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ANALYSIS OF SELECTED PROPERTIES OF Al-Si-Cu BASED ALLOY WITH TUNGSTEN ADDITION

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Abstract
Al-Si-Cu based alloys are key structural materials in industry due to their favorable combination of low weight, casting, and mechanical properties. In recent years, the influence of refractory metal additions has been investigated, with tungsten being a subject of interest for its potential to influence the crystallization process. This work deals with the effect of tungsten addition on the microstructure and porosity of the AlSi5Cu2Mg alloy. The experimental alloy was alloyed with tungsten in concentrations of 0.05, 0.10, and 0.15 wt.%. The addition of tungsten showed a significant effect on the size of the primary α(Al) phase dendrites as well as on the morphology of the eutectic silicon. The most significant refinement of the dendritic network was observed at the highest concentration of 0.15 wt. % W. Analysis of microporosity revealed that while the 0.05 wt.% W addition suppressed pore formation, higher concentrations led to its significant increase in the as-cast state.

***Keywords**: Al-Si-Cu alloy, tungsten, microstructure, microporosity*

1. INTRODUCTION

Al-Si-Cu based alloys are widely used materials in the automotive, aerospace, and mechanical engineering industries, mainly due to their excellent casting properties, favorable strength-to-weight ratio, and good thermal properties. The quality of these alloys can be significantly influenced by the addition of microalloying elements, which serve to refine the microstructure and improve mechanical properties [1]. Tungsten is a refractory metal with an extremely high melting point and thermal stability, the presence of which in Al-Si based alloys can fundamentally affect their behavior during solidification [2].

Previous studies indicate that the addition of tungsten can significantly influence the crystallization process and the resulting properties of Al-Si based aluminum alloys. It has been shown that an optimal amount of tungsten leads to a significant refinement of the structure, specifically to the transformation of coarse plates of eutectic silicon into a fine fibrous morphology and to a uniform distribution of the eutectic. This subsequently results in an increase in tensile strength, yield strength, and elongation. The mechanism of this influence is complex. On one hand, tungsten can act as a refractory element creating nuclei for crystallization, thereby shifting the onset of eutectic crystallization to higher temperatures and refining the structure. On the other hand, at high cooling rates, supersaturation of the α(Al) solid solution with tungsten atoms can occur, leading to its strengthening [3,4]. Tungsten can also lead to the formation of thermally stable tungsten-containing intermetallic phases. At higher concentrations, it can promote the formation of primary intermetallic phases, such as $Al_{15}(Fe,Mn,W)_3Si_2$. These phases can act as effective barriers against the movement of grain boundaries during thermal stress, thereby increasing high-temperature strength, but they can also have a negative effect if their size and quantity are excessive. The mechanisms by which tungsten interacts with the main alloying elements and its influence on the development of the microstructure and the resulting mechanical properties have not yet been fully explored [5].

2. EXPERIMENTAL METHODOLOGY

A non-standardized hypoeutectic AlSi5Cu2Mg alloy, which is used for casting high-duty components due to its specific properties, was chosen as the experimental material. The AlSi5Cu2Mg alloy in its original state served as the reference material for comparing the results.

Within the experiment, three variants of the AlSi5Cu2Mg alloy were prepared with defined additions of tungsten in concentrations of 0.05, 0.1, and 0.15 wt.%. The melting of the base charge took place in an electric resistance furnace at a stable temperature of 750 ± 5 °C. To ensure homogeneous distribution, the tungsten addition was prepared in advance in the form of an AlW5 master alloy, which was melted separately in an induction furnace with a graphite crucible. After its complete melting, the liquid metal was added in a precisely calculated dosage to the main melt in the resistance furnace. From the thus modified alloy, a series of ten identical experimental castings for each variant was subsequently cast by gravity die casting into preheated permanent molds with a temperature of 150 ± 5 °C. The results of the chemical composition of the alloys are listed in Table 1. Half of the samples were heat-treated using the T7 regime, which included solution treatment (500 ± 5 °C / 6.5 h), quenching in water (85 ± 5 °C), and artificial aging (250 ± 5 °C / 4 h) with final air cooling.

Table 1. Chemical composition of the experimental AlSi5Cu2Mg alloys [wt.%].

