INFLUENCE OF RECYCLING OF CAST ALUMINIUM ALLOYS ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES

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Abstract

Considering the rising prices of materials, the enterprises engaged in processing of alloys and in the manufacture of castings seek for ways of production cost reduction. One way of saving is consists in utilisation of recycled materials or in re-melting of foundry returns. This study is focused on evaluation of mechanical and thermo-mechanical properties of the Al-Cu alloy (RR.350) at multiple re-melting in cast condition. The research team focused on a change of following properties: tensile strength, hardness, micro-hardness, change of chemical composition of the alloy, change of the microstructure of the alloy and dilatation after re-melting.

Keywords: tensile strength, hardness, micro-hardness, change of the microstructure of the alloy, dilatation after re-melting

1. INTRODUCTION

Importance of alloys of non-ferrous metals as structural materials is currently growing thanks to their good mechanical and thermo-mechanical properties, low specific mass and possibility of thermal processing enhancing utility properties of the alloy. Thanks to the above-mentioned properties the non-ferrous metals alloys replace in various industries the iron-based alloys [1]. Use of these alloys is very important in machine-building industry: e.g. for heat exchangers, equipment for oil refining, distillation apparatuses, pumps and piping. The largest use is, however, still in the transport industry, where they are used mainly for the components exposed to heat, such as cylinder heads, gears or aerospace components. This trend was intensified by the current economic crisis. One of the ways is to use recycled material or to re-melt foundry returns.

1.1. Alloy RR.350

Some of the most commonly used alloys are the aluminium based alloys. We focused on the Al-Cu based alloy of the type RR.350 due to its favourable properties, low mass, minimal dilatation and its ability to withstand higher temperatures up to 350 °C [2]. The RR.350 alloy is used for the heat-stressed castings and for the castings exposed to higher pressures. This alloy is widely used not only in the automotive industry, and it is used in heat-treated state when its properties achieve the highest values. Our research is focused on the evaluation of mechanical and thermo-mechanical properties of this alloy after its multiple re-melting in the cast state. Chemical composition of the alloy used for the experiment is given in Table 1. The alloy is rich in additive elements, which enhance its (mechanical) properties. The alloy itself has very poor casting properties and impaired resistance to corrosion. It is difficult to ensure its risering as it creates dispersed shrink holes and also cavities of all kinds.
2. METALLURGY FOR TESTING OF THE ALLOY

The aluminium Al-Cu alloy with technical designation RR.350, according to the German standard ALUFOND 60 and under British standard HIDUMINIUM was chosen for investigation of re-melting of non-ferrous metals [3]. The alloy can be used in the environment of cyclic changes of temperatures up to 350 °C.

Table 1 Chemical composition of the alloy RR.350

<table>
<thead>
<tr>
<th>Element [wt. %]</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Ni</th>
<th>Zn</th>
<th>Ti</th>
<th>Pb</th>
<th>Sn</th>
<th>Co</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
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<tr>
<td></td>
<td>0.368</td>
<td>4.731</td>
<td>0.310</td>
<td>0.034</td>
<td>1.937</td>
<td>0.126</td>
<td>0.117</td>
<td>0.011</td>
<td>0.042</td>
<td>0.203</td>
<td>0.007</td>
<td>92.115</td>
</tr>
</tbody>
</table>

Metallic (two-piece) ingot mould with applied special silicone coating was used for casting of test bars for tensile testing machine. The casting consisted of the gating system with bottom inlet (for laminar filling of the mould), the actual test bar and the riser. Since this alloy had bad qualities casting properties forming dispersed shrink holes, the riser had to be oversized. Melting was performed in a resistance crucible furnace with use of graphite-fireclay crucible. The charge for the first melt consisted of the foundry ingot bars of precise chemical composition (Table 1). After casting of a series of test bars marked as the melt I., the gating with the riser inlet was removed and it was used as a charge for the second melt. In this way the initial material was re-melted four times. After casting of test specimens these castings were cooled freely on air. No heat treatment was applied, because we wanted to determine the thermo-mechanical properties of the alloy itself. The samples were cast at the temperatures from 660 °C to 860 °C. Test bars (Fig. 1) were machined and subjected to a tensile test within the temperature range from 20 °C to 350 °C. Measurements were performed on the tensile testing machine INOVA PRAHA. The test specimens were reheated in a resistance furnace under an inert atmosphere. At each temperature three samples were broken and the average numerical value was used for plotting the graph. The actual grinding was performed on a horizontal water-cooled grinder, sandpaper with different gradations from 180 to 2500 was used as abrasive tool.

