explained with the repeated melt oxidation and the formation of oxide membranes and intermetallic phases. The formation of oxides and intermetallic phases increases the alloy hardness and decreases the tensile strength owing to the unsuitably excluded shapes causing the notch effects in the material matrix[3]. Through their properties, aluminum oxides and intermetallics have a negative effect on the machining of the casting.

Multiple remelting does not affect only mechanical properties, but it changes chemical composition and structure morphology as well.

Comparing I. and II. melt (**Tables 1** and **2**) we can see that weakening of the alloy occurred at II. melt on account of decrease of some elements. The biggest decrease was observed for Cu (0.9129 %), Mn (0.06921 %), Ni (0.2191 %), Mg (0.0213 %). Compared to this, Al content was increased (1.318 %).

Table 2: Chemical analysis of II. melt (*w*/%)
Tabela 2: Kemijska sestava II. taline (*w*/%)

Fe	Cu	Mn	Mg	Ni	Zn
0.234	3.8181	0.24079	0.0127	1.7179	0.0828
Ti	**Pb**	**Sn**	**Co**	**Cr**	**Al**
0.172	0.00366	0.0141	0.271	0.000426	93.433

Table 3: Chemical analysis of III. melt (*w*/%)
Tabela 3: Kemijska sestava III. taline (*w*/%)

Fe	Cu	Mn	Mg	Ni	Zn
0.251	3.7737	0.25548	0.0112	1.6621	0.0758
Ti	**Pb**	**Sn**	**Co**	**Cr**	**Al**
0.159	0.00257	0.00947	0.529	0.000488	93.541

Comparing I. and III. melts (**Tables 1** and **3**) we can see that a weakening of the alloy also occurred with III.

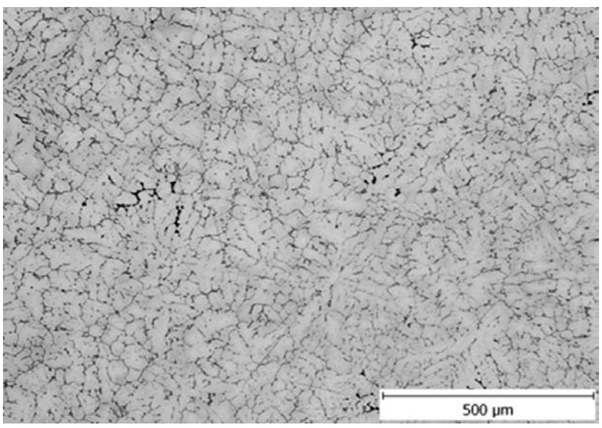

Figure 5: I. melt – magnified 100-times
Slika 5: I. talina – povečava 100-kratna

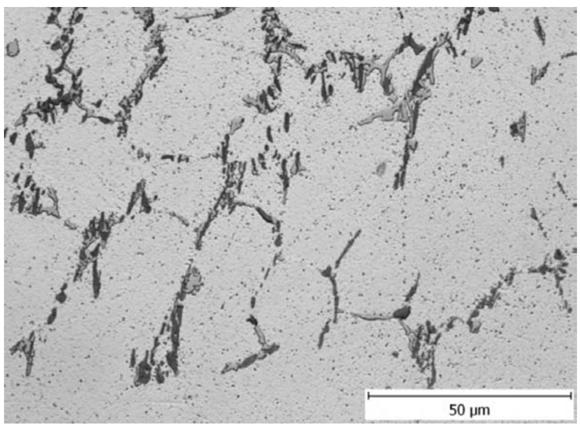

Figure 6: I. melt – magnified 1000-times
Slika 6: I. talina – povečava 1000-kratna

