DOI: 10.21062/mft.2026.008 http://www.journalmt.com

Influence of High-melting-point Metals on the Mechanical Properties of Selected Al–Si Alloys

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This article is dedicated to exploring the potential enhancement of mechanical properties, such as hardness and tensile strength, in selected Al-Si alloys (AlSi7Mg0.3, AlSi7Cu4, and AlSi10.5Cu1.2Mn0.8Ni1.2). High-melting-point elements, such as chromium and molybdenum, are rarely utilized as additives in Al-Si alloys. However, the article demonstrates the feasibility of improving the mechanical properties of these alloys through the addition of high-melting-point elements. High-melting-point metals, often referred to as refractory metals, typically have melting points above 2000 degrees Celsius. Common refractory metals include tungsten, molybdenum, tantalum, niobium, rhenium, and others. These metals exhibit excellent mechanical properties at elevated temperatures and often possess high density and good corrosion resistance. All casts were made using by gravity casting with different heat treatment conditions at 740 °C. The microstructures, hardness, microhardness and tensile strenght of the samples were analyzed. Hardness measurements were conducted using two types of hardness testers according to ČSN EN ISO 6506-1 for the Brinell hardness test method and ČSN EN ISO 6507-1 for the Vickers hardness test method. A static tensile test was performed on a universal testing machine, Inspekt 100, in accordance with the standard ČSN EN ISO 6892-1. The measured data demonstrated that high-melting-point metals affect each alloy differently. In some alloys, mechanical properties improved after heat treatment, while in others, a significant deterioration was observed, particularly in tensile strength.

Keywords: Al-Si alloys, Intermetallics, High-melting-point metals, Hardness, Tensile strength

1 Introduction

High-melting point elements, such as chromium and molybdenum are rarely used as additions in Al-Si alloys [1]. The addition of high-melting elements to aluminium-silicon (Al-Si) alloys serves various purposes and imparts beneficial properties to the alloy, depending on the specific element added [2]. High-melting elements like chromium, iron, nickel, molybdenum, niobium, and copper can enhance the mechanical properties of Al-Si alloys, contributing to increased strength, hardness, and toughness, making the alloys suitable for applications requiring high mechanical performance [3]. Certain high-melting elements can also improve the thermal stability of Al-Si alloys, enabling them to maintain their properties at elevated temperatures [4]. This is crucial for applications exposed to high temperatures during service. Elements such as chromium and copper additionally contribute to improved corrosion resistance, a critical factor in applications exposed to corrosive environments, ensuring a longer service life [5]. Specific alloying elements can enhance the wear resistance of Al-Si alloys, making them suitable for applications where resistance to abrasion and wear is crucial [6]. High-melting elements play a role in controlling the microstructure of Al-Si alloys, influencing the size, distribution, and morphology of phases within the alloy, leading to desirable material properties [7]. The addition of specific elements can modify the solidification behaviour of the alloy, influencing the formation of phases during the casting process. This modification can lead to improved casting properties and reduced susceptibility to defects. High-melting elements enable engineers and metallurgists to tailor the properties of Al-Si alloys to meet specific application requirements [8]. The alloy composition can be adjusted to achieve a balance of properties such as strength, ductility, and machinability. In summary, the addition of high-melting elements is a strategic approach to optimizing the properties of Al-Si alloys for diverse applications. The choice of elements and their concentrations depends on the desired characteristics of the final alloy and the intended use of the material.

In this study, three Al-Si alloys were selected. AlSi7Mg0.3 is an aluminium alloy containing silicon, magnesium, and trace elements. The alloy designation provides information about the major alloying elements present in the material. Silicon enhances the alloy's castability and contributes to the formation of a silicon phase, while magnesium adds to its strength and heat treatability [9]. AlSi7Mg0.3 is commonly used in casting applications, and its properties can be customized through heat treatment. The alloy is recognized for its favourable combination of strength, castability, and heat treatability [10]. Potential applications for this alloy include components in the automotive industry, aerospace, and other sectors where a balance of strength and lightweight characteristics is desirable [11].

AlSi7Cu4 is an aluminium alloy containing silicon and copper as major alloying elements, with other trace elements contributing to its composition. Copper provides additional strength, and in combination with silicon, can contribute to improved wear resistance and heat dissipation [12]. AlSi7Cu4 is often used in casting applications where a combination of good strength, wear resistance, and thermal properties is needed. The alloy's characteristics make it suitable for components in automotive applications, such as engine components and other parts where a balance of strength and heat dissipation is essential [13].

AlSi10.5Cu1.2Mn0.8Ni1.2 is an aluminium alloy with a composition that includes various elements to achieve specific mechanical and thermal properties. Manganese is often added for solid solution strengthening and to improve the alloy's hot-working properties. Nickel enhances strength and can improve the alloy's resistance to corrosion and high-temperature oxidation [14].

The addition of certain alloying elements, including Cr, Fe, Ni, Mo, and Cu, to Al-Si alloys can significantly influence their properties. Each of these elements has specific effects on the alloy's mechanical, thermal, and corrosion-resistant characteristics. Chromium can enhance the corrosion resistance of aluminium alloys, forming a protective oxide layer on the surface, improving resistance to oxidation and corrosion [15]. Iron is often present as an impurity in aluminium alloys, but controlled additions influence the alloy's mechanical properties. Iron has a beneficial effect on reducing the tendency of castings to adhere to metal molds. Therefore, iron is intentionally added to alloys used for pressure die casting. However, excessive iron content may lead to the formation of undesirable phases [16]. Nickel improves the strength and toughness of aluminium alloys, enhancing corrosion resistance and thermal stability. Nickel-containing alloys are often used in high-strength applications [17]. Molybdenum improves the high-temperature strength and creep resistance of aluminium alloys, making it suitable for elevated-temperature applications [18]. Niobium is a carbide-forming element that contributes to grain refinement, enhancing the mechanical properties of Al-Si alloys, particularly at elevated temperatures [19]. Copper is a common alloying element in aluminium alloys, improving strength, hardness. However, excessive copper reduce corrosion re-sistance and can reduce ductility. Copper is often added to enhance the age-hardening response of the alloy [20-23].