Alloy	Si	Cu	Mg	Mn	Fe	Cr	W	Al
AlSi5Cu2Mg - Reference	6.77	2.54	0.15	0.015	0.23	0.004	-	90.16
AlSi5Cu2Mg + 0.05 hm. % W	6.58	2.38	0.16	0.014	0.22	0.007	0.020	90.55
AlSi5Cu2Mg + 0.10 hm. % W	6.31	2.36	0.22	0.013	0.22	0.006	0.044	90.74
AlSi5Cu2Mg + 0.15 hm. % W	6.41	2.37	0.18	0.012	0.23	0.006	0.075	90.65

The preparation of samples for structural analysis was carried out according to standard metallographic procedures. After the preparation of the metallographic sections, the samples were etched with a 0.5 % solution HF. The thus-prepared microstructure was subsequently observed using light and scanning electron microscopy. The quantification of the areal microporosity of the samples was performed on five random fields of each section using a Keyence microscope.

3. RESULTS AND DISCUSSION

3.1 Microstructure evaluation

The observed structure of the reference alloy consisted of the primary α-Al phase, Al-Si eutectic components, and intermetallic phases containing elements such as Cu, Mg, and Fe (Figure 1a). The addition of tungsten to the AlSi5Cu2Mg alloy showed a clear influence on the refinement of its microstructure, which was mainly manifested in the morphology of the primary α(Al) phase dendrites. Compared to the reference alloy without additions, which exhibited a coarser and branched dendritic structure, the addition of tungsten in the amount of 0.05 wt.% led to a visible reduction in dendrites (Figure 1b). Observations showed that the presence of tungsten caused a reduction in the distance between the dendrite arms. A subsequent increase in the amount of tungsten to 0.10 and 0.15 wt.% resulted in only a slight further reduction of the dendrites (Figure. 1c,d). This refinement can be attributed to the action of tungsten as a heterogeneous nucleating agent. Insoluble tungsten particles, or intermetallic phases containing it, serve as nuclei for the crystallization of α-Al, leading to a higher grain density.

The refining effect of tungsten was also evident on the eutectic silicon. While in the reference alloy it occurred in the form of imperfectly rounded grains (Fig. 1a), after the addition of tungsten, a gradual reduction in their size was observed (Figure 1b). At higher tungsten contents, large clusters

of small and fine rounded grains of eutectic Si were more frequently observed (Figure 1c,d). This refinement is closely related to the refinement of the dendritic network, which creates smaller interdendritic spaces and thus limits the growth of silicon particles.

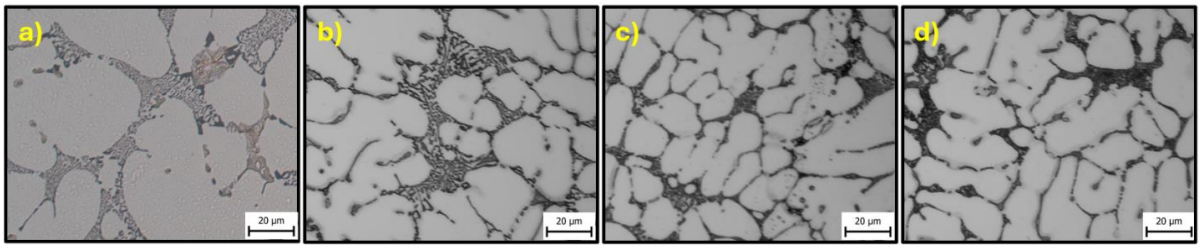

Figure 1. Microstructure of the AlSi5Cu2Mg alloy in the as-cast state: a) 0 wt.% W, b) 0.05 wt.% W, c) 0.10 wt.% W, d) 0.15 wt.% W.

After the application of T7 heat treatment, the morphology of the eutectic silicon further changed towards compact, rounded to spheroidized grains (Figure 2a). This process was most pronounced in the alloys with tungsten (Figure 2b, c), with the microstructure being significantly fine, with spheroidized silicon, at the highest addition of 0.15 wt.% W (Figure 2d). The pronounced spheroidization is an expected consequence of solution annealing at high temperature, where the system minimizes its surface energy. The finer initial structure in the tungsten-containing alloys probably accelerates this process. These morphological changes have a direct impact on potential mechanical properties, as the transformation of irregular particles into fine, rounded grains significantly reduces internal stress concentrations.

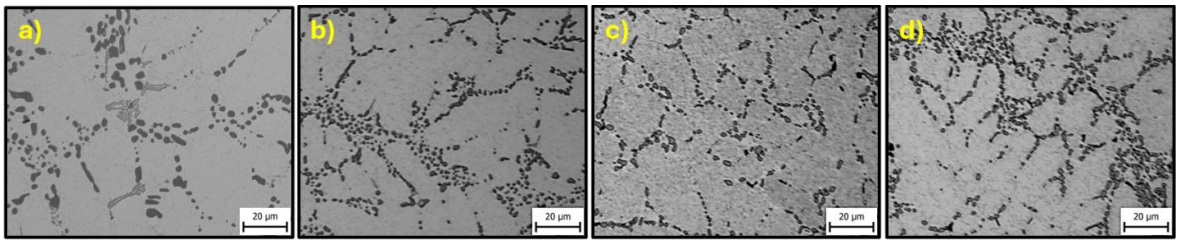

Figure 2. Microstructure of the AlSi5Cu2Mg alloy after heat treatment: a) 0 wt.% W, b) 0.05 wt.% W, c) 0.10 wt.% W, d) 0.15 wt.% W.

