Investigating the Possibility of Alloying an Alloy AlSi25Cu5Cr with Co, Cr and Mo Using Metal Powder

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Abstract. A base aluminium-silicon alloy AlSi25Cu5Cr was used to investigate the possibility of alloying aluminium alloys with hard-to-melt elements. The alloying elements Co, Cr and Mo were introduced into the melt using metal powder from a hard-melting dental cobalt-chromium-molybdenum alloy. The metal powder was packed in aluminium foil and introduced into the melt of the studied alloy at a temperature of 810°C. After alloying and mechanical stirring of the melt, it stood for 30 min. at a temperature, raised to 850°C and experimental castings were cast from it. After spectral analysis, the degree of absorption of the alloying elements by the aluminium melt was determined. The structure and mechanical properties of the thus obtained alloy were investigated.

Keywords: alloying, aluminium-silicon alloy, dental cobalt-chromium-molybdenum alloy, hard-melting elements.

I. INTRODUCTION

The eutectic and hypereutectic aluminium-silicon alloys have found application in automotive industry for manufacturing pistons for internal combustion engines. The heavy loads, endured by the pistons during their operation are the reason behind the increased requirements toward the alloys, used for their production. Piston manufacturer MAHLE uses a great variety of aluminium-silicon alloys, mainly eutectic (M124, M142, M174+) and hypereutectic (M126, M138, M145, M244). The used alloying elements are copper, nickel, and magnesium in various concentrations. Copper in the alloys M124, M126, M138 and M244 is within 0,8-1,5%, while nickel and magnesium are in the range of 0,8-1,3%. The eutectic alloy M124 has won recognition as the “classic” piston alloy and it has been the basis of the vast number of pistons produced in the recent decades. The pistons, made of hypereutectic aluminium-silicon alloys, demonstrate higher wear resistance. Of this group, alloys M138 and M244 are preferred for producing two-stroke engine pistons, while alloy M126 is used in the USA for passenger car petrol engines. Alloys M142, M145 and M174+ have been developed and used since recently. Their common feature is the increased content of the alloying elements copper (2,5-5%) and nickel (1-3%). This is the reason for their high strength at increased temperatures, which, in turn, has led to their quick launch into the market. The M142 eutectic alloy is mainly used in petrol engines, while the M174+ alloy, also of the eutectic type, is increasingly used in diesel engines. The hypereutectic aluminium-silicon alloy M145 is used in several petrol engines [1]. The development of new hypereutectic aluminium-silicon piston alloys to be competitive to those, used so far by the global piston manufacturers is the subject of many researchers [2]-[7]. The use and combination of different concentrations of alloying elements aims at increasing the strength parameters of the alloys both at normal and at high temperatures. The influence of the alloying elements on the structure and properties of the aluminium-silicon alloys is presented in [8]-[10]. In order to influence the structure and obtain aluminium-silicon alloys with high mechanical and operational properties, experiments are conducted, in which Co, Ni, Cr and Mo and combinations of them are used for alloying the alloys [11]-[15].

The aim of the present research is to establish the possibility of alloying AlSi25Cu5Cr alloy with Co, Cr and Mo by using metal powder.
II. MATERIALS AND METHODS

A basic non-standardized hypereutectic aluminium-silicon alloy AlSi25Cu5Cr, whose chemical composition is shown in Table 1, was used to study the possibility of alloying aluminium alloys with hard-to-melt (churlish) elements.

| TABLE 1 CHEMICAL COMPOSITION OF AlSi25Cu5Cr (%) |
|-----------------|-----|-----|-----|-----|-----|
| Si | Cu | Cr  | Fe  | Mg  | Al  |
| 24.92 | 4.05 | 0.559 | 0.136 | 0.003 | rest |

The alloying elements cobalt, molybdenum, and part of chromium were introduced into the melt by using metal powder from the high-melting dental cobalt-chromium-molybdenum alloy WIRONIT, with a chemical composition, presented in Table 2.

| TABLE 2 CHEMICAL COMPOSITION OF WIRONIT (%) |
|-----|-----|-----|-----|-----|
| Co | Cr  | Mo  | Mn  | Si  |
| 64  | 28.5 | 5   | 1   | 1   |

The metal powder was packed in aluminium foil and introduced into the melt of the studied alloy at a temperature of 810ºС. After alloying and mechanical stirring, the melt stood for 30 minutes at a temperature, increased to 850ºС. After metallurgical processing of the alloy, including refining, degassing and modification with phosphorus in the amount of 0.07%, experimental castings were made of it. The metallurgical processing of the melt was carried out at a temperature of 850ºС, while the casting temperature was 830ºС. Metal equipment, preheated to 200ºС in advance, was used for casting the experimental samples.

