INFLUENCE OF SB ON GAS CONTENT AND FLOWABILITY OF ALLOY ALSI6CU4

Dušan Medlen
***Iva Nová**
****Dana Bolibruchová**
*****Dušan Urgela**

University of Žilina
Department of Technological Engineering
Univerzitná 1, 010 26 Žilina, Slovakia
dusan.medlen@fstroj.uniza.sk
*Technical University of Liberec
Faculty of Mechanical Engineering
Studentská 2, 461 17, Liberec 1, Czech Republic
iva.nova@tul.cz
**University of Žilina
Department of Technological Engineering
Univerzitná 1, 010 26 Žilina, Slovakia
danka.bolibruchova@fstroj.uniza.sk
***University of Žilina
Department of Technological Engineering
Univerzitná 1, 010 26 Žilina, Slovakia
dusan.urgela@fstroj.uniza.sk

Abstract

Cast aluminum-silicon alloys are used in a number of automotive and industrial weight sensitive applications because of their low weight and very good castability. Modifiers are usually added to molten aluminum-silicon alloys to refine the eutectic phase particle shape and improve the mechanical properties of the final cast products and Al-Si alloys cast properties. In terms of aluminum-silicon, this usually involves the addition of strontium (Sr), sodium (Na) or antimony (Sb). The cast properties fluidity and mould filling capacity play a key role in the production of thin-section and geometrically complex cast parts. The presence of trapped gas or shrinkage pores in certain locations within castings has been shown to influence fatigue life. In this paper the influence of Sb on the gas content and flowability of AlSi6Cu4 has been researched.

Introduction

The excellent castability and mechanical properties of the AlSi6Cu4 alloy make it a popular foundry alloy for automotive applications. [1] Nowadays foundry plants are forced to reduce the wall thickness of cast pieces, to keep the narrow tolerance extent (combustion chamber, canal position) and to minimize the surface roughness (suction canal). The higher requirements on cast pieces make the construction more extensive and more complicated. [2]

The cast properties and mechanical properties of the AlSi6Cu4 alloys can be improved not only through modifying grain refinement but also through applying heat treatment and other technologies. In practice, the most common elements with the modifying effect are strontium, sodium and antimony. Adding these elements leads to a change in the shape of eutectic silicon, resulting in an increase of the mechanical and cast characteristics of the alloys. [1, 3]

Many experiments have been carried out to study and explain the effect of eutectic modifiers on hydrogen, microporosity and flowability. In general, it is observed that modified castings contain more porosity than unmodified ones. However, there is no consensus on the mechanism. Some possible reasons have been proposed and studied. In general, modifiers can increase the inclusion content in the melt, decrease hydrogen solubility in the solid metal, change the solid-liquid interface morphology, reduce the surface tension of the liquid metal and increase the volumetric shrinkage. [1]

The AlSi6Cu4 castings must meet the high requirements not only on the mechanical properties but must meet high requirements on pressure tightness as well. Strontium is now widely used in practice for the modification of the AlSi6Cu4 alloy. When modifying the AlSi6Cu4 alloys by strontium, it was found out that the alloy subjected to this type of modification has higher values of the gas content, leading to higher porosity and thus reducing the pressure tightness. The aim of the experimental work was to investigate the influence of antimony on the gas content of the aluminum alloy AlSi6Cu4. [4, 5]

1 Experimental procedure

1.1 Melt treatment and casting procedures

The Aluminum alloy AlSi6Cu4 was used as the experimental material. The chemical composition of the alloy is listed in *Tab. 1*. The melting process and the modification were carried out in a graphite-chamotte melting crucible in an resistance oven. The grain refinement process using the refining salt AlCuAB6 was carried out while overheating the metal bath to 730 °C ± 5 °C. The modification process using antimony was carried out under the same technological conditions.

The amount of antimony chosen for each cast is listed in *Tab. 2*. This amount was determined and based on the most widely used quantities shown in the literature for Al-Si-Cu based alloys.

