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Š. EPERJEŠI*, M. MATVIJA*, Ľ. EPERJEŠI**, M. VOJTKO*

EVALUATION OF CRACKING CAUSES OF AlSi5Cu3 ALLOY CASTINGS

OKREŚLENIE PRZYCZYN PĘKANIA ODLEWÓW ZE STOPU AlSi5Cu3

Recently, the castings made from aluminum-silicon alloys by pressure die casting are increasingly used in the automotive industry. In practice, on these castings are high demands, mainly demands on quality of their structure, operating life and safety ensuring of their utilization. The AlSi5Cu3 alloy castings are widely used for production of car components. After the prescribed tests, the cracks and low mechanical properties have been identified for several castings of this alloy, which were produced by low pressure casting into a metal mould and subsequent they were heat treated. Therefore, analyses of the castings were realized to determine the causes of these defects. Evaluation of structure of the AlSi5Cu3 alloy and causes of failure were the subjects of investigation presented in this article.

Keywords: AlSi5Cu3 alloy, microstructure, cracks, hardness

Zastosowanie odlewów ciśnieniowych ze stopów Al-Si ustawicznie wzrasta w przemyśle samochodowym, gdzie stopy te muszą spełniać wysokie wymagania odnośnie do jakości ich struktury, żywotności i bezpiecznego użytkowania. Odlewy ze stopu AlSi5Cu3 są szeroko stosowane w produkcji części samochodów. Wg pracy wady pęknięć wewnętrznych i niskie właściwości mechaniczne posiada część odlewów obrabianych cieplnie, odlanych do form metalowych pod niskim ciśnieniem. Praca poświęcona jest ocenie struktury i przyczynom pękania odlewów ze stopu AlSi5Cu3.

1. Introduction

Nowadays, the most common material for non-ferrous casting production is aluminum and its alloys, mainly due to its low density and relatively good machinability and castability. In last decade, the ratio of aluminum castings in cars increased approximately 2.5-times [1, 2]. Motor blocks, gearboxes and wheels of cars represent a great ratio of total assortment of castings in automotive industry, the importance of which is mainly to reduce weight of castings, loudness and vibrations, which finally will increase of vehicle performance.

During production of castings for automotive industry, important role are playing the costs on production and requirements on casting quality and their mechanical loading during vehicle operation. During production of turbo-blower from AlSi5Cu3 alloy cast under low pressure into metal mould, after heat treatment and prescribed tests, on some castings disruption of their surface was discovered. To prevent a recurrence of these defects the castings alloy was analyzed to evaluation of surface disruption causes.

Low pressure die casting is in principle belong to gravity pouring into metal moulds pressure casting [3]. This method of casting production ensures high inner quality of castings with very high usage of molten metal. Because of specific conditions of solidification and cooling of castings in metal mould, such foundry defects as misrun, surface disruption (cracks and tears), cold laps, shrinkage, etc. can be awaited.

Defects occurrence in castings poured under low pressure is influenced by following factors: construction of metal mould with venting and cooling system, die casting machine, type of poured alloy and its metallurgical processing, set technological parameters of pouring and operators of die casting machine. Given factors influence each other and present complex of bindings, which influence final quality of castings.

The nature of low pressure die casting is that mould is filled with molten metal by pressure induced by compressed air or gas. Mould filling can be controlled by the change of gas pressure. Therefore, during calm filling of mould cavity it is possible to produce casting with high quality and non-permeable. Crystallization of alloy in the mould takes place under the thumb of pressure, which stimulates inter-dendritic thickening in two-phase area and creates dense arrangement of alloy structure. Increase of casting denseness insures increase of strength, air-tightness and reliability of casting.

Evaluation of causes of these defects, which was occurred on given castings, will allow a prevention of their repeating occurrence by suitable corrective steps. For evaluation the samples were cut from the parts of casting, where the defects were occurred – from suitable and also non-suitable casting.

* FACULTY OF METALLURGY, TECHNICAL UNIVERSITY OF KOŠICE, LETNÁ 9, 040 01 KOŠICE, SLOVAKIA

** ČZ, A. S., TOVÁRNÍ 202, 386 15 STRAKONICE, CZECH REPUBLIC

Surface disruption – cracks and tears – were occurred using this technology due to formation of temporary or residual shrinking or thermal stresses. Tears begin to create during solidification, if free shrinking is broken mechanically or thermally. Cause of cracks formation is stress caused by shrinking, non-suitable structure of casting which causes stresses in casting after cooling, very soon taking-out of casting from mould. Surface disruption can be prevented by ensure of even solidification of every volume in casting.

