

Relation between Mechanical Properties and Microstructure of Cast Aluminum Alloy AlSi9Cu3

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One common material for engine applications is the AlSi9Cu3 alloy. This alloy has a good castability, excellent machinability, medium strength, and low specific weight. The study was focused on the investigation of the effect of the solution heat treatment on the microstructure and mechanical properties of the alloy (strength – R_m , hardness – HBS). The temperatures of the solution heat treatment were 505°C, 515°C, and 525°C ± 5°C and the solution time ranged from 0 to 32 h (0, 2, 4, 8, 16, and 32 h). Alloy AlSi9Cu3 contained α -matrix, eutectic silicon, and other Fe- and Cu-rich phases with different morphology (needle-like, Chinese script, skeleton-like, blocky, etc.). The results obtained revealed the relation between the mechanical properties and the morphologies of the eutectic silicon and the predominant copper-rich phase Al–Al₂Cu–Si during the solution treatment.

Keywords: aluminum cast alloys, microstructure, mechanical properties, intermetallic phases, fracture zones.

Introduction. In industry, particularly in aerospace and automobile branches, there is a tendency to reduce costs, prices, and weight of complete products. In this respect, of importance are easy availability and the industry requirements for environmental protection, i.e., recyclability of industry materials. Significant is the fact that the density of steel materials is three times higher than that of aluminum alloys. The substitution of aluminum alloys for magnesium ones is a momentous aim in the development of many branches of industry, but magnesium alloys have a lot of disadvantages: the contact with magnesium melts is hazardous that excludes their recycling possibilities [1].

Cost effectiveness of the production and application of aluminum alloys is being constantly improved, e.g., at present an average European automobile contains about 90% of recycled aluminum alloys out of the total share of aluminum alloys in an automobile [1]. Al–Si cast alloys are extensively used in the automotive and aerospace industries due to their excellent castability, good mechanical properties and wear resistance. The addition of alloying elements such as Mg and Cu make these alloys heat treatable further improving their mechanical properties and allowing their use in new, more demanding applications (e.g., engines, cylinder heads, etc.). The most used heat treatment for these Al–Si–Cu cast alloys is the solution treatment followed by age hardening that is required for the precipitation of the Al₂Cu hardening constituent. The solution heat treatment of Al–Si–Cu cast alloys affects the microstructure of the alloy in three aspects, namely: the dissolution of coarse Al₂Cu, homogenization of the microstructure, improvement of eutectic silicon morphology (fragmentation, spheroidization, and coarsening), and the ensuing changes in the fracture zones [2].

The present study is a part of a larger research project, which was conducted to investigate and to provide a better understanding of the influence of heat treatment on the structure (structural analyses) and mechanical properties of cast Al–Si–Cu alloys. The study was conducted on the most popular AlSi9Cu3 alloy that contains about 9% Si and 3% Cu.

T a b l e 1

Chemical Composition of AlSi9Cu3 Alloy

Element	Si	Cu	Mn	Zn	Mg	Ni	Pb	Fe	Ti	Al
wt.%	10.7	2.4	0.22	1.1	0.27	0.08	0.11	0.9	0.03	base

Experimental. Experiments were performed on AlSi9Cu3 cast alloy whose chemical composition is given in Table 1. This alloy has a lower corrosion resistance and is suitable for high-temperature (up to max. 250°C) applications (dynamically exposed casts). In this case, the requirements to its mechanical properties are not so restrictive. This cast alloy was produced at the Foundry Co. CONFAL, a.s., Slovenská Lupča.

Alloys of the Al–Si–Cu type are usually heat treated in order to develop higher mechanical properties. Heat treatment involves solution and aging heat treatments during which a series of changes in microstructure occur which then lead to the improvement of strength. These changes in microstructure include the dissolution of precipitates, homogenization of the cast structure, such as minimization of alloying element segregation, spheroidization and coarsening of eutectic silicon, and precipitation of finer hardening phases [3, 4]. Different solution heat treatment procedures were used to evaluate their influence on the mechanical properties (tensile strength, R_m , and hardness, HBS) and on the morphology of the eutectic Si and Cu-rich phase (ternary eutectic Al–Al₂Cu–Si phase) and on ensuing changes in the fracture pattern.