Fig. 1 Test bar

Altogether nine samples were used for hardness measurements and three indents were applied to each of them. Preparation of the samples for measurement of hardness (HB) and of micro-hardness (HV) was performed in metallographic laboratory. At first we cut from the cast sample a cylinder with length of 1 cm using the emulsion cooled saw. This was followed by polishing of the surface on the horizontal water-cooled grinder with use of emery cloth with granulation from 360 to 1200. A hardened ball with a diameter of 2.5 mm was used as a testing body. The test specimen was placed on a working pad and arranged in such a way that indentor pointed to its centre. The indentor arm was now shifted to vertical position and shifting of the arm to the sample was switched on. The testing instrument applied a load of 306.5 N with a dwell of 10 seconds and indentor was then released [4, 5]. Metallographic analysis was performed with use of the microscope GX 51, which was equipped with a polarised light, at magnification of 12.5 - 1000.
analysis was performed on the spectrometer GDS-LECO with use of calibration of the reference materials with guaranteed content of elements.

3. RESULTS AND DISCUSSION

3.1 Tensile strength

If we compare all four heats (Fig. 2), we can see that at 20 °C the strength of the first two heats remained unchanged. The strength of the third cast, however, decreased by 11% and that of the fourth melt dropped by 18%. At the temperature of 100 °C the second melt showed in comparison with the first melt a decrease in strength of 5%, and strength of the third and fourth heats decreased by 11% and 15% respectively. At the temperature of 150 °C the strength values of the first three heats did not change much, while the strength of the fourth melt decreased by 14%. The temperatures of 200 °C, 250 °C and 300 °C show almost identical strength values for all four heats. This trend is the same for majority of the tested materials. Comparison of tensile strength at elevated temperatures can be explained by the melting of the low-melting components in material, which might have been created by segregation.

![Fig. 2](image1.png)  ![Fig. 3](image2.png)

**Fig. 2** Temperature dependence of strength of the alloy RR.350  **Fig. 3** Temperature dependence of the temperature of plasticity

3.2 Plasticity

Another criterion is the degree of plasticity of the material (Fig. 3), which increases with the thermal exposure. In the first melt we registered an increase of plasticity at the temperature of 100 °C. At the temperature of 150 °C plasticity decreased by 3.3%, and at the temperature of 300 °C it increases by 20.4%. Plasticity in the melt II. showed an increase already from the temperature of 100 °C up to 300 °C. In the melt III. plasticity increased 150 °C (by 4.7%), this was followed by a slight decline and sharp increase at the temperature of 300 °C (by 18.8%). The values measured for the melt IV. showed a slight decrease at the temperature of 150 °C (by 1.7%) and then an increase at the temperature of 300 °C (by 18.1%). Between the heats I.-III. and IV. a considerable decrease of plasticity by 5.2% took place at the temperature of 300 °C.
3.3 Hardness and micro-hardness

The values of hardness (Fig. 4) and micro-hardness (Fig. 5) in both graphs are the highest in the fourth melt. This trend can be explained by repeated oxidation of the melt and by formation of oxide membranes and inter-metallic phases. Formation of oxides and inter-metallic phases increases hardness of the alloy, reduces the tensile strength due to improperly excluded shapes having notch effects in the material matrix. Properties of aluminium oxides and inter-metallics have a negative effect on machining of the casting.