Insufficient mechanical properties require careful evaluation of all parameters of metallurgical operations of alloy for casting production.

2. Experimental material and methods

The commercial hypoeutectic heat-treatable AlSi5Cu3 alloy was experimental material in this investigation. The standard chemical composition of experimental alloy is given in Table 1. The castings of this alloy were molten into metal moulds using the technology of low pressure casting. Subsequently, the alloy castings were heat treated. The experimental samples of alloy for analyzes of their microstructures were cut from the surface of non-suitable casting with present defects and a suitable casting without defects.

TABLE 1
Standard chemical composition of AlSi5Cu3 alloy

element	Si	Cu	Fe	Mn	Mg
wt. %	4.5-6.0	2.6-3.6	0.5-0.6	0.55	0.05
Ni	**Zn**	**Pb**	**Sn**	**Ti**	**Al**
0.1	0.2	0.1	0.05	0.2	bal.

The analysis of non-suitable and suitable castings microstructures consists in evaluation of eutectic Si-particles and intermetallic phase particles character focusing on their morphology and distribution. Recently analysis of the structure and inner defects has been frequently performed using automated methods and procedures [4, 5, 6]. In this work the average size and number per unit area of these particles were evaluated by statistical metallographic methods. Microstructures of castings were documented by light microscope (LM) Olympus Vanox T AH-2 and scanning electron microscope (SEM) Jeol 7000F. Metallographic samples were prepared using the common grinding and polishing methods and they were etched using the 0.5% HF in distilled water. Chemical nature of intermetallic phase particles was evaluated by SEM using EDX analyzes. The effect of microstructure changes of experimental alloy on castings hardness was evaluated by Vickers hardness measurement (HV10).

3. Results and discussion

3.1. Microstructure of AlSi5Cu3 alloy castings

In both castings, non-suitable and suitable, the microstructure was dendritic and heterogeneous, what is typical for castings molten from hypoeutectic silumine [7, 8, 9]. Microstructure consisted of (i) α-solid solution dendrites, (ii) eutectic cells, which consisted of α-solid solution and eutectic Si-particles in form (α + Si) and (iii) intermetallic phase particles of an irregular shape. Microstructures of non-suitable and suitable castings documented by light microscope are shown in Fig. 1.

On the non-suitable casting surface the cracks were observed. They initiated on casting surface and propagated along eutectic Si-particles networks and intermetallic phase particles on interface with α-solid solution dendrites, what is clear from Fig. 2. This mechanism of crack propagation in AlSi5Cu3 alloy castings is typical for silumine with dendritic structure [10].

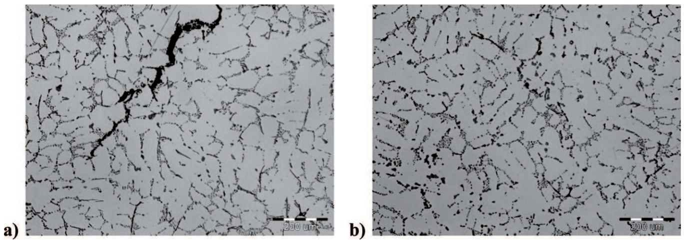

Fig. 1. Microstructure of casting with not acceptable defect (a) and acceptable casting (b) of AlSi5Cu3 alloy

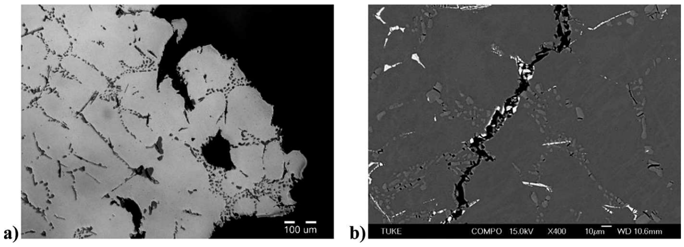

Fig. 2. Character of crack propagation in structure of casting with not acceptable defect documented by LM (a) and SEM (b)

