Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 14th International Scientific and Practical Conference. Volume 3, 79-82

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 810º C. After alloying and mechanical stirring of the melt, it stood for 30 min. at a temperature, raised to 850º 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 aluminum-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 aluminum-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 aluminum-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 aluminum-silicon alloy M145 is used in several petrol engines [1]. The development of new hypereutectic aluminum-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 aluminum-silicon alloys is presented in [8]-[10]. In order to influence the structure and obtain aluminum-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.

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol3.7180

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 810ºC. After alloying and mechanical stirring, the melt stood for 30 minutes at a temperature, increased to 850ºC. 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 850ºC, while the casting temperature was 830ºC. Metal equipment, preheated to 200ºC 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 510-515ºC, the retention time at this temperature was 6h30min., and the used cooling medium was water with a temperature of 20ºC. The artificial ageing of the samples after their hardening was carried out at a temperature of 180ºC, 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 aluminum-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.

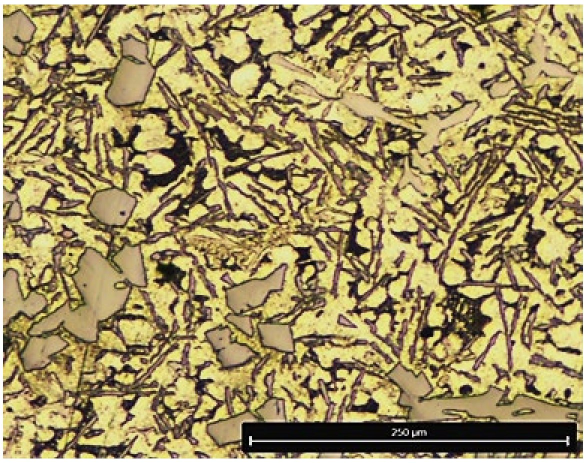

Fig. 1. Microstructure of alloy AlSi25Cu5Cr + 0.07% P + Co, Cr and Mo.

TABLE 4 MECHANICAL PROPERTIES OF ALSI25CU5CR+ WIRONIT

Alloy	Microhardness	Macrohardness	Rm [MPa]
AlSi25Cu5Cr	79.2µ$HV_{50/10}$	129.5$HV_{10/10}$	121

After heat treatment under the T6 mode, during which the artificial ageing was carried out at a temperature of 180ºC 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.

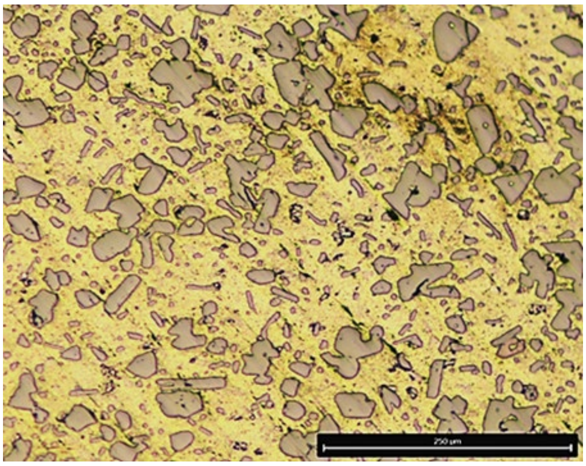

Fig. 2. Microstructure of alloy AlSi25Cu5Cr + 0.07% P + Co, Cr and Mo - T6 (artificial ageing 180ºC/12h).

TABLE 5 MECHANICAL PROPERTIES OF ALSI25CU5CR+ WIRONIT+ T6 (ARTIFICIAL AGEING 180ºC/12h)

Alloy	Microhardness	Macrohardness	Rm [MPa]
AlSi25Cu5Cr	86.2µ$HV_{50/10}$	142.1$HV_{10/10}$	215

In the structure of the studied alloy after its heat treatment under the T6 mode, in which the artificial ageing was carried out at 180ºC 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 180ºC, and the retention time is 14h.

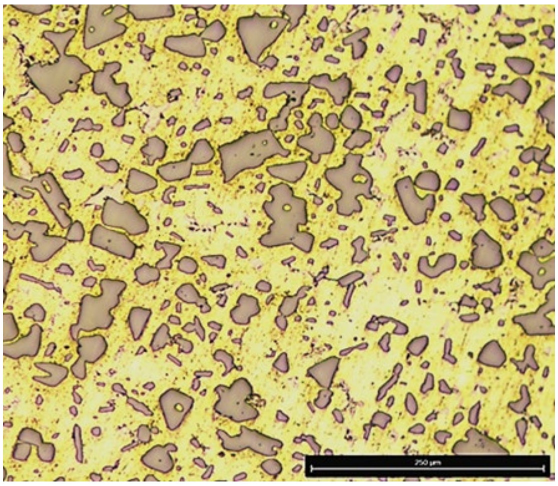

Fig. 3. Microstructure of alloy AlSi25Cu5Cr + 0.07% P + Co, Cr and Mo - T6 (artificial ageing 180ºC/14h).