Detailed observation of the eutectic Si morphology (Figure 3) confirmed these trends. In the as-cast state with 0.05 wt.% W, eutectic Si had a predominantly rod-like morphology with rounded edges (Figure 3a), while at 0.15 wt.% W, it was already in the form of clusters of fine, rounded grains (Figure 3b). After heat treatment, the eutectic silicon was more uniformly distributed in rounded particles (0.05 wt.% W, Figure 3c) up to almost perfectly round grains in the alloy with the highest tungsten content (0.15 wt.% W, Figure 3d).

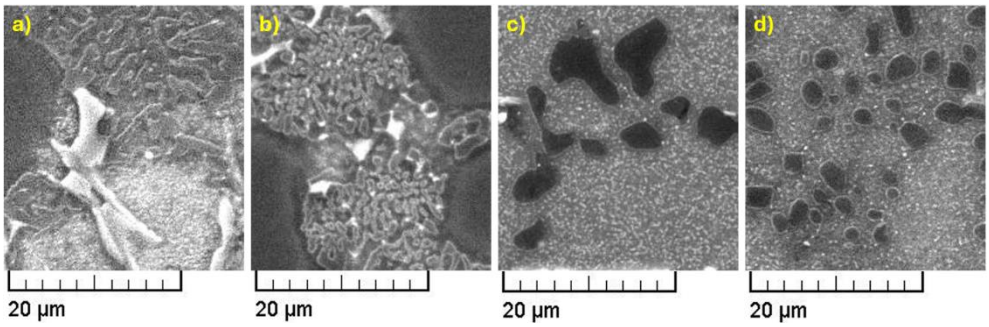

Figure 3. Detail of eutectic Si morphology: a) 0.05 wt.% W in as-cast state, b) 0.15 wt.% W in as-cast state, c) 0.05 wt.% W after heat treatment, d) 0.15 wt.% W after heat treatment.

3.2 Microporosity evaluation

Analysis in the as-cast state revealed that the sample with the lowest addition of 0.05 wt. % tungsten exhibited minimal pore occurrence with an average areal microporosity 0.15 %, which suggests that a low concentration of tungsten effectively suppresses their formation. However, with an increasing content of tungsten to 0.10 and 0.15 wt. %, a significant increase in the areal microporosity to 0.29 % and 0.45 %, respectively, occurred. This trend indicates a correlation between tungsten concentration and the tendency for pore formation, which may be related to changes in the solidification mechanism. The application of heat treatment resulted in an expected increase in microporosity in all tested samples, with the highest value of 0.73 % being measured at the highest concentration of 0.15 wt. % W. This increase can be explained by the coalescence of existing pores or the formation of new ones due to volume changes associated with phase transformations. Observation of the microstructure revealed an irregular shape of the pores, suggesting that the micorporosity originated primarily due to shrinkage in the interdendritic regions during solidification. The resulting values of areal microporosity are shown in Table 2.

Table 2. Areal microporosity in samples of AlSi5Cu2Mg alloy with different tungsten content in the as-cast state and after heat treatment.

State	**As-cast state**			**After heat treatment**		
Alloy	0,05 W	0,10 W	0,15 W	0,05 W	0,10 W	0,15 W
Microporosity	0.15 %	0,27 %	0.45 %	0.34 %	0.37 %	0.74 %

4. CONCLUSION

This study investigated the influence of tungsten additions in amounts of 0.05, 0.10, and 0.15 wt.% on the microstructure and porosity of a cast AlSi5Cu2Mg alloy. It was confirmed that the addition of tungsten acts as an effective refining agent for the primary α(Al) phase, leading to a visible reduction in dendrites. A positive influence was also observed on the morphology of eutectic silicon, which was refined and, after T7 heat treatment, acquired a more compact, spheroidized structure. However, the analysis of microporosity revealed a complex relationship, where the lowest porosity (0.15%) was measured in the as-cast alloy with 0.05 wt.% W, but further increases in tungsten content led to its significant increase. The T7 heat treatment consistently increased porosity in all samples, with the highest value (0.73%) being found in the alloy with 0.15 wt.% W. The results suggest that while tungsten promotes the refinement of phases, at higher concentrations it may negatively affect the solidification mechanism and promote the formation of shrinkage porosity in interdendritic areas.

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