Eutectic Si-particles were partially spheroidized in both analyzed alloy castings. Average size of Si-particles in the case of non-suitable casting was 3.2 μm and their number per unit area was 6.6×10^3 mm^{-2}. In the suitable casting microstructure, the average size of Si-particles was 3.5 μm and their number per unit area was almost two times lower in comparison with number of non-suitable casting and it was 3.5×10^3 mm^{-2}. A partial spheroidizing of eutectic Si-particles in both castings was consequence of their heat treatment [9, 11]. However, from evaluation of Si-particles average size and their number per unit area follows that it was not observed the same condition (temperature and/or holding time) of heat treatment. In the case of non-suitable casting, it is possible to expect a lower temperature and/or holding time of heat treatment because of eutectic Si-particles coarsening was lower, however difference of average sizes of these particles in the structure of both castings, non-suitable and suitable, is quite small, and so it is possible to expect a small deviation in process of castings heat treatment. The more significant difference was observed in the case of number per unit area.

In both castings structure, intermetallic phase particles were of irregular morphology. These particles of non-suitable casting were of needle-like shape and they had blocky morphology with sharp edges and high notch effect. Their morphology and distribution is shown in Fig. 3. The average size of particles was 3.6 μm and their number per unit area was 1.6×10^3 mm^{-2}. In the case of suitable casting, the average size of intermetallic phase particles (3.5 μm) was almost the same in comparison with non-suitable casting, however their number per unit area was lower and the value was 1.1×10^3 mm^{-2}. These particles were not sharp-edged like as particles in non-suitable casting structure, but they were of rod-like morphology with rounded edges, what resulted in lower notch effect in comparison with non-suitable casting. The character of these particles is clear from Fig. 4.

It follows that higher temperature and/or longer holding time of a suitable casting heat treatment in comparison with heat treatment of non-suitable casting led to the rounding sharp and square ends of the intermetallic phase particles in alloy structure.

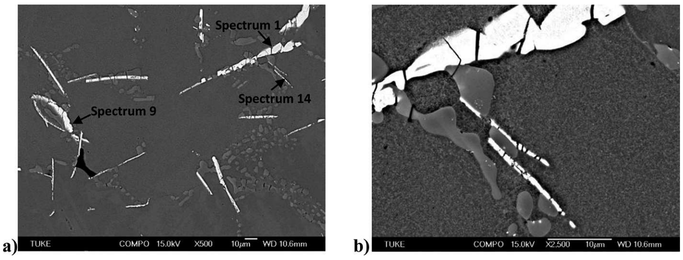

Fig. 3. Morphology of intermetallic phase particles in structure of non-suitable casting (a) and detail of particles (b)

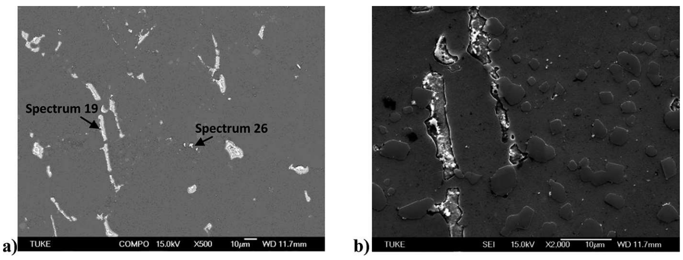

Fig. 4. Morphology of intermetallic phase particles in structure of suitable casting (a) and detail of particles (b)

The chemical nature of intermetallic phase particles in both castings, non-suitable and suitable, of analyzed alloy indicated EDX analyze. In the case of non-suitable casting, the intermetallic phase particles were detected on the Al-Si-Fe-Mn-base and Al-Si-Fe-Mn-Ni(Cr)-base. Specific spectra of analyzed particles are shown in Fig. 5. In the case of suitable casting, the particles were detected on the Al-Si-Fe-Mn-base and Al-Si-Fe-Ni-base. EDX spectra of analyzed particles are shown in Fig. 6.

3.2. Hardness of AlSi5Cu3 alloy castings

Differences in microstructure parameters were reflected in different hardness values of both the present alloy castings. A non-suitable casting was marked by a lower value of hardness HV 10 (105.7) compared to a suitable casting (112.0).