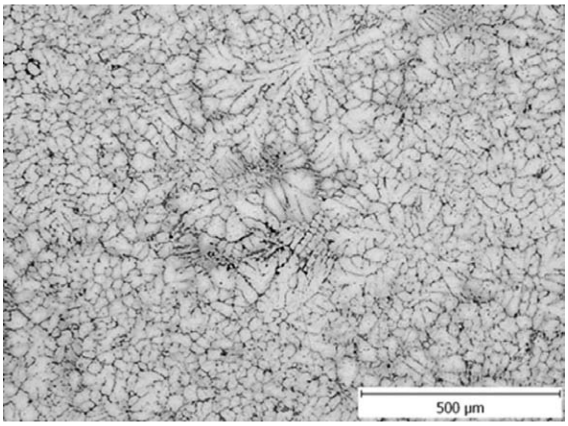

Figure 7: II. melt – magnified 100-times
Slika 7: II. talina – povečava 100-kratna

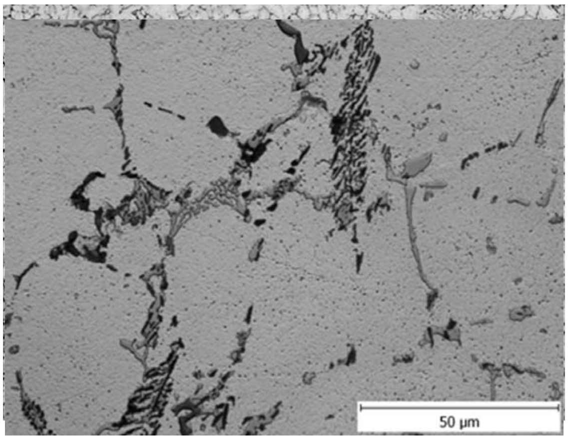

Figure 8: II. melt – magnified 1000-times
Slika 8: II. talina – povečava 1000-kratna

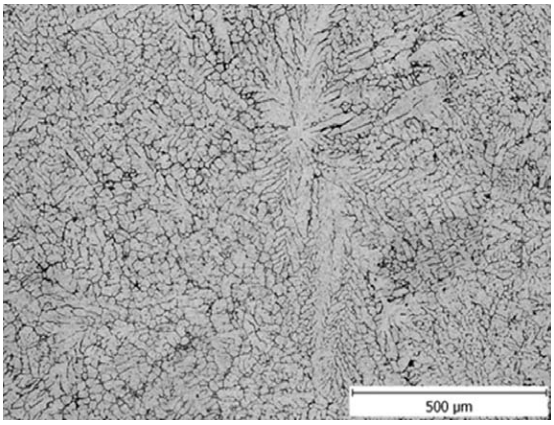

Figure 9: III. melt – magnified 100-times
Slika 9: III. talina – povečava 100-kratna

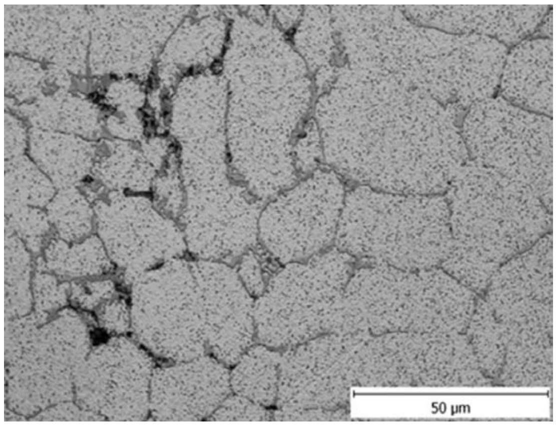

Figure 10: III. melt – magnified 1000-times
Slika 10: III. talina – povečava 1000-kratna

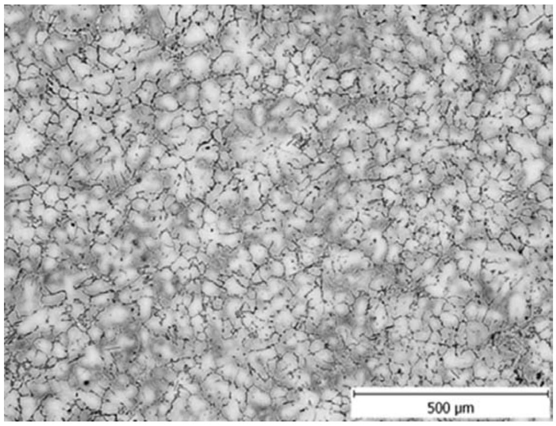

Figure 11: IV. melt – magnified 100-times
Slika 11: IV. talina – povečava 100-kratna