2 Materials and methods

First, the base alloys AlSi7Mg0.3, AlSi7Cu4 and AlSi10.5Cu1.2Mn0.8Ni1.2 were prepared with 10% master alloy and then cast into a metal mold (at a temperature of 740 °C). The chemical composition of the master alloy with high melting point metals is in Tab. 1.

Chemical composition of the alloys with high-melting-point metals in the form of a master alloy is shown in the Tab. 2.

***Tab. 1** Composition of the master alloy with high-melting-point metals*

Chemical el.	**Al**	**Si**	**Cr**	**Fe**	**Ni**	**Mo**
wt. [%]	base	0.51	2.98	1.72	3.39	1.15

***Tab. 2** Composition of the alloys after preparation with a master alloy*

AlSi7Mg0.3								
Chemical el.	**Al**	**Si**	**Cr**	**Fe**	**Ni**	**Mo**	**Mg**	**Cu**
wt. [%]	base	6.95	0.32	0.14	0.36	0.24	0.33	0.07
AlSi7Cu4								
Chemical el.	**Al**	**Si**	**Cr**	**Fe**	**Ni**	**Mo**	**Mg**	**Cu**
wt. [%]	base	6.90	0.27	0.13	0.38	0.11	<0.01	4.12
AlSi10.5Cu1.2Mn0.8Ni1.2								
Chemical el.	**Al**	**Si**	**Cr**	**Fe**	**Ni**	**Mo**	**Mg**	**Cu**
wt. [%]	base	10.2	0.29	0.18	1.39	0.14	<0.01	1.13

2.1 Sample preparation

This resulted in the formation of 4 castings in the form of rods. Subsequently, these rods were heat-treated (hardened), with 2 pieces WITHOUT heat treatment and 2 pieces WITH heat treatment. The aim was to analyse the influence of heavy metals on the properties of the AlSi7Mg0.3, AlSi7Cu4, and AlSi10.5Cu1.2Mn0.8Ni1.2 alloys.

The heat treatment (HT) was carried out in a resistance furnace LAC L06V, followed by subsequent artificial aging in a hot air dryer from the brand BINDER. The parameters of heat treatment (melting and artificial aging) varied for all alloys. Values for AlSi7Mg0.3 and AlSi7Cu4 were determined used parameters from practice/industry, and for the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy based on the EP306352 patent. Samples in the form of bars are not thin-walled castings, therefore a lower temperature of the cooling medium was chosen. Two cast rods were taken from each alloy, and the curing process was carried out. The remaining two rods underwent no heat treatment and were used only for comparison. Heat treatment of individual alloys is in Tab. 3.

Tab. 3 *Heat treatment of individual alloys*

Alloy	Homogenization annealing	Cooling into water	Aging
AlSi7Mg0.3	540 °C / 1 h / 4 h	40 °C	170 °C / 6 h
AlSi7Cu4	520 °C / 1 h / 4 h	40 °C	180 °C / 6 h
AlSi10.5Cu1.2Mn0.8Ni1.2	530 °C / 1 h / 4 h	40 - 50 °C	160 °C / 6 h

For sampling from heat-treated and non-heat-treated alloys, a Labotom 5 saw from the manufacturer Struers was used. The sample was cut perpendicular to the surface of the cast rod. The samples were then placed into moulds and cast with a fast-setting mixture called dentacryl. Dentacryl is a two-component methyl methacrylate resin widely used in technical practice in metallographic laboratories. After the dentacryl had solidified, individual samples were removed from the moulds. The prepared samples were ground using mechanical grinding on a double-disc grinder and a Saphir 360 polisher, and then polished to reveal the structure. Grinding was performed using abrasive papers of various grit sizes, ranging from the coarsest to the finest grit. After grinding all the samples on abrasive papers, polishing followed. During polishing, there is no material removal in the form of chips, as in grinding, but rather a deformation of the peaks of surface roughness. A mirror-like surface suitable for microscopic analyses was obtained using polishing cloths with different sizes of abrasive grains in the presence of a suitable emulsion containing corundum (Al_2O_3) particles.

The Brinell test was conducted using the ERNST AT 250X hardness tester. A tungsten carbide ball with a diameter of 2.5 mm was used as the indenter, applying a force of 62.5 kg for a duration of 10 seconds. Individual measurements were performed on samples in both the hardened and non-hardened states. Ten measurements were taken, and the average value was calculated from these measurements.

Tensile testing was performed on all cast sample rods. Prior to the test, all cast rods were turned to a specific dimension according to the standard. Initially, the actual initial diameter of each turned rod was determined using a Vernier caliper, as it could slightly deviate from the prescribed diameter due to machining inaccuracies. Subsequently, the initial length of the rod was measured, and both values were recorded in the software. Individual test rods were clamped one by one into the jaws of the tensile testing machine, and an appropriate speed was set. During the test, the load was gradually increased until the rod finally ruptured. After the test, the software displayed the measured values of corresponding parameters and a curve describing the material behaviour during increasing loading. The marking of samples for microhardness measurement and tensile testing is shown in the Tab. 4 below.

Tab. 4 *The marking of samples for microhardness measurement and tensile testing*

Alloy		Sample	Heat treatment
AlSi7Mg0.3	SA	A	without
		B	without
		C	with
		D	with
AlSi7Cu4	SB	E	without
		F	without
		G	with
		H	with
AlSi10.5Cu1.2Mn0.8Ni1.2	SC	I	without
		J	without
		K	with
		L	with

3 Results

3.1 Microscopy observation

The structure of the AlSi7Mg0.3 alloy consists of a solid solution α (Al) - the matrix, and a second structural component represented by the eutectic. The eutectic is composed of a mixture of the solid solution α (Al) and crystals of pure silicon. The microstructure of the AlSi7Mg0.3 alloy, as seen in Figure 1, is composed of dendrites of the solid solution α (Al), exhibiting a spatially dendritic shape with primary, secondary, and ternary arms in the plane of the metallographic section. In the as-cast state (WITHOUT heat treatment), the eutectic silicon appears as needles in the metallographic section. After heat treatment, there was a change in the morphology of silicon, as shown in Figure 2, which is now present in the form of small rounded particles.

