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Influence of the crystallization condition on Al–Si–Cu casting alloys structure

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Properties

ABSTRACT

Purpose: The purpose of this paper is to show the effect of solidification rate on microstructural features, hardness and microhardness of Al–Si–Cu alloys in as cast state.

Design/methodology/approach: The main base of the paper is to compare the properties of aluminium cast alloys of ACAlSi7Cu, ACAlSi7Cu2 and ACAlSi7Cu4. Microstructural features were characterised using light optical microscopy. For rapid determination of the parameters: grains size and Secondary Dendrite Arm Spacing – SDAS were used Leica Q-WinTM computer image analyzer.

Findings: Increasing the solidification rate increases refines all microstructural features grain size and SDAS. Increasing the solidification rate have an impact on the hardness and microhardness of investigated aluminium cast alloys.

Research limitations/implications: In this paper influence of solidification rate on mechanical properties was described. Further investigations should be concentrate on assessment an influence of silicon contents and solidification rate on microstructural features and mechanical properties.

Practical implications: The aim of this work is describe the effect of different solidification conditions on changes of microstructure and mechanical properties of ACAlSi7Cu, ACAlSi7Cu2, ACAlSi7Cu4 alloys used to produce the car engine block.

Originality/value: The paper contributes to better understanding and recognition an influence of different solidification condition on microstructure and mechanical properties of aluminium alloys.

Keywords: Mechanical properties; Aluminium alloys; Solidification rate; Secondary Dendrite Arm Spacing - SDAS

1. Introduction

Aluminium alloys are used in five main areas: building and constructions, containers and packaging, transportation, electrical conductors and machinery and equipment. The major area where aluminium cast alloys is commonly used is automotive industry due to its good casting characteristics, mechanical properties as well as good corrosion resistance and weldability. Application of the aluminium cast alloys Al–Si–Cu in engine cars, on engine block and cylinder heads, is expected to be a growth area in many countries in which they are manufactured in the nearest years. That why is very important for designers to have an intimate knowledge of how Al–Si–Cu alloys solidifies at different cross section of the cast part and how influence the solidification rate on mechanical properties[1, 3, 5].

The mechanical properties of Al–Si–Cu alloys depend on many factors including: chemical composition, molten metal processing, casting method, solidification rate, heat treatment and microstructure. Grain size and its morphology and Secondary Dendrite Arm Spacing (SDAS) are effective parameters, which control mechanical properties of aluminium alloys [2, 4, 5].

Crystallization process of aluminium cast alloys begins with the development of primary aluminium dendrite network. The SDAS depends on chemical composition of investigated alloy, solidification rate and temperature gradient on the crystallization front.

Table 1.
Average chemical composition (wt%), equilibrium liquidus temperature – T_L and cooling rate – CR, of the AC AlSi7CuX series of experimental Al alloys

Alloy ID	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sr	T_L, ºC	CR, $ºCs^{-1}$
AC AlSi7Cu	7.166	0.138	0.990	0.11	0.268	0.046	0.082	0.002	614	0.18
										0.46
										0.96
AC AlSi7Cu2	6.982	0.168	1.91	0.110	0.255	0.425	0.090	0.003	612	0.16
										0.33
										0.71
AC AlSi7Cu4	7.449	0.138	3.595	0.154	0.283	0.055	0.012	0.001	604	0.12
										0.36
										0.72

The size and distribution of porosity in Al-Si-Cu casting alloy are essentially controlled by secondary dendrite arm spacing [2]. As SDAS becomes smaller, porosity and second phase constituents are more evenly distributed. Increase of solidification rate refines all microstructural features including SDAS, grain size and intermetallic phases what leads to substantially improvement in mechanical properties [8, 10, 12].