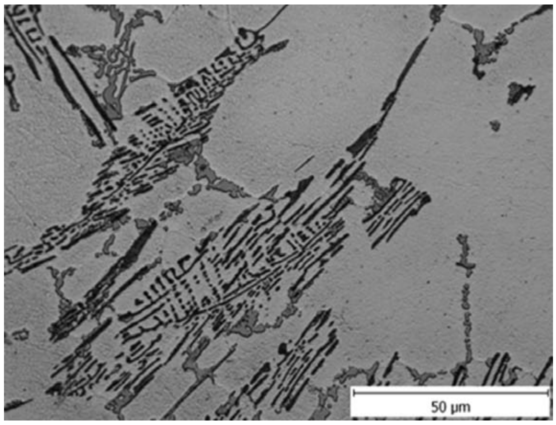

Figure 12: IV. melt – magnified 1000-times
Slika 12: IV. talina – povečava 1000-kratna

melt due to a decrease in some elements. The biggest decrease was again observed for Cu (0.9573 %), Mn (0.05452 %), Ni (0.2749 %) and Mg (0.0228 %). On the other hand, the Al content was increased (1.426 %).

Due to multiple remelting the material structure changes its morphology as well (**Figures 5** to **12**). The changes in the material structure are shown as grain coarsening, unevenness of dendritic cells and dendrites[4], higher content of cavities and coarsening of intermetallic phases.

4 CONCLUSIONS

Properties of the RR.350 alloy after repeated remelting were observed. For each remelting, the basic material properties were determined, i.e., tensile strength, hardness, structure and chemical composition. The cast-material tensile strength dropped by 11 % at the temperatures of up to 100 °C. The hardness reached the highest values in the case of IV. melt. The material structure change influenced most of the above-mentioned changes. By multiple remelting, a grain coarsening, unevenness of dendritic cells, a higher content of cavities and coarsening of the intermetallic phases occur. The reason for a decrease in the alloying elements is the re-melt loss in the resistance furnace. The RR.350-alloy testing offers other ways of mechanical-property enhancement. An advisable option is a substitution of the elements decreased due to multiple remelting and follow-up inoculations with an AlTi5B1 master alloy[5]. Further, the alloy can be very well hardened with the help of a heat treatment (the strength values reach up to 300 MPa). As mentioned above, the alloy is susceptible to various kinds of cavities, therefore degassing before casting would be advisable. For the manufacture of castings, we can also recommend filtration to remove the inclusions which decrease mechanical properties.

This paper was created within the project No. CZ.1.05/2.1.00/01.0040 "Regional Materials Science and Technology Centre", under the frame of the operation programme "Research and Development for Innovations" financed by the Structural Funds and by the state budget of the Czech Republic.

5 REFERENCES

[1] J. Roučka, Metalurgie neželezných slitin, VUT Brno, 2004

[2] R. Kořený, Možnosti zvýšení kvality vysokopevnostních a žáropevných slévárenských slitin hliníku, VŠB, Ostrava, 1991

[3] F. Píšek, L. Jeníček, P. Ryš, Nauka o materiálu I., Nauka o kovech 3. svazek: Neželezné kovy, Academia, Praha 1973

[4] L. Bäckerud, G. Chai, J. Taminen, Solidification Characteristic of Aluminium Alloys, Foundry Alloys, Volume 2, ASF Skanaluminium, Stockholm, 1990

[5] D. Bolibruchová, E. Tillová, Zlievarenské zliatiny Al-Si, ŽU v Žilině, 2005