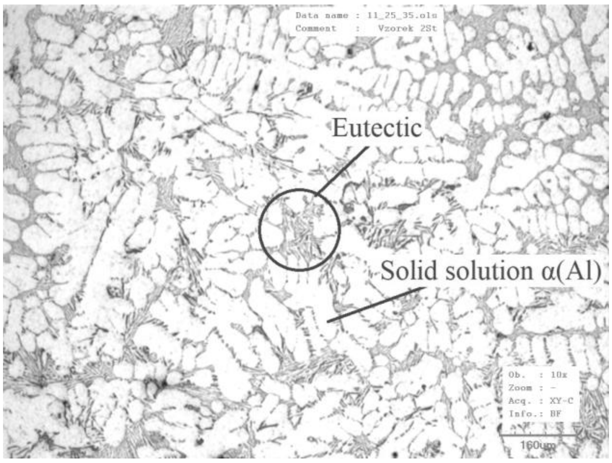


Fig. 1 *Microstructure of the AlSi7Mg0.3 alloy before heat treatment*

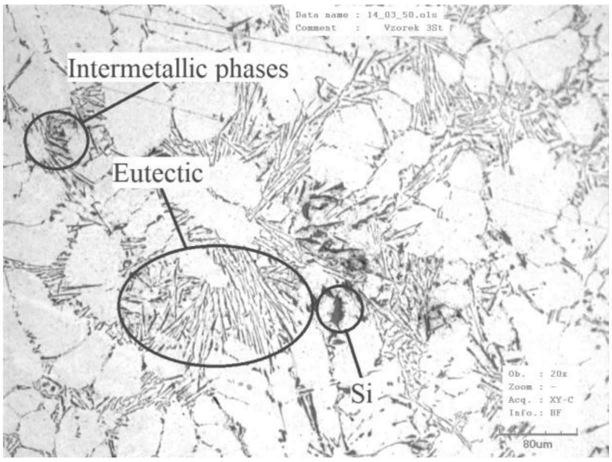


Fig. 2 *Microstructure of the AlSi7Mg0.3 alloy after heat treatment*

The microstructure of the AlSi7Cu4 alloy consists of dendritic cells of the solid solution α (Al) (Figure 3). In the interdendritic space, there is a eutectic composed of coarse silicon needles arranged in hexagonal plates. Along the boundaries of individual grains, there is an intermetallic phase with copper (Figure 4).

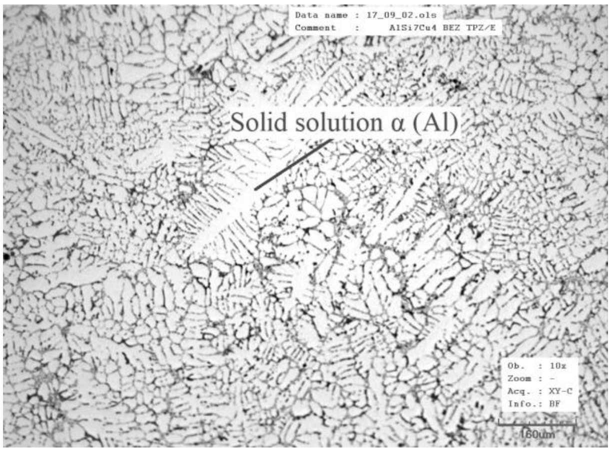


Fig. 3 *Microstructure of the AlSi7Cu4 alloy before heat treatment*

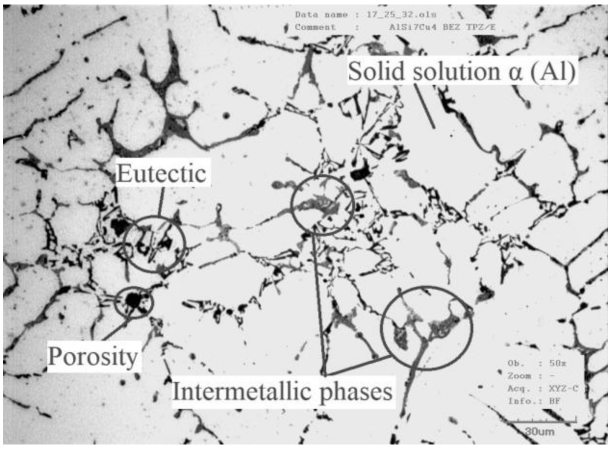


Fig. 4 *Intermetallic phases of the AlSi7Cu4 alloy before heat treatment*

After heat treatment, there was a significant change in the morphology of the eutectic silicon, as shown in Figure 5 and Figure 6.