TABLE 6 MECHANICAL PROPERTIES OF ALSI25CU5CR+ WIRONIT+ T6 (ARTIFICIAL AGEING 180ºC/14h)

Alloy	Microhardness	Macrohardness	Rm [MPa]
AlSi25Cu5Cr	89.2µ$HV_{50/10}$	153.2$HV_{10/10}$	183

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 180ºC 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 180⁰C 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.

Acknowledgments: The study was part of the „Young Researchers and Postdocs–2"National Scientific Programme and was funded by the Technical University of Sofia, Branch Plovdiv, Faculty of Mechanical Engineering.

REFERENCES

[1] Mahle GmbH „Piston materials. In: Pistons and engine testing". ATZ/MTZ-Fachbuch. Vieweg+Teubner Verlag, Wiesbaden.2012 https://doi.org/10.1007/978-3-8348-8662-0_4

[2] N. Raghukiran, R.Kumar, „Effect of scandium addition on the microstructure, mechanical and wear properties of the spray formed hypereutectic aluminum–silicon alloys", Materials Science and Engineering: A, Volume 641, p. 138-147, 2015 https://doi.org/10.1016/j.msea.2015.06.027

[3] P. Xing, B. Gao, Y. Zhuang, K. Liu, G. Tu, „On the modification of hypereutectic Al-Si alloys using rare earth Er". Acta Metallurgica Sinica (English Letters), Vol. 23, Issue 5, p.327-333, 2010 https://doi.org/10.11890/1006-7191-105-327

[4] M. Zuo, D. Zhao, X. Teng, H. Geng, Z. Zhang, „Effect of P and Sr complex modification on Si phase in hypereutectic Al–30Si alloys". Materials & Design, Volume 47, May, p. 857-864, 2013 https://doi.org/10.1016/j.matdes.2012.12.054

[5] S. Miladinović, B. Stojanović, S. Gajević, A. Vencl, „Hypereutectic Aluminum Alloys and Composites: A Review" https://link.springer.com/article/10.1007/s12633-022-02216-2

[6] K. Kamarska, „ Study of the corrosion behavior of aluminum-silicon alloy AlSi18Cu3CrMn in acidic media", AIP Conference Proceedings 2449, 060018, September 2022, https://doi.org/10.1063/5.0090753

[7] K. Kamarska, „Corrosion of AlSi18Cu3CrMn aluminum alloy in a chloride-containing medium", AIP Conference Proceedings 2449, 60019, September 2022, https://doi.org/10.1063/5.0090754

[8] R. Rana, R. Purohit, S. Das, „Reviews on the Influences of Alloying elements on the Microstructure and Mechanical Properties of Aluminum Alloys and Aluminum Alloy Composites", International Journal of Scientific and Research Publications, Volume 2, Issue 6, 2012, ISSN 2250-3153

[9] O. Joseph, P. Olubambi, O. Joseph, B. Edun, J. Okeniyi, O. Abioye, „Effects of Alloying on Aluminium-Silicon Alloys – A Review", IOP Conference Series: Materials Science and Engineering, Volume 1107, 2021 https://iopscience.iop.org/article/10.1088/1757-899X/1107/1/012116/pdf

[10] E. Efzan, H. Kong, C. Kok, „Review: Effect of Alloying Element on Al-Si Alloys", Advanced Materials Research, Volume 845, p. 355-359, 2013 https://doi.org/10.4028/www.scientific.net/AMR.845.355

[11] T. Bogdanoff, A. Dahle, S. Seifeddine, „Effect of Co and Ni Addition on the Microstructure and Mechanical Properties at Room and Elevated Temperature of an Al–7%Si Alloy", International Journal of Metalcasting, Volume 12, p.434–440, 2018 https://link.springer.com/article/10.1007/s40962-017-0178-z

[12] J. Yeh, S. Chang, Y. Hong, S. Chen, S. Lin, „Anomalous decrease in X-ray diffraction intensities of Cu–Ni–Al–Co–Cr–Fe–Si alloy systems with multi-principal elements", Materials Chemistry and Physics, Volume 103, Issue 1, 15 May, p. 41-46, 2007 https://doi.org/10.1016/j.matchemphys.2007.01.003

[13] C. Nwambu, E. Nnuka, J. Odo, C. Nwoye, S.Nwakpa, „Effect of Molybdenum and Cobalt Addition on Structure and Mechanical Properties of Aluminium-12.5%Silicon Alloy", International Journal of Engineering Science Invention, Volume 3 Issue 4, p.20-24, 2014 http://www.ijesi.org/

[14] M. Sha, S. Wu, X. Wang, L. Wan, P. An, „Effects of cobalt content on microstructure and mechanical properties of hypereutectic Al–Si alloys", Materials Science and Engineering: A, Volume 535, February, p. 258-263, 2012 https://doi.org/10.1016/j.msea.2011.12.077

[15] M. Sha, S. Wu, L. Wan, „Materials Science and Engineering: A", Volume 554, September, p. 142-148, 2012 https://doi.org/10.1016/j.msea.2012.06.026