Al-Si-Cu alloys are use to contain three main alloying elements such as Si, Cu, and Mg and impurity elements such as Fe, Mn, Ni and Cr, several brittle intermetallic compounds may form in addition to the eutectic silicon particles. Addition of copper to Al-Si alloys leads to formation Al_2Cu phases and other intermetallic compounds. Copper phases can solidify in two different forms: Al_2Cu and eutectic Al + Al_2Cu. Strontium modification tends to segregate the copper phase in areas away from the Al–Si eutectic regions. Due to this segregation, the $CuAl_2$ phase tends to solidify in the block-like Al_2Cu, rather than the eutectic form. In order to improve the mechanical properties of Al-Si-Cu alloys is heat-treated using processes such as solution treatment and artificial aging. Copper also increase heat treatability of aluminium alloys. Addition of copper decrease significantly melting point and eutectic temperature of Al-Si-Cu alloys [9, 11, 13, 14].

In this research, the effect of solidification rate and contents of copper on microstructure and mechanical properties of AC AlSi7Cu, AC AlSi7Cu2 and AC AlSi7Cu4 alloys have been investigated [15].

2. Experimental methods

2.1. Melting and alloying

Investigated alloys were obtained by mixing AC AlSi5Cu1(Mg) alloy and two master alloys AlSi49 and AlCu55 in a 10 kg capacity ceramic melting pot. Samples were held in Lindberg™ electric resistance furnace at temperature 850±5 °C under argon inert gas atmosphere by 12 hours. For reducing the hydrogen level below 0.100±0.005 ml H_2/100g the melted aluminium alloy were homogenized and degassed. Chemical composition of samples Al-Si-Cu was analyzed by Optical Emission Spectroscopy as per the ASTM E1251 specification. Chemical compositions of the alloys prepared for this research is given in Table 1.

2.2. Grain size and secondary dendrite arm spacing measurements

For determination of the major parameters such as grains size and Secondary Dendrite Arm Spacing – SDAS was used Leica Q-Win™ computer image analyzer in conjunction with Leica MEF4A light optical microscopy.

2.3. Hardness and microhardness test

Hardness and microhardness test consist in measurement of hardness along the diameter and along the height of the ingot. Hardness was measured by Rockwell method in scale F, using ZWICK ZHR hardness tester. Microhardness test was carried out on SHIMADZU DUH 202 microhardness tester.

3. Results and discussion

Figure 1 shows the impact of solidification rate and contents of copper on Secondary Dendrite Arm Spaces in investigated alloy. SDAS decrease with increase of solidification rate, also dendrites has been refined partially with increasing of copper contents. Decrease of SDAS improve casting microstructure and tensile properties. In crystallization process dendrites growth is slow at high solidification rate because occur short solidification time and slow diffusion of atoms. In the sample of aluminium alloy AlSi7Cu cooled with 0.96 $ºCs^{-1}$ the SDAS is fine, about 37 μm but in the sample cooled with the 0.18 $ºCs^{-1}$ rate the SDAS is coarse (82.6 μm). Velocity movement of solid and liquid increases with increasing of solidification rate, what lead to increase of surface to volume ratio of dendrites. It means that high solidification rate cause reduce of dendrites arm spaces and increase the surface of dendrites.

Increasing of solidification rate refines grain size of Al-Si-Cu alloys what is presented on Figure 2. This phenomenon is very beneficial for crystallization process, because decrease of the grain size allow to achieve desired properties of aluminium alloys for its intended application.

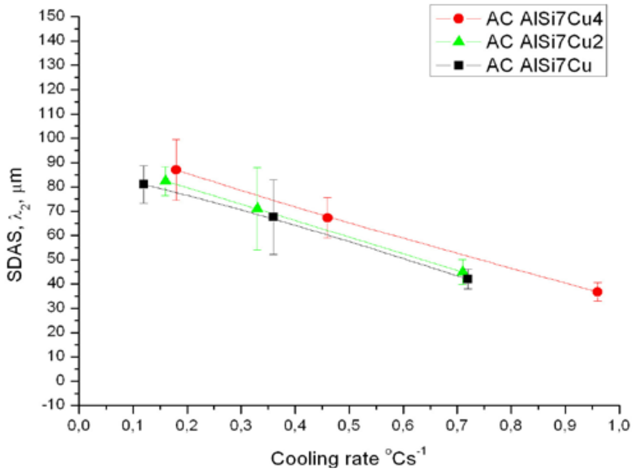

Fig. 1. Influence of solidification rate on Secondary Dendrite Arm Spaces of alloys: ACAlSi7Cu, ACAlSi7Cu2 and ACAlSi7Cu4