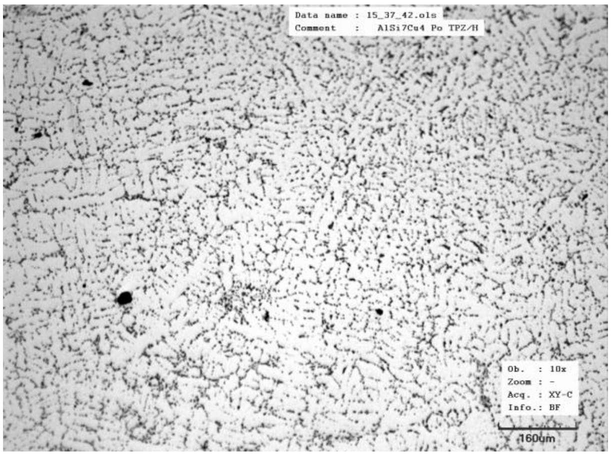


Fig. 5 *Microstructure of the AlSi7Cu4 alloy after heat treatment*

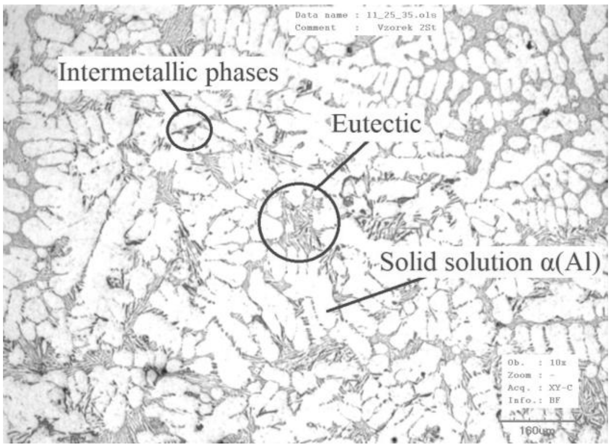


Fig. 6 *Intermetallic phases of the AlSi7Cu4 alloy after heat treatment*

At higher magnification, as shown in Figure 6, the mesh-like structure of the eutectic and intermetallic phases becomes evident. The gray-colored intermetallic phases are Al-Cu, Al-Cu-Si, and Al-Si-Fe-Cu phases. Various shades of the intermetallic phases are caused by a higher concentration of heavy metals with additional elements. The predominant elements contributing to these phases are likely to be copper, iron, nickel, and chromium. Similar to the AlSi7Mg0.3 alloy, accumulations of intermetallic phases in globular shapes appeared here. These phases were present both without heat treatment and after heat treatment.

The AlSi10.5Cu1.2Mn0.8Ni1.2 alloy is the most alloyed, and therefore, in its structure, a denser eutectic appears containing the largest number of different intermetallic phases among all alloys (Figure 7 and 8). The microstructure is similar to that of the AlSi7Cu4 alloy. The eutectic is composed of coarse silicon needles.

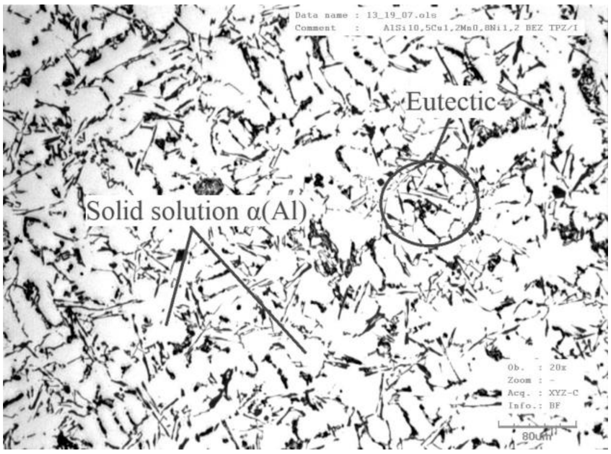


Fig. 7 *Microstructure of the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy before treatment*

Similarly to the AlSiCu4 alloy, after heat treatment, the silicon sharp needles in the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy became finer and more rounded. In this alloy, the same accumulations of spherical intermetallic phases were observed, as shown in Figure 9. Due to the aforementioned higher number of alloying elements, we can observe intermetallic phases of the Al-Fe-Si, Al-Cu, Al-Ni, and Al-Fe-Mn-Si types in this alloy, forming the already familiar Chinese characters. Various shades of intermetallic phases in the structure are caused by an increased amount of alloying heavy metals with additional elements. The predominant elements here are likely to be copper, iron, nickel, and chromium.

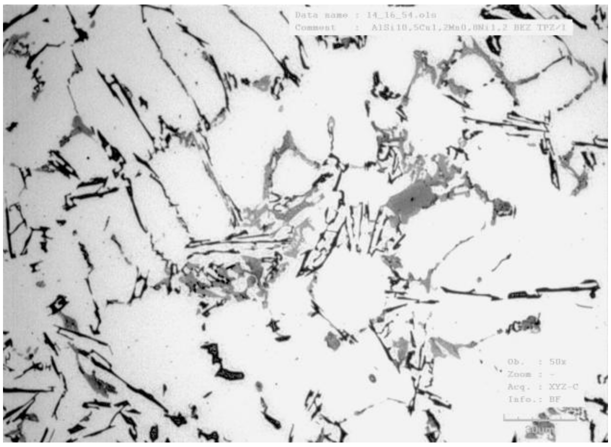


Fig. 8 *Detailed microstructure of the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy before treatment*

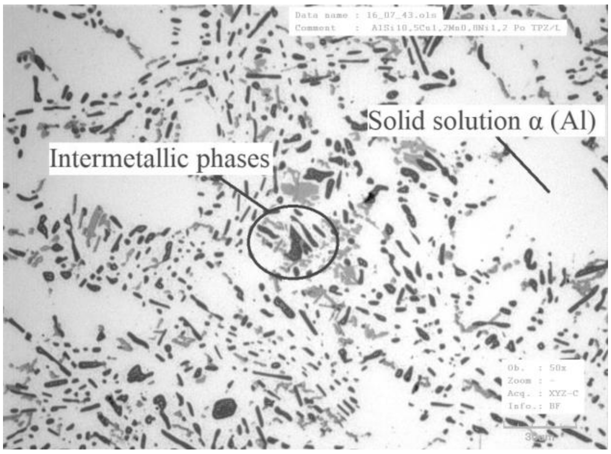


Fig. 9 *Microstructure of the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy after treatment*

In order to investigate the chemical composition of the solid solution and intermetallic phases, a Tescan Vega 3 scanning electron microscope equipped with a Bruker X-Flash 410-M Nano EDS analyzer was employed.

Intermetallic phases were identified in all samples, corresponding to the nominal chemical composition of the respective alloys. The following figures present the microstructure and elemental distribution maps of the analyzed specimens. Fig. 10 indicates the specific area subjected to chemical composition analysis in sample L after heat treatment, produced from the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy.