Tab. 1 Chemical composition of the AlSi6Cu4 alloy

Elements	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Cr
(wt.%)	6,52	0,43	3,88	0,45	0,29	0,01	0,46	0,15	0,01

Tab. 2 Amount of antimony for each cast of AlSi6Cu4 alloy used in the present work

Number of cast	1	2	3	4	5	6	7	8	9	10	11
Amount of Sb (ppm)	0	100	300	500	800	1000	1500	2000	2500	3000	10000

1.2 Gas content of the AlSi6Cu4 alloy

To improve the mechanical properties of these materials, the common practice is to refine the microstructure of the casting, such as modification. It has been shown that the defect area and distance from the free surface are important factors that determine the impact of defects on the fatigue life of castings. A large level of porosity, which is located in the center of the casting, may not effect the mechanical properties or the fatigue performance. A smaller, isolated pore near the surface may have a significant impact. The designers need to know how the cast part geometry and process will impact the porosity formation. As such, it is important to develop a comprehensive model to predict the size and location of microporosity in a casting as a function of the process variables. Microporosity usually results from a failure of the interdendritic feeding or of the exsolution of the dissolved gas from the melt, or a combination of the two. [1]

To detect the gas content the Vacuum Density Tester 3VT-LC, the vacuum forming and the weighing-machine MK 2200LC were used for the weight identification of the experimental samples (*Fig. 1*). The weighing-machine evaluated the density of the samples and also the percentage, based on the mathematical and physical relationships and formulas, and determined the density index - DI. In each cast there were made two samples where the first one was solidifying in the air and the second one was placed in a vacuum for 7 minutes. The cross-section cuts of the individual samples can be seen in *Tab. 3*.

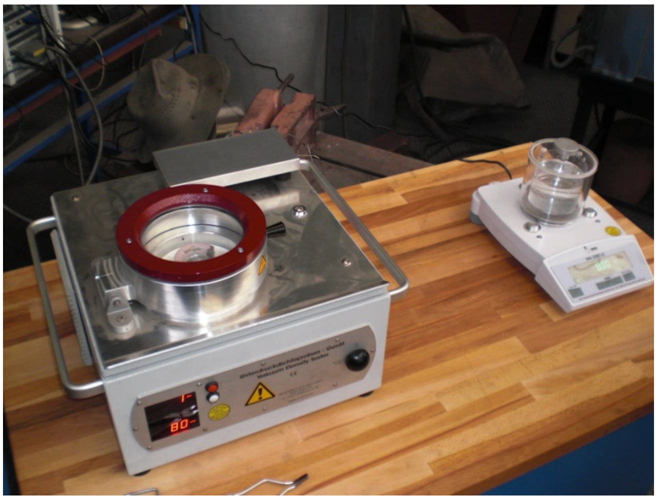


Fig. 1 Vacuum Density Tester 3VT-LC and weighing-machine MK 2200LC

Tab. 3 Cross-section cuts of AlSi6Cu4 modified by Sb

			
air	vacuum	air	vacuum
Cast no. 1 (0 ppm Sb)		Cast no. 2 (100 ppm Sb)	
			
air	vacuum	air	vacuum
Cast no. 3 (300 ppm)		Cast no. 4 (500 ppm Sb)	

			
air	vacuum	air	vacuum
Cast no. 5 (800 ppm Sb)		Cast no. 6 (1 000 ppm Sb)	
			
air	vacuum	air	vacuum
Cast no. 7 (1 500 ppm Sb)		Cast no. 8 (2 000 ppm Sb)	
			
air	vacuum	air	vacuum
Cast no. 9 (2 500 ppm Sb)		Cast no. 10 (3 000 ppm Sb)	
			
	air	vacuum	
	Cast no. 11 (10 000 ppm Sb)		

The samples of AlSi6Cu4 modified by antimony solidified in the air in *Tab. 3*, can be considered as a brief overview of the porosity formation and location.

Fig. 2 shows the calculated values of the density index of the AlSi6Cu4 alloy modified by graduated amounts of antimony on the basis of the mathematical and physical relationships. Based on the comparison *Tab. 3* and *Fig. 2*, it can be noted that the mathematically determined amount of the gas content was confirmed by observing the cross-section cuts of the experimental samples.

The unmodified AlSi6Cu4 alloy showed DI = 11.11%, while by adding a Sb modifier there were obtained significant changes, approx. a 63 percent reduction, in the gas content corresponding to 500 ppm Sb.