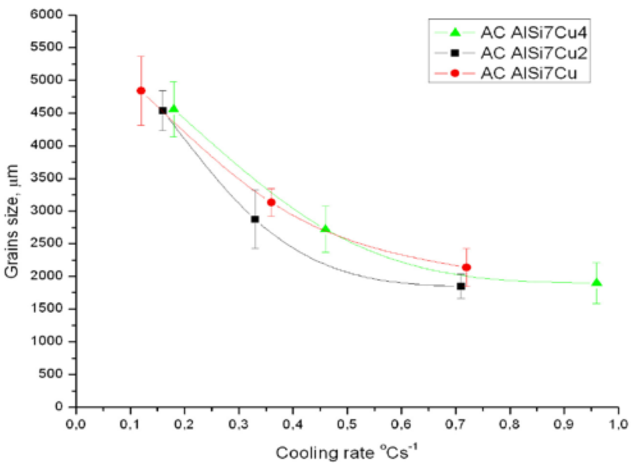

Fig. 2. Influence of solidification rate on grain size of alloys: ACAlSi7Cu, ACAlSi7Cu2 and ACAlSi7Cu4

Microstructural features were characterised using light optical microscopy Leica MEF4A and computer image analyzer Leica Q-Win^{TM}. Microstructure of aluminium cast alloys AlSi7Cu solidified at cooling rate of 0.18 ºC s^{-1}, 0.46 ºC s^{-1} and 0.96 ºC s^{-1} are shown on Figure 3, 4 and 5 respectively. In the samples solidified with high cooling rate the silicon particles is smaller then for sample with lower cooling rate. Changes the morphology of precipitates of silicon strongly depends on solidification rate. Magnitude of the precipitates of silicon in aluminium alloys is closely connected with mechanical properties. Increasing the solidification rate cause changes of the eutectic morphology from lamellar structure on fibrous structure.