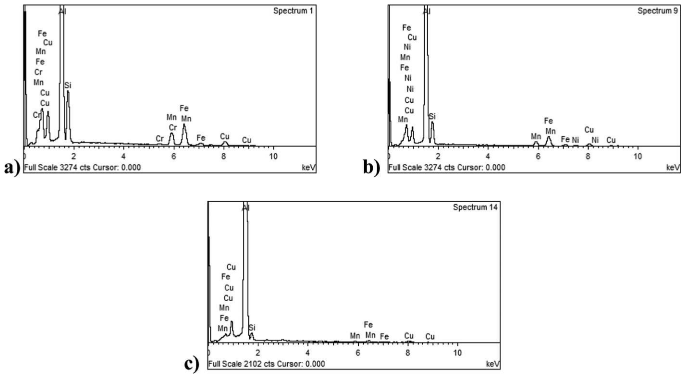

Fig. 5. EDX spectra of intermetallic phase particles in non-suitable casting structure: Spectrum 1 (a), Spectrum 9 (b) and Spectrum 14(c)

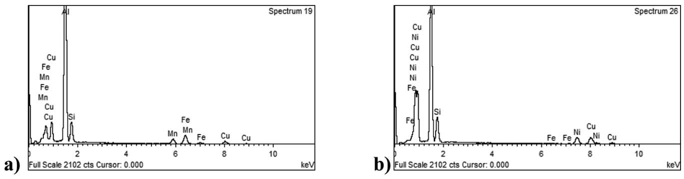

Fig. 6. EDX spectra of intermetallic phase particles in suitable casting structure: Spectrum 19 (a) and Spectrum 26 (b)

4. Conclusions

1. As it is clear from Fig. 2, the casting surface disruption was initiated on interface of α-solid solution and eutectic Si-particles, and/or intermetallic phase particles, which could show, that the break shrinking occurred due to mechanical or thermal resistance during solidification of casting in the mould. It could be caused by insufficient temperature of mould or uneven solidification of casting in the mould, or resistance of the mould during solidification and shrinking of casting in the mould. So created microtears by this manner caused total surface disruption after heat treatment.
2. From observing the morphology of intermetallic phase particles it is clear, that during heat treatment of non-suitable casting sufficient spheroidizing of intermetallic particles did not occur, which resulted in higher notch effect after load of casting and also in lower mechanical properties.
3. From metallurgical point of view it is recommended to pay increased attention during preparation and composition of charge and refining of melt.

REFERENCES

[1] J. Malik, Technológia liatia zliatin hliníka, Košice, 2013.
[2] R. Kantorík, D. Bolibruchová, International Foundry Reseach **63**, 2, 18-23 (2011).
[3] T. Grígerová, R. Kořený, I. Lukáč, Zlievarenstvo neželezných kovov, Bratislava, 1988.
[4] W.K. Krajewski, J. Lelito, J.S. Suchy, P. Schumacher, Computed tomography – a new tool in structural examinations of castings, Archives of Metallurgy and Materials **54**, 2, 335-338 (2009).

[5] K. Haberl, W.K. Krajewski, P. Schumacher, Microstructural features of the grain-refined sand cast AlZn20 alloy, Archives of Metallurgy and Materials **55**, 3, 837-841 (2010).
[6] W.K. Krajewski, A.L. Greer, P.K. Krajewski, Trends in developments of high-aluminium zinc alloys of stable structure and properties, Archives of Metallurgy and Materials **58**, 3, 859-861 (2013).
[7] E. Tillová, M. Chalupová, L. Hurtalová, M. Bonek, L.A. Dobrzański, Journal of Achievements in Materials and Manufacturing Engineering **47**, 1, 19-25 (2011).
[8] R. Colás, E. Velasco, S. Valtierra, Castings, In: G. E. Totten, D. C. MacKenzie (Ed.), Handbook of Aluminum, Physical Metallurgy and Processes, Boca Raton, 591-641 (2003).
[9] M. Fujda, O. Milkovič, M. Vojtko, T. Kvačkaj, T. Donič, Metallurgical Journal **62**, 1, 14-19 (2009).
[10] M. Matvija, M. Fujda, M. Vojtko, R. Kočiško, Acta Metallurgica Slovaca – Conference **3**, 75-81 (2013).
[11] E. Sjölander, S. Seifeddine, Journal of Materials Processing Technology **210**, 1249-1259 (2010).

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