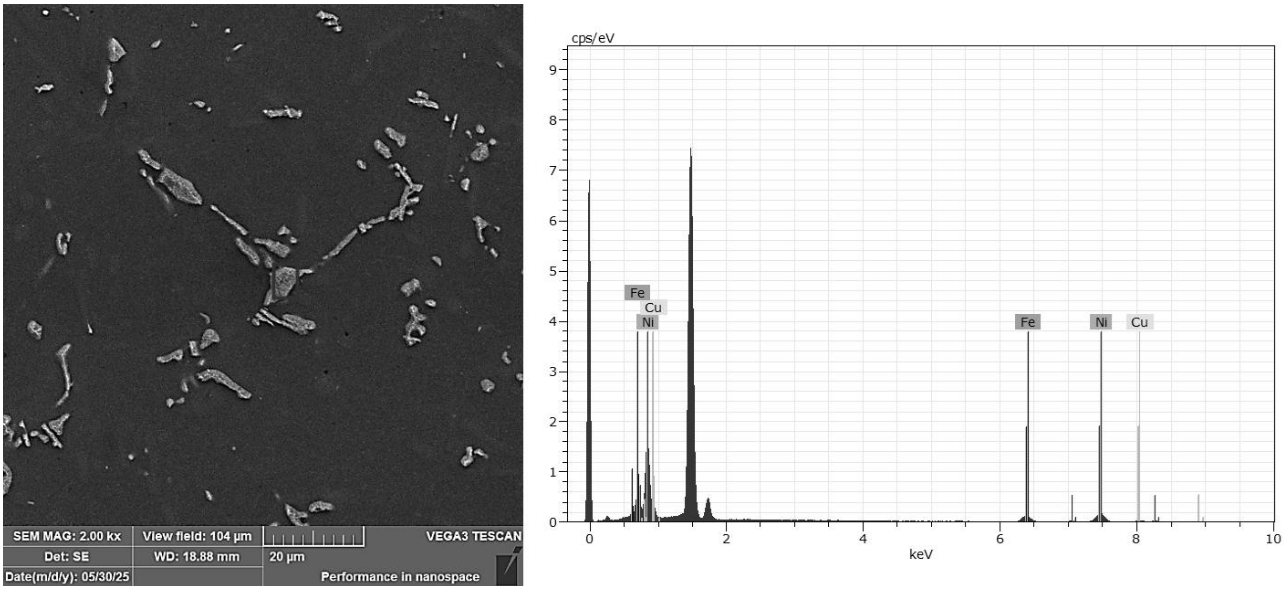


Fig. 10 *Analyzed Area and EDS Spectrum of Sample L*

Figure 11 below presents the elemental distribution map of sample L, produced from the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy. The measured values corresponding to the marked region in the above image are summarized in Table 5. Based on the obtained data, the identified phase is most likely an intermetallic compound of the NiFeCu type, which is consistent with the alloy's chemical composition.

Molybdenum, niobium, and chromium were detected only in trace amounts, ranging from hundredths to tenths of a percent. Due to the limited resolution of the EDS analyzer, it cannot be conclusively determined whether these three elements are incorporated into any of the intermetallic phases such low concentrations fall below the analyzer's reliable detection threshold.

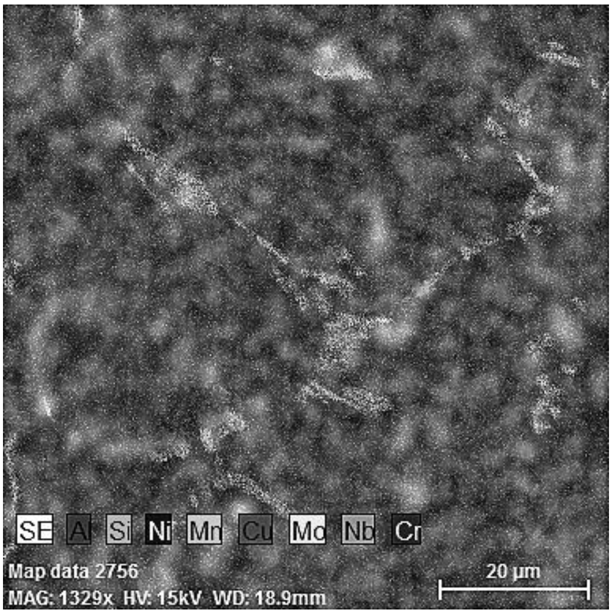


Fig. 11 *Elemental Map of Sample L from the AlSi10.5Cu1.2Mn0.8Ni1.2 Alloy*

Tab. 5 *Chemical Composition of the Analyzed Area in Sample L*

Sample L after HT		
Element	**[wt. %]**	**[at. %]**
Ni (K)	60.58	60.46
Fe (K)	25.26	26.50
Cu (K)	14.16	13.04
Total	100.00	100.00

3.2 Mechanical properties

To verify how the presence of high-melting-point elements in the alloy affects its mechanical properties, hardness and microhardness measurements of the solid solution were performed. The authors of the study assumed that diffusion of high-melting-point elements into the α-phase matrix could occur, thereby influencing its mechanical properties. Brinell hardness measurements were carried out to determine the overall ("bulk") hardness of the individual samples. Vickers microhardness measurements were considered appropriate for evaluating the matrix itself – the aluminum solid solution.