The castings were thermally treated under the T6 mode, during which the heating for homogenizing of the structure was carried out at a temperature 510-515ºС, the retention time at this temperature was 6h30min., and the used cooling medium was water with a temperature of 20ºС.

The castings were thermally treated under the T6 mode, during which the heating for homogenizing of the structure was carried out at a temperature 510-515ºС, the retention time at this temperature was 6h30min., and the used cooling medium was water with a temperature of 20ºС. The artificial ageing of the samples after their hardening was carried out at a temperature of 180ºС, with retention times at the chosen operational temperature 12h and 14h.

To determine the degree of absorption of the alloying elements introduced into the melt by using metal powder from the dental cobalt-chromium-molybdenum alloy WIRONIT, a spectral analysis was carried out with an ARUN Technology spectrometer. Microstructural analysis and mechanical tests of the alloy AlSi25Cu5Cr, interfused with Co, Cr and Mo, were carried out before and after its exposure to heat treatment.

III. RESULTS AND DISCUSSION

The used amount of metal powder aimed at introducing Co-0.2%, Cr-0.09% and Mo-0.016% into the melt. The results from the performed spectral analysis show that not all amount of the metal powder was absorbed by the melt of the studied aluminium-silicon alloy. The degree of absorption of the alloying elements Co, Cr and Mo is about 85%. Table 3 presents the chemical composition of the alloy after its modification by 0.07% P and alloying with WIRONIT.

| TABLE 3 CHEMICAL COMPOSITION OF AlSi25Cu5Cr+ WIRONIT (%) |
|-----------------|-----|-----|-----|-----|-----|
| Si | Cu | Cr  | Co  | Mo  | Fe  | Al  |
| 24.93 | 4.5 | 0.638 | 0.172 | 0.014 | 0.443 | rest |

Increase in the amount of Cu in the composition of the alloy was also registered, which is due to the used amount of the modifier phosphorus, introduced into the melt through the ligature CuP10.

The primary Si crystals in the structure of the alloy AlSi25Cu5Cr, modified by 0.07% P and alloyed with Co, Cr and Mo before being subjected heat treatment, are 24.8 μm in size. Single crystals of Si with slightly larger sizes are observed, and their calculated arbitrary average diameter is of the order of 40-46 μm. The Si crystals in the composition of the eutectic have crystallized in the form of needles and have an average linear size of 33.4 μm (total average size). The main amount of eutectic Si crystals is up to 20 μm in size, though crystals, measuring from 30 to 80 μm are also observed (Fig.1). The mechanical properties of the alloy, infused this way, are shown in Table 4.

| TABLE 4 MECHANICAL PROPERTIES OF AlSi25Cu5Cr+ WIRONIT |
|-----------------|-----|-----|-----|
| Alloy | Microhardness | Macrohardness | Rm [MPa] |
| AlSi25Cu5Cr | 79.2μHV | 129.5HV | 121 |

After heat treatment under the T6 mode, during which the artificial ageing was carried out at a temperature of 180ºС and the retention time was 12h, a change in the shape
and size of the eutectic silicon crystals was observed. From a needle-like one, their shape spheroidized, and their arbitrary average diameter, both measured and calculated, was 6.7 µm. The main amount of primary Si crystals measured about 22 µm. Single crystals with slightly larger dimensions of the order of 55 µm are observed (Fig. 2). The conducted mechanical tests established an increase in the micro- and macro-hardness of the alloy, as well in its tensile strength compared to the same alloy before being subjected to heat treatment. After the heat treatment, performed in the described way, the alloy has the mechanical properties, shown in Table 5.