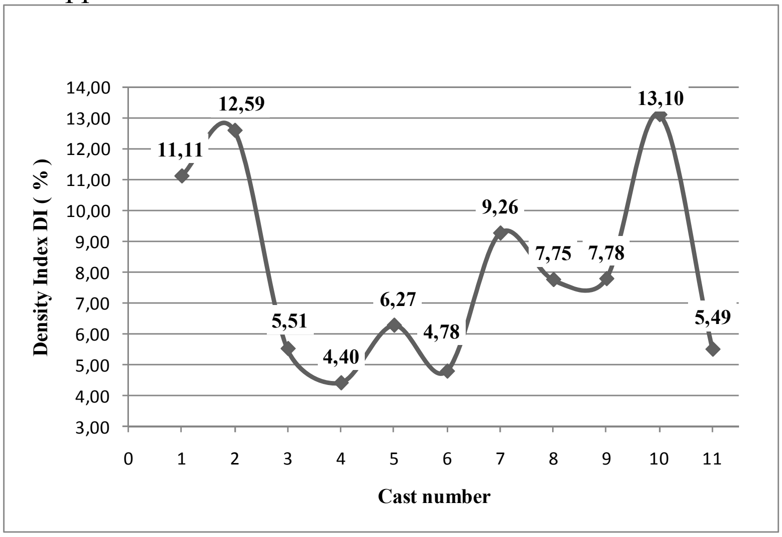


Fig. 2 *Density index of AlSi6Cu4 modified by Sb*

1.3 Flowability of the AlSi6Cu4 alloy

The literature survey has shown that the addition of strontium (Sr) decreases the flowability of the aluminium alloys. The authors have revealed in their works that the modification in a sand form reduces the flowability of an AlSi alloy from 5 to 7%, while in a steel mould the reduction is a little bit smaller varying between 2% or 3% [6, 7]. Mollard [8] has found out that the flow property of the aluminium alloys can be reduced up to 8% due to Sr addition. Kotte and Serak [9, 10] have shown that the lowering of the flowability through Sr addition is not so high as through the modification with sodium. According to them, the reason for the strong decrease of the flowability of the AlSi alloys through the sodium (Na) addition might be due to its effect on the surface tension of the AlSi alloys. The influence of antimony (Sb) on AlSi6Cu4 has not been investigated.

In this subchapter the effect of the antimony addition on the flowability of the AlSi6Cu4 alloy has been investigated. The amount of antimony was varied from 0 ppm up to 10 000 ppm (*Tab. 2*). The process parameters such as the casting temperature 730°C and the pouring temperature 730°C were held constant during these experiments. The accuracy of the casting is limited by the type of sand and the molding process. In terms of the flowability experiments, sand molds were used. The used molding sand consisted of silica sand (SiO2) 85%, bentonite (clay) 11%, and water 4%.

Traditionally, the flowability is measured by using the spiral test. The flowability is determined through the flow length of an alloy in a spiral contour. *Fig. 3* shows the values of the flow length (cm) for each spiral. The final casts (spirals) from each casting used for the evaluation of the flow length are shown in *Tab. 4*.

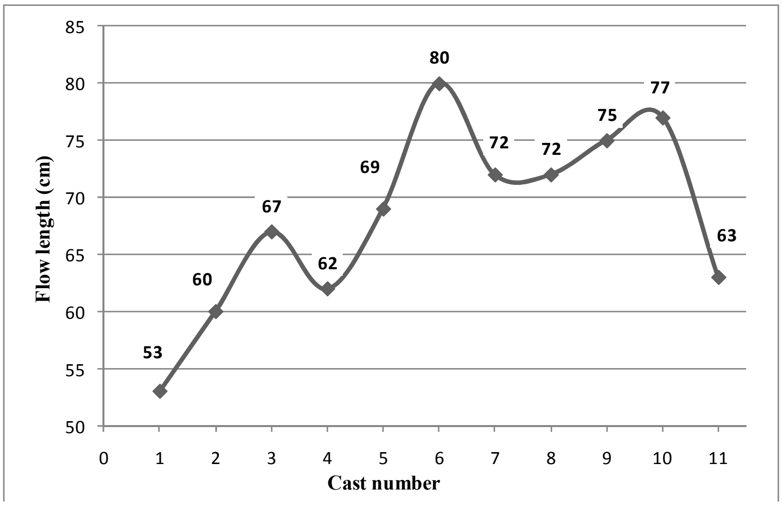
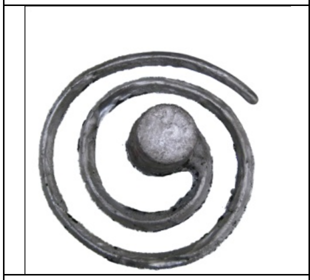
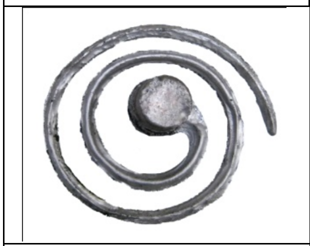