The experiments were carried out in an electric induction furnace. The castings were subjected to the solution treatment at three temperatures (505, 515, and 525°C) during the periods of time ranging from 2 to 32 hours (0, 2, 4, 8, 16, and 32 h), then quenched in warm water in the temperature range from 40 to 60°C, and aged naturally at room temperature for 24 hours. The samples for microscopic analysis were prepared by standard metallographic procedures (wet ground, DP polished with diamond pastes and etched by Dix-Keller, HNO₃ or MA [2]).

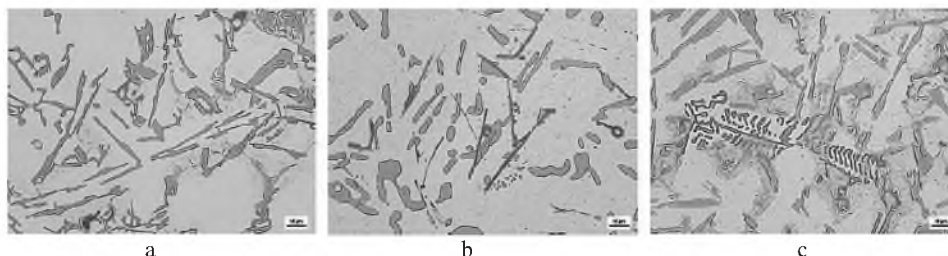


Fig. 1. Typical microstructure patterns in AlSi9Cu3 cast alloy (etched by a Dix Keller solution): (a) α -matrix, platelets of eutectic Si; (b) Al₃FeSi, Al–Al₂Cu–Si phase; (c) Al₁₅(MnFe)₃Si phase – “Chinese script.”

Generally, the as-cast microstructure of AlSi9Cu3 alloy comprises α -matrix, the platelets of eutectic silicon (dark grey) (Fig. 1a) and many intermetallic phases. In this alloy there were also observed the following intermetallic phases: the iron phase Al₃FeSi in the shape of black needles (Fig. 1b), which has a monoclinic crystal structure and precipitates in interdendritic and intergranular regions as platelets [5]. Long Al₃FeSi platelets (more than 500 μ m) can adversely affect the mechanical properties, especially ductility, and they also lead to the formation of excessive shrinkage porosity defects in castings. The Al₃FeSi phase appears as a nucleation locality for Cu-rich phase Al–Al₂Cu–Si (Fig. 1b).

Another common iron intermetallic is the Al₁₅(MnFe)₃Si phase with a cubic crystal structure [6]. This phase has a compact morphology in the form of “Chinese script”

(Fig. 1c) and thus it contains less initiated cracks as compared to the needle-like phase Al_5FeSi . The effect of the applied heat treatment on these iron-rich phases (Al_5FeSi – 16% Fe, $\text{Al}_{15}(\text{MnFe})_3\text{Si}$ – 14% Fe) is not significant and results only in partial segmentation of these phases. Half or more of copper is found as a component of intermetallic compounds, primarily, the Al_2Cu phase with tetragonal crystal structure precipitates in two distinct morphologies: Al_2Cu and in the form of blocky phase with a high copper concentration ~38–40% Cu (ternary eutectic $\text{Al}-\text{Al}_2\text{Cu}-\text{Si}$ – Fig. 2a). These compounds that form at the later stages of freezing are located in the interdendritic regions and at the grain boundaries. Gradual dissolving of the Cu-rich phase occurs with increasing heat treatment temperature (Fig. 2) and this fact is also confirmed by hardness measurement results.

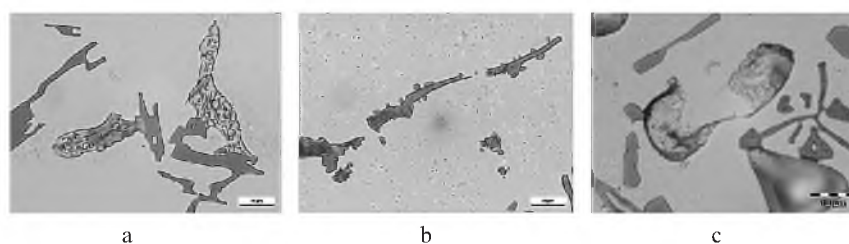


Fig. 2. The influence of heat treatment on the morphology of the $\text{Al}-\text{Al}_2\text{Cu}-\text{Si}$ phase: (a) untreated; (b) at $515^\circ\text{C}/4$ hours; (c) at $525^\circ\text{C}/4$ hours.