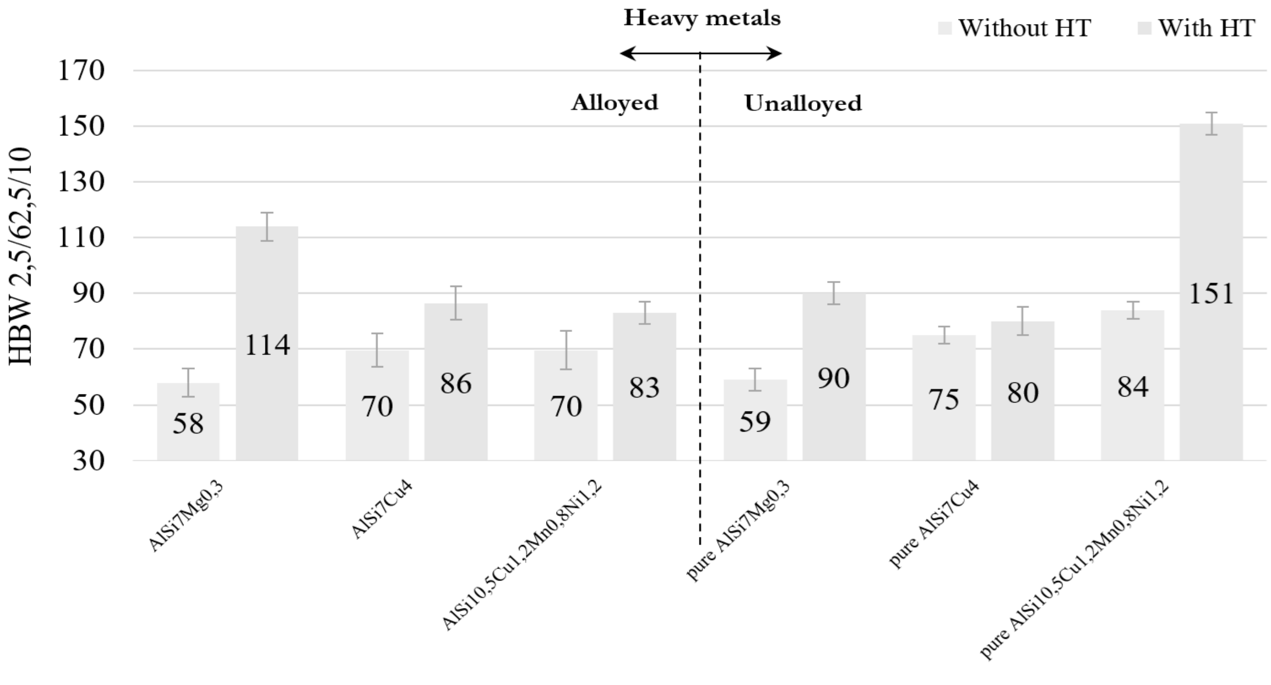
3.2.1 Hardness according to Brinell

For the measurement of the hardness of the samples according to Brinell, a ERNST AT 250 DR-NX hardness tester was used. The Graph 1 below shows the results of Brinell hardness measurements for the alloys AlSi7Mg0.3, AlSi7Cu4, and AlSi10.5Cu1.2Mn0.8Ni1.2. On the left side of the graph, there are alloys alloyed with heavy metals (Cr, Mo, Nb, Ni), while on the right side there are alloys in the "basic" pure state, meaning without the addition of heavy metals – in the as-cast condition. For all alloys, the samples after heat treatment (HT) showed higher hardness values than the samples without HT.

The highest hardness values for the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy alloyed with heavy metals were measured in the heat-treated sample (83 HBW2.5/62.5/10), while the sample without HT reached 70 HBW2.5/62.5/10. When comparing the pure and alloyed states, a decrease in hardness was observed in both the non-heat-treated and precipitation-hardened samples. In the samples without HT, the hardness decreased by 14 HBW, which is 17 %. In the samples after HT, the difference was 68 HBW, or 45 %. Therefore, it can be said that for this alloy, the heavy metal alloying elements negatively affected the Brinell hardness, both before and after heat treatment.

The highest hardness values for the AlSi7Mg0.3 alloy alloyed with heavy metals were found in the heat-treated sample (114 HBW2.5/62.5/10), while the sample without HT reached 90 HBW2.5/62.5/10. When comparing the pure and alloyed states, an increase in hardness was observed for the heat-treated samples — the difference was 24 HBW, or 27 %. The values for the samples without HT differed by only 1 HBW. In this alloy, heavy metals had a positive effect on the Brinell hardness after heat treatment and almost no effect on the samples without HT.

The highest hardness values for the AlSi7Cu4 alloy alloyed with heavy metals were found in the heat-treated sample (86 HBW2.5/62.5/10). On the other hand, the highest value was recorded for the pure-state sample of the alloy without HT (75 HBW2.5/62.5/10). When comparing the pure alloy state with the alloyed state with heavy metals, it can be said that heavy metals increased the hardness of heat-treated samples but decreased the hardness of samples without HT.



Graph 1 *Brinell hardness of the alloys*

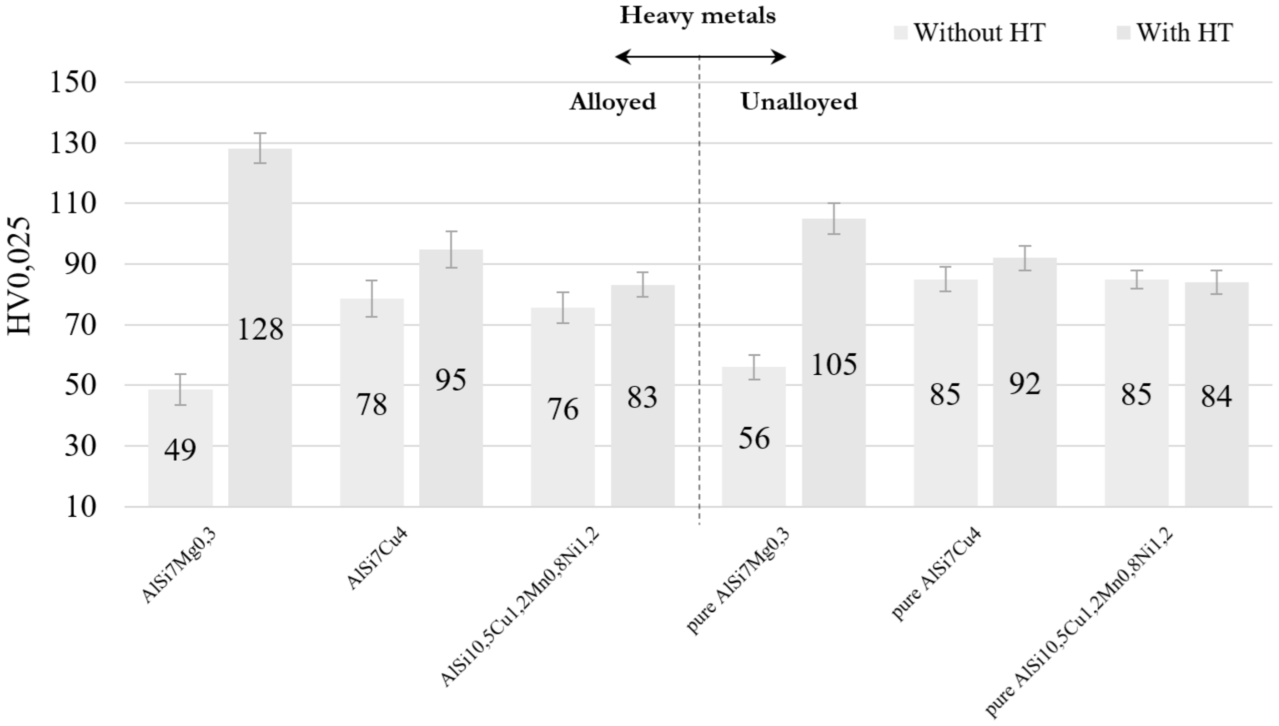
3.2.2 Microhardness according to Vickers