![Fig. 2. Microstructure of alloy AlSi25Cu5Cr + 0.07% P + Co, Cr and Mo - T6 (artificial ageing 180⁰C/12h).](image)

**TABLE 5 MECHANICAL PROPERTIES OF ALSi25Cu5Cr+ WIROTIN+ T6 (ARTIFICIAL AGEING 180⁰C/12h)**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Microhardness</th>
<th>Macrohardness</th>
<th>Rm [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlSi25Cu5Cr</td>
<td>86.2µHV&lt;sub&gt;90/10&lt;/sub&gt;</td>
<td>142.1HV&lt;sub&gt;10/10&lt;/sub&gt;</td>
<td>215</td>
</tr>
</tbody>
</table>

In the structure of the studied alloy after its heat treatment under the T6 mode, in which the artificial ageing was carried out at 180°C and the retention time was 14h, no significant change in the shape and sizes of the primary silicon crystals was observed. Their arbitrary average diameter was 19.7 µm. A change in the shape and size of the silicon crystals in the composition of the eutectic was registered. Part of the crystals had a spheroidal shape and dimensions of the order of 6.2 µm, though ones in the form of plates, about 12.5 µm long and 2 µm wide, were also observed (Fig. 3). With increasing the retention time (14h) during artificial ageing, an increase in the micro- and macro-hardness of the alloy is observed, but the value of the tensile strength decreases. Table 6 shows the mechanical properties of the studied alloy after heat treatment under the T6 mode, in which the artificial ageing is carried out at a temperature of 180°C, and the retention time is 14h.

![Fig. 3. Microstructure of alloy AlSi25Cu5Cr + 0.07% P + Co, Cr and Mo - T6 (artificial ageing 180⁰C/14h).](image)

**TABLE 6 MECHANICAL PROPERTIES OF AlSi25Cu5Cr+ WIROTIN+ T6 (ARTIFICIAL AGEING 180⁰C/14h)**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Microhardness</th>
<th>Macrohardness</th>
<th>Rm [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlSi25Cu5Cr</td>
<td>89.2µHV&lt;sub&gt;90/10&lt;/sub&gt;</td>
<td>153.2HV&lt;sub&gt;10/10&lt;/sub&gt;</td>
<td>183</td>
</tr>
</tbody>
</table>

The results from the conducted studies show that the absorption of the hard-to-melt elements Co, Cr and Mo by the melt of the base aluminum-silicon alloy AlSi25Cu5Cr is not complete. One possible reason is that the metal powder of the dental cobalt-chromium-molybdenum alloy is oxidized to a certain extent, which, in turn, makes its complete absorption by the melt impossible. The other probable reason is that part of the metal powder floated on the surface of the metal melt and passed into the slag, which hindered the absorption of the hard-melting elements Co, Cr and Mo.

The T6 heat treatment leads to an increase in the mechanical properties of the studied alloy. The tensile strength and macrohardness values of the alloy are competitive with those of the standardized piston hypereutectic aluminum-silicon alloys. The selected parameters of artificial ageing after hardening lead to a change in the shape and size of the eutectic silicon crystals in the structure of the alloy. During artificial ageing at 180°C and retention time 12h the eutectic silicon crystals have a spheroidal shape and significantly small dimensions - 6.7 µm. As the retention time during artificial ageing increases to 14h, a change in the shape of the eutectic Si is observed. Some of the crystals is in the form of plates, which, in turn, leads to a decrease in the tensile strength of the alloy.

IV. CONCLUSIONS

A technology for alloying hypereutectic aluminum-silicon alloys with Co, Cr and Mo by using metal powder from a dental cobalt-chromium-molybdenum alloy is proposed. With the selected parameters (temperature and
time) for the introduction of the alloying elements, their absorption by the melt of the studied alloy amounts at 85%.

After conducting T6 heat treatment, the mechanical properties of the studied alloy AlSi25Cu5Cr, interfused with Co, Cr and Mo, meet the requirements toward the standardized hypereutectic aluminum-silicon piston alloys.

The parameters (temperature and time) of artificial ageing after hardening, in which the eutectic silicon is refined and has a spheroidal shape, which, in turn, is the reason for the increased mechanical properties of the alloy, have been experimentally established. When the retention time during artificial ageing at 180°C operational temperature is increased to 14h, a change in the spheroidal shape of the eutectic silicon crystals is observed. It acquires a plate-like shape, its cutting effect on the α-phase in the composition of the eutectic increases, and a decrease in the tensile strength values of the investigated alloy is observed.

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