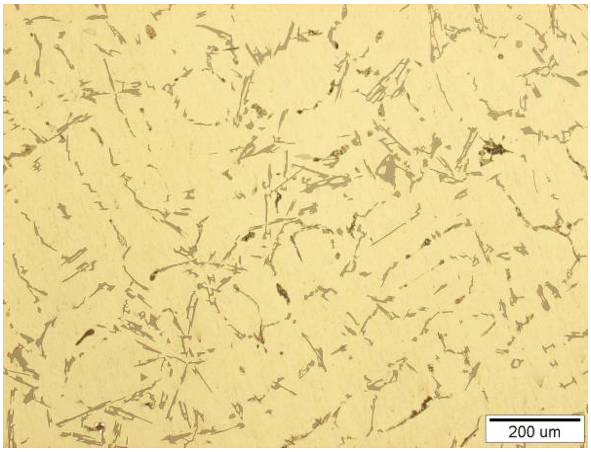

Fig. 3. Microstructure of AC AlSi7Cu alloy solidified with rate 0.18 ºC s^{-1}

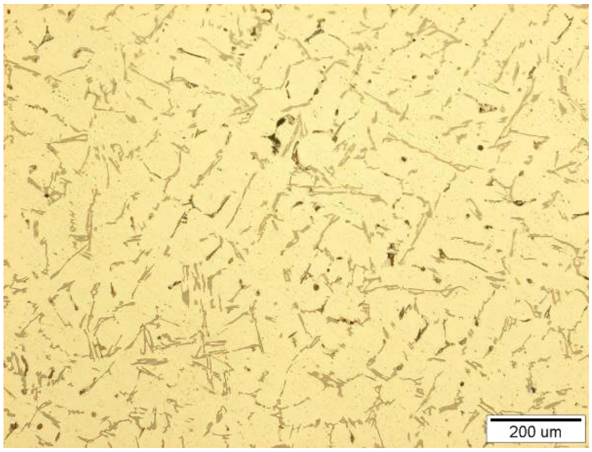

Fig. 4. Microstructure of AC AlSi7Cu alloy solidified with rate 0.46 ºC s^{-1}

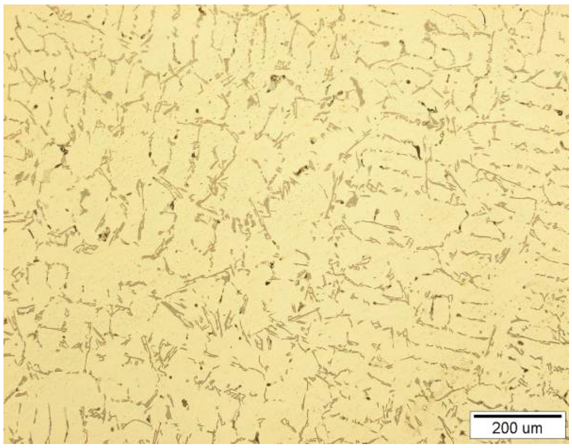

Fig. 5. Microstructure of AC AlSi7Cu alloy solidified with rate 0.96 ºC s^{-1}

Increase of solidification rate has impact on increase in hardness of investigated alloys, what is shown in table 2. Changes of solidification rate for AC AlSi7Cu alloy from 0.18 ºCs^{-1} to 0.96 ºCs^{-1} cause increase of hardness about 6 HRF, for AC AlSi7Cu2 increase about 5.3 HRF and for AC AlSi7Cu4 about 3.5 HRF. Contents of copper have also significant meaning on mechanical properties such as hardness. Changes in content of copper from about 1% to 4% causes increase of hardness about 15 HRF in investigated alloys.

Influence of the solidification rate and content of copper on microhardness of Al-Si-Cu alloys is shown in table 3. The results of microhardness test are comparable to hardness test, it means that increase of solidification rate and contents of copper cause the increase of aluminium alloys microhardness.

Table 2.
Hardness of aluminium alloys: AC AlSi7Cu, AC AlSi7Cu2, AC AlSi7Cu4, cooling with different rates

Alloy ID	Cooling rate, ºC s^{-1}	Hardness HRF	Standard deviation
C AlSi7Cu	0.18	68.43	0.91
	0.46	70.63	0.91
	0.96	74.58	2.15
AC AlSi7Cu2	0.16	79.56	1.33
	0.33	82.67	1.64
	0.71	84.89	1.87
AC AlSi7Cu4	0.12	85.54	1.23
	0.36	87.12	3.07
	0.72	89.00	1.40

Table 3.
Microhardness of matrix aluminium alloys: AC AlSi7Cu, AC AlSi7Cu2, AC AlSi7Cu4, cooling with different rates

Alloy ID	Cooling rate, ºC s^{-1}	Microhardness, HV 0.025	Standard deviation
AC AlSi7Cu	0.18	75.76	5.89
	0.46	77.94	2.47
	0.96	80.30	3.54
AC AlSi7Cu2	0.16	81.71	7.19
	0.33	82.97	2.84
	0.71	85.83	4.68
AC AlSi7Cu4	0.12	91.81	7.66
	0.36	93.29	7.14
	0.72	96.10	3.08

4. Conclusions

A comprehensive understanding of influence of solidification rate considerable importance on mechanical properties of aluminium-silicon-copper alloys.

Increasing solidification rate decreases the effect of Secondary Dendrite Arm Spacing and grain size of Al-Si-Cu cast alloys.

Increasing solidification rate increase hardness and microhardnes of aluminium cast alloys, also the hardness and microhardness increase with escalation contents of copper in Al-Si-Cu alloys.

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