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## Quality control of cylinder head casting

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### Abstract

New challenges for the Aluminium alloys used for the production of castings for automotive engine components result from an evolutionary trend of internal combustion engines towards higher specific power output. Cylinder heads, in particular, have to withstand higher operating temperature and stress levels. Present work describes quality control of microstructure (Si-morphology and Si-size) and mechanical properties (UTS, elongation, Brinell hardness) of cylinder head casting as effect of different T6 heat treatment (solution heat treatment time - 2, 3, 4, 5, 6, 7 hours). The data obtained from this study will be used to improve process control, and to help the selection of heat treatment of the casting for future products.

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## 1. Introduction

Aluminium castings are widely used in automotive industry for several components such as engine blocks and cylinder heads, which are produced in high volumes, owing to their favourable combination of low weight, easy machinability, recyclability and low cost (TILLOVÁ E. 2009). In the last years the evolution of internal combustion engines has been driven mainly by the need to meet new stringent emissions standards (like Euro 5 or future Euro 6 in Europe) and to improve fuel economy of the vehicles aiming to reduce the amount of CO<sub>2</sub>, which is considered a “greenhouse gas” with potential effect on global warming, released to the ambient (MOLINA R. 2011).

Development in aluminium alloys and optimization of casting techniques has led to improved material properties and functional integration which enable aluminium castings to satisfy the new market requirements and has allowed replacing, in many cases, engine components made with heavy cast iron alloys. Nevertheless, requirements for new products are becoming more and more challenging for conventional aluminium alloys and their further improvement or the introduction of new alloys are under evaluation (MOLINA R. 2011, GONZÁLEZ E. 2013).

The mechanical properties of an Al-Si cast alloy are mainly determined by its cast structure (ASM 2002) and the microstructural characteristics such as the grain size, dendrite arm spacing (DAS) (ZHANG B. 2003), the size, shape and

distribution of the eutectic silicon particles (COMALCO 1997), as well as the morphologies and amounts of intermetallic phases (TAYLOR J.A. 2013) present. These parameters are completely changed after heat treatment, which, in turn, influences the resultant mechanical properties (FAN K. L. 2013, MOUSTAFA M. A. 2003, PARAY F. 1994, SJÖLANDER E. 