Fig. 3 Flow length of AlSi6Cu4 modified by Sb

Tab. 4 Spiral test samples used for evaluation of the flow length of AlSi6Cu4

			
Cast no. 1 (0 ppm Sb)	Cast no. 2 (100 ppm Sb)	Cast no. 3 (300 ppm Sb)	Cast no. 4 (500 ppm Sb)
			
Cast no. 5 (800 ppm Sb)	Cast no. 6 (1 000 ppm Sb)	Cast no. 7 (1 500 ppm Sb)	Cast no. 8 (2 000 ppm Sb)
			
Cast no. 9 (2 500 ppm Sb)	Cast no. 10 (3 000 ppm Sb)	Cast no. 11 (10 000 ppm Sb)	

Conclusion

In this work the influence of antimony on the AlSi6Cu4 alloy on the gas content and flowability has been investigated.

When modifying the AlSi6Cu4 alloys by antimony, it was found, that the alloy subjected to this type of modification has lower values of the gas content, leading to the lower porosity that has an effect on the pressure tightness comparing to modifying the AlSi6Cu4 alloys by strontium. Based on the experimental results of the gas content (*Tab. 3* and *4*), it can be claimed that the most appropriate amount of antimony with the lowest DI= 4,04 % is 500 ppm Sb. The gas content of the tested AlSi6Cu4 alloy sample, modified by 500 ppm Sb, decreased down to approx. 37 % of the original unmodified alloy (DI= 11,11%).

The spiral test experiments have shown that the amount of antimony in the aluminium melt has an effect on the flow length. The increase in the amount of antimony extends significantly the flow length of the aluminium melt. Based on the experimental results, the spiral test experiments (*Tab. 5* and *6*) can claim that the most appropriate amount of antimony for the flow length of AlSi6Cu4 is 1 000 ppm Sb. By addition of 1 000 ppm Sb the flow length increased to 51 % (80 cm) of the original unmodified alloy (53 cm).

Combining the best achieved results of these two experiments we can get 2 combinations:
A. Choosing the best achieved result in the gas content experiments - 500 ppm Sb (decreased to 37%) - the flow length increased to approx. 14 % of the unmodified AlSi6Cu4.
B. Choosing the best achieved result in the spiral test experiments – 1 000 ppm Sb (51 % increase) - DI decreased to approx. 43 % of the unmodified AlSi6Cu4.

Acknowledgement:
The authors wish to thank the European Regional Development Fund for the received financial support to create the present paper within the execution of the project called "The Equipment for the Production of the Prototype Parts by Casting on a Computer-controlled Base" with the ITMS code 26220220047.

Literature

[1] CONLEY, J.G.; HUANG, J.; ASADA, J.; AKIBA, K..: *Modeling the effects of cooling rate, hydrogen content, grain refiner and modifier on microporosity formation in Al A356 alloy.* Materials Science and Engineering A 285, 2000. 49-55

[2] BOUSKA, O.: T*he effect of different casting parameters on the relationship between flowability, mould filling capacity and cooling conditions of al-si alloys*. Metalurgija - Journal of metallurgy, Serbia, 2008. 17-30

[3] MEDLEN, D.; BOLIBRUCHOVÁ, D.: *Teoretical studies of AlSi6Cu4 alloys*. Technológ Vol. 2, 2010. 151-156

[4] GRZINCIC, M.: *Manufacturing trends for engine blocks of automobiles*. Slévárenství Vol. 2-3, 2003. 74-80

[5] ROMANKIEWICZ, R.; ROMANKIEWICZ, F.: *Influence of modification of silumin AlSi6Cu4 on fracture morphology*. Journal of machine manufacturing, vol. XLIX, 2009.