The improvement of the eutectic silicon morphology and its distribution have the most significant influence on the changes in the mechanical properties (Fig. 3). The morphology of the eutectic silicon not subjected to heat treatment has the shape of platelets (Fig. 3a). Figure 3b–d demonstrates changes in the eutectic Si morphology caused by the solution treatment with a holding time of 8 hours. At temperatures of 505 and 515°C gradual spheroidization of the eutectic Si particles begins (Fig. 3b and c). As the solution treatment continued to the temperature 525°C , the spheroidized particles gradually grew larger (overcoarsed) (Fig. 3d).

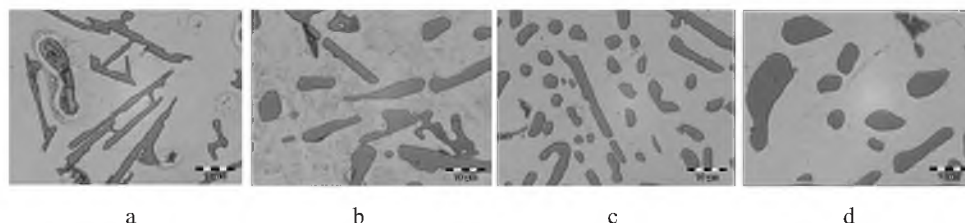


Fig. 3. Changes in the eutectic silicon morphology during heat treatment: (a) untreated; (b) heat treated at 505°C during 8 hours; (c) heat treated at 515°C during 8 hours; (d) heat treated at 525°C during 8 hours.

These changes in the eutectic Si influence the the characterpattern of the fracture zones as well. In the eutectic silicon not subjected to the solution treatment, brittle fracture fragile breach of the eutectic platelets and ductile failure of the α -matrix are observed. With gradual spheroidization of the eutectic Si, the share of the ductile failure in the alloy increases.

The microstructure of AlSi9Cu3 alloy is a reflection of the mechanical properties (Fig. 4). The increase in the strength and hardness values is significant chiefly for temperatures of 505 and 515°C and for holding time of 8 hours at the most. By the eighth hour of the holding time the values of the mechanical properties (chiefly *HBS*) begin to decrease. This trend is typical for all solution heat treatment temperatures and relates to

gradual coarsening of the eutectic Si for the hold time longer than 8 hours (Fig. 4). At the a temperature of 525°C a decrease in the values of the mechanical properties is observed due to a significant coarsening of the eutectic Si (Fig. 3d).

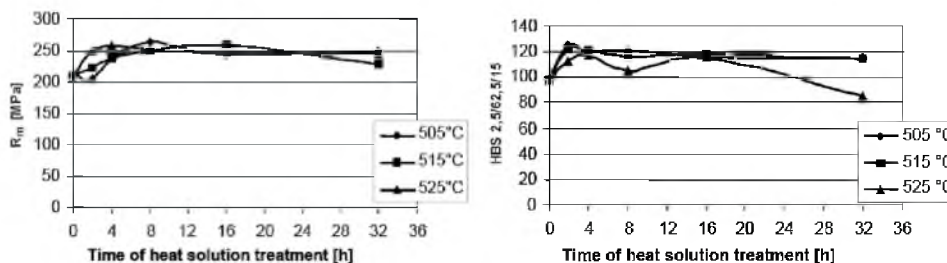


Fig. 4. Changes in the mechanical properties of AlSi9Cu3 alloy during heat treatment.

With a decrease in the heat treatment temperatures, gradual dissolution of the Cu-rich phase takes place and this fact also confirms the results obtained for hardness and tensile strength. With an increase in the solution treatment temperature, the hardness and strength values increase to a maximum value at 515°C and then decrease. Hardness correlates with a reflection of the solution strengthening and silicon particle distribution in the matrix. Temperature 515°C is a suitable appropriate temperature for this alloy. Below this temperature, the solutionization process is insufficient, whereas above it, overcoarsening of the Si particles and melting of Al_2Cu occurs. These two unsatisfied conditions aspects all result in the reduction of hardness and strength.

Conclusions. The contribution investigation was focused on the influence of the solution heat solution treatment on the microstructure and mechanical properties (R_m and HBS) of aluminum cast alloy AlSi9Cu3 for automotive applications. As shown by the results shown, the optimum conditions of the heat solution heat treatment for this alloy are the temperature 515°C and holding time max. 8 hours. The changes of in the microstructure confirmed that these outcomes. A heat treatment by temperature of heat treatment 525°C get leads to gradual coarsening of the eutectic Si, decreasing of the values of the mechanical properties, values and dissolving dissolution of the ternary eutectic Al- Al_2Cu -Si.

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