3.4 Electron microscope

Due to the large number of samples only the mean temperatures from casting of each melt were selected for analysis (samples Nos. 31, 42, 82 and 101). The samples used are those that have already been used for metallographic evaluation. We give her for comparison only the samples for the melts I and IV. (Figs. 6 and 7). The results from the electron microscope are shown in Tables 2 and 3.
Table 2 Chemical composition of the melt I

<table>
<thead>
<tr>
<th>Designation</th>
<th>O</th>
<th>Al</th>
<th>Mn</th>
<th>Fe</th>
<th>Co</th>
<th>Ni</th>
<th>Cu</th>
<th>Zr</th>
<th>Sb</th>
</tr>
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<tbody>
<tr>
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<td>2.8</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Spectrum1</td>
<td>15.3</td>
<td>25.0</td>
<td>0.7</td>
<td>1.7</td>
<td></td>
<td></td>
<td>57.4</td>
<td></td>
<td></td>
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<tr>
<td>Spectrum2</td>
<td>49.8</td>
<td>0.6</td>
<td>1</td>
<td>11.0</td>
<td>37.6</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Spectrum3</td>
<td>62.8</td>
<td>1.7</td>
<td>2.9</td>
<td>2.7</td>
<td>4.9</td>
<td>24.3</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrum4</td>
<td>76.5</td>
<td>0.7</td>
<td>2.7</td>
<td>3.6</td>
<td>12.8</td>
<td>3.7</td>
<td></td>
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</tbody>
</table>

Table 3 Chemical composition of the melt IV

<table>
<thead>
<tr>
<th>Designation</th>
<th>O</th>
<th>Al</th>
<th>Ti</th>
<th>Mn</th>
<th>Fe</th>
<th>Co</th>
<th>Ni</th>
<th>Cu</th>
<th>Sb</th>
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<tbody>
<tr>
<td>matrix</td>
<td>96.9</td>
<td>0.6</td>
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<td></td>
<td></td>
<td></td>
<td>2.5</td>
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<tr>
<td>Spectrum1</td>
<td>16.9</td>
<td>22.8</td>
<td></td>
<td>0.4</td>
<td>0.7</td>
<td>22.5</td>
<td>32.7</td>
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<tr>
<td>Spectrum2</td>
<td>43.7</td>
<td></td>
<td>2.3</td>
<td>3.9</td>
<td>2.9</td>
<td>4.6</td>
<td>27.7</td>
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<tr>
<td>Spectrum3</td>
<td>58.5</td>
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<td>4.3</td>
<td>5.3</td>
<td>14.8</td>
<td>3.8</td>
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<tr>
<td>Spectrum4</td>
<td>71.1</td>
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<td>0.7</td>
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</table>

3.5 Microstructures

Material structure also changes its morphology as a result of multiple re-melting (Figs. 8 and 9). Changes in the material structure are manifested by grain coarsening [6, 7], unevenness of dendritic cells and dendrites, by higher content of cavities, by coarsening of inter-metallic phases. In the I. various inter-metallic phases can be seen, such as: CuAl\(_2\) (light gray to light pink), which creates networking along the grain boundaries, AlCuFeMn (brown to black). In the heat IV. a very distinct inter-metallic phase AlFeMn ("Chinese characters") are very distinct [8].

![Fig. 8 Microstructures of the melts I.](image)

![Fig. 9 Microstructures of the melts IV.](image)

4 CONCLUSIONS

Aluminium alloy RR.350 was investigated after repeated re-melting. At each re-melting the defined basic material properties were determined, such as tensile strength, plasticity, hardness, structure and chemical composition. The tensile strength of the cast material decreased at the temperatures below 100 °C by 11%. Plasticity dropped in the melt IV. in comparison with the melts I. - III. by 5.2% at the temperature of 300 °C.
The highest values of hardness were determined in the fourth melt. The change of the material structure has the greatest impact on the above changes. Repeated re-melting brings the following changes: grain coarsening, irregularity of dendritic cells, higher content of cavities and coarsening of inter-metallic phases. Decrease of contents of tramps elements is caused by a burn-off in a resistance furnace. Testing of the alloy RR.350 offers other ways to enhancement of mechanical properties. Addition (replenishment) of elements lost due to multiple re-melting and subsequent inoculation of the alloy by the foundry alloy AlTi5B1 seems to be an appropriate treatment [9,10]. The alloy can be furthermore hardened by heat treatment (strength values achieve even 300 MPa). As mentioned above, the alloy is susceptible to formation of various types of cavities, so it should be degassed before casting. It is also advisable to apply at production of the casting a filtration in order to remove inclusions, which reduce the mechanical properties.

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LITERATURE