[6] BOLIBRUCHOVÁ, D.; TILLOVÁ, E.: *Foundry Alloys Al-Si*, EDIS Žilina, 2005. 180

[7] SABATINO, M. D.; SHANKA, S.; APELIAN, D.; ARNBERG, L.: *Influence of temperature and alloying elements on fluidity of Al-Si alloys.* Doctoral Thesis Fluidity of aluminium foundry alloys, Trondheim, 2005

[8] MOLLARD, F.R.; FLEMMINGS, M.C.; NYAMA E.F: *Understanding aluminium fluidity: the key to advanced cast products*. AFS Trans., 1987. vol. 95, p. 647-652

[9] KOTTE, R.: *Strontium modification gives critical melt control*, Modern Casting, 1985. 33-35

[10] SERAK, V.: *Modifikace slitiny AlSi10Mg sodikem a stronciem*, Sbornik Konference Aluminium, 2001

Ing. Dušan Medlen, Prof. Ing. Iva Nová, CSc., Doc. Ing. Dana Bolibruchová, PhD.,
Ing. Dušan Urgela

VLIV SB NA NAPLYNENÍ A ZABÍHAVOST SLITINY ALSI6CU4

Slévárenské Al-Si slitiny se používají v řadě automobilových a průmyslových aplikací náročných na nízké tíhové účinky z důvodu jejich relativně malé měrné hmotnosti a velmi dobré slévatelnosti. Modifikátory se obvykle přidávají do roztavených Al-Si pro zjemnění tvaru částic eutektické fáze a zlepšení mechanických vlastností finálních odlitků Al-Si slitin a jejich slévárenské vlastnosti. Pro slitiny Al-Si toto obvykle zahrnuje přidání stroncia (Sr), sodíku (Na), nebo antimonu (Sb). Od slévárenských vlastností jako tekutost a schopnost vyplnění formy hraje klíčovou roli v produkci tenkostěnných, geometricky složitých odlitků. Bylo prokázáno, že přítomnost zachyceného plynu a tedy pórů v některých místech odlitků, má vliv na únavovou životnost. V tomto příspěvku byl zkoumán vliv Sb na naplynení a zabíhavost AlSi6Cu4.

DER EINFLUSS VON SB AUF DEN GASGEHALT UND DIE FLIESSFÄHIGKEIT DER LEGIERUNG ALSI6CU4

Aluminium-Silizium-Legierungen sind werden in der großenr Anzahl in der Automobil- und Industrieelektronik aufgrund ihresr geringen Gewichts und ihrer sehr guten Gießbarkeit verwendet. Modifikatoren sind werden normalerweise im geschmolzenen Aluminium-Silizium-Legierungen zugefügt, um die Partikelform von der eutektischen Phase zu verfeinern und die mechanischen Eigenschaften ders fertigen Gussteile und der Al-Si-Legierungen und deren gegossenen Eigenschaften zu verbessern. Für Aluminium-Silizium beinhandelthaltet es sich normalerweise um die Zugabe von Strontium (Sr), Natrium (Na) oder Antimon (Sb). Von den Gusseigenschaften spielen Fließfähigkeit und Formfüllungsvermögen bei der Produktion von Dünnschicht- und geometrisch komplexen Gussteilen eine Schlüsselrolle. Die Anwesenheit von aufgefangenem Gas oder die Schrumpfung der Poren an bestimmten Orten im Guss führt zu einer Beeinflussung desr Lebensdauer. In dieser Arbeit wurde der Einfluss von Sb auf den Gasgehalt und Fließfähigkeit von AlSi6Cu4 untersucht.

WPŁYW SB NA ZAWARTOŚĆ GAZU I LEJNOŚĆ STOPU ALSI6CU4

Odlewy stopu aluminiowo-krzemowego mają często zastosowanie w rozwiązaniach przemysłowych i motoryzacyjnych wrażliwych na ciężar, ponieważ są lekkie oraz mają bardzo dobrą lejność. Modyfikatory dodaje się zazwyczaj do roztopionych stopów Al-Si w celu złagodzenia kształtu cząstek fazy eutektycznej i poprawy właściwości mechanicznych produktów końcowych ze stopów aluminiowo-krzemowych (Al-Si). Ten stop zwykle wymaga dodania strontu (Sr), sodu (Na) lub antymonu (Sb). Właściwości lejności i zdolności napełniania formy odgrywają kluczową rolę w produkcji form o cienkich ściankach i geometrycznie skomplikowanych. Stwierdzono, że obecność gazu, czyli pęcherzyków w niektórych miejscach odlewu wpływa na żywotność i tzw. "zmęczenie materiału". W niniejszym artykule badano wpływ antymonu (Sb) na zawartość gazu oraz płynność AlSi6Cu4.