For the measurement of the microhardness of the α(Al) solid solution according to Vickers, a Shimadzu HMV 2 hardness tester was used. Ten measurements were carried out on each sample. The Graph 2 below shows the measured values for the alloys AlSi7Mg0.3, AlSi7Cu4, and AlSi10.5Cu1.2Mn0.8Ni1.2. On the left side of the graph are alloys alloyed with heavy metals (Cr, Mo, Nb, Ni), while on the right side are alloys in the "basic" pure state, i.e. without the addition of heavy metals – in the as-cast condition. For all alloys, the samples after heat treatment (HT) showed higher microhardness values of the α(Al) solid solution compared to the samples without HT.

The highest values for the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy were found in the pure (as-cast) sample without HT (85 HV0.025) and in the heat-treated sample (84 HV0.025). When comparing the pure and alloyed states of the alloy, a decrease in microhardness was observed in both the non-heat-treated and precipitation-hardened samples. In the heat-treated samples, the microhardness values differed by only 1 HV0.025, while in the samples without HT, the difference was 9 HV0.025, which means a decrease of about 11 %. Based on the measured values, it can be stated that alloying elements from the group of heavy metals had a rather negative effect on the microhardness of the α(Al) solid solution.

The highest values for the AlSi7Mg0.3 alloy alloyed with heavy metals were found in the heat-treated sample (128 HV0.025), while in the pure-state sample without HT, the value was 56 HV0.025. When comparing the pure and alloyed states, an increase in hardness was observed in the heat-treated samples — the difference was 23 HV0.025, i.e. 22 %. In the samples without HT, a decrease in microhardness was observed, with a difference of 7 HV0.025, or 13 %. For this alloy, heavy metals had a positive effect on the microhardness after heat treatment and a negative effect on the samples without HT.

The highest microhardness values for the AlSi7Cu4 alloy alloyed with heavy metals were found in the heat-treated sample (95 HV0.025) and in the non-heat-treated sample (78 HV0.025). When comparing the pure and alloyed states of the alloy, an increase in microhardness was observed for the heat-treated samples, while a decrease was found for the samples without HT. The differences were relatively small, indicating that heavy metals had only a minimal influence on microhardness.



***Graph 2** Vickers microhardness of solid solution a(Al) of the alloys*

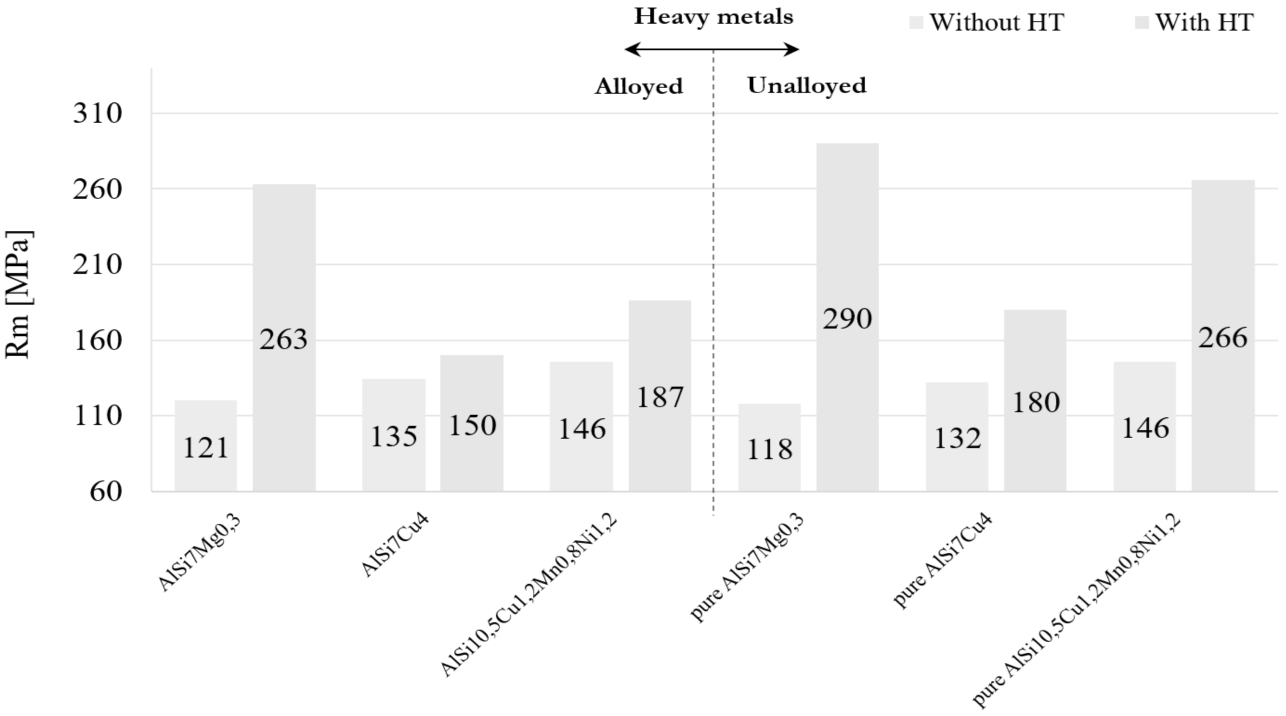
3.2.3 Tensile strenght

For the static tensile test, a universal testing machine *Inspekt 100* from Hegewald und Peschke was used. One set of alloys was alloyed with heavy metals (Cr, Mo, Nb, Ni), and the other set was in the pure – as-cast state, without the addition of heavy metals. Four cast bars were produced from each alloy. Two of them were left without heat treatment (HT), and two were precipitation-hardened. Afterwards, all castings were turned on a lathe, and test specimens for the static tensile test were prepared according to the standard ČSN EN ISO 6892-1. The obtained values of ultimate tensile strength are shown in the Graph 3.

The highest values for the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy were observed in the pure (as-cast) sample without HT (146 MPa) and in the heat-treated sample (266 MPa). When comparing the pure and alloyed states, a decrease in tensile strength was found for the heat-treated samples — the difference was 76 MPa, or 30 %. For the samples without HT, both the pure and alloyed states of the alloy reached the same tensile strength value of 146 MPa. For this alloy, the heavy metals had a negative influence on the tensile strength, both before and after HT.

The highest values for the AlSi7Mg0.3 alloy alloyed with heavy metals were found in the heat-treated sample (263 MPa), while the pure-state sample without HT reached 121 MPa. When comparing the pure and alloyed states, a decrease in tensile strength was observed for the heat-treated samples — the difference was 27 MPa, or 9 %. In the non-heat-treated samples, a slight increase in tensile strength was recorded; the difference was 3 MPa, or 2 %. For this alloy, heavy metals had a negative effect on tensile strength after heat treatment, and practically no effect on the samples without HT.

The highest values for the AlSi7Cu4 alloy alloyed with heavy metals were found in the heat-treated sample (150 MPa) and in the sample without HT (135 MPa). When comparing the pure and alloyed states of the alloy, a decrease in tensile strength was observed for the heat-treated samples — the difference was 30 MPa, or 17 %. On the other hand, in the samples without HT, the addition of heavy metals caused a slight increase in tensile strength from 132 MPa to 135 MPa, a difference of 3 MPa, or 2 %. For this alloy, the addition of heavy metals had a negative influence on tensile strength after heat treatment, while the differences between samples without HT were minimal.



Graph 3 *Tensile strenght of the alloys*

4 Conclusion

The aim of this article was to analyse the effects of high-melting-point metals on the resulting microstructure and mechanical properties of alloys AlSi7Mg0.3, AlSi7Cu4, and AlSi10.5Cu1.2Mn0.8Ni1.2. The structures of the individual alloys did not differ significantly without and after heat treatment. In the unhardened state, sharp silicon needles were observed, which softened and rounded during quenching. Intermetallic phases were observed in all alloys, clustering into one location and forming a gathering of intermetallic phases. After heat treatment, some of these phases dissolved more and spread into the matrix. From the Brinell hardness results, an increase in hardness in the rod set after heat treatment can be observed. The highest hardness [HBW] was recorded for the AlSi7Mg0.3 alloy, where the hardness increase was almost double. The AlSi7Cu4 alloy had a hardness increase of 25 %, and the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy had just under a 20 % increase.

Microhardness values [HV0.025] according to Vickers showed an increase in the microhardness of the solid solution α(Al) in the samples after heat treatment. The largest increase was observed in the AlSi7Mg0.3 alloy. The AlSi7Cu4 alloy had a 20 % increase in microhardness, and the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy had only a 10 % increase. Heat-treated samples exhibited higher tensile strength than the untreated ones. In the AlSi7Mg0.3 alloy, the tensile strength increased by more than double. The AlSi7Cu4 alloy showed a strength increase of 12.5 %, and the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy increased by 22 %.

The individual alloys were then compared with alloys of the same composition but without heavy metals. The AlSi7Mg0.3 and AlSi7Cu4 alloys had higher hardness values [HBW] after heat treatment than their pure alloys after the same process. In the unhardened state, the AlSi7Mg0.3 alloy had higher Vickers hardness, while the AlSi7Cu4 alloy had lower. The AlSi7Mg0.3 and AlSi7Cu4 alloys showed higher microhardness valu-es [HV0.025] after heat treatment than their pure alloys after the same process. In the unhardened state, these alloys had lower microhardness compared to pure alloys. This alloy is capable of hardening even without the addition of any other alloying elements. The authors of the study assume that diffusion of heavy metals into the α-phase matrix may have occurred, thereby contributing to its strengthening. The measured microhardness values may also have been influenced by phases precipitated along grain boundaries, which hinder plastic deformation during the indentation of the hardness tester indenter and thus may have led to partial distortion of the measurement results.

The AlSi7Mg0.3 and AlSi7Cu4 alloys in hardened state exhibited lower tensile strength in static tensile testing compared to pure alloys without heavy metals. When using heavy metal powders, the aforementioned hardness [HBW] and microhardness [HV0.025] increased after heat treatment and, in some cases, without heat treatment. However, their addition to alloys led to a decrease in tensile strength in both heat-treated and untreated alloys.

It is important to note that the addition of the powder, which contained chromium, nickel and molybdenum, acts synergistically on the alloys, so it is not possible to say which specific element from the above-mentioned ones influenced the mechanical properties of the alloys the most, either positively or negatively. In the future, it would be appropriate to conduct appropriate research with the same elements, with each element separately. It would also be appropriate to increase the additions of individual elements.

Acknowledgement

This research was supported by grant within Student grant agency at UJEP (UJEP-SGS-2024-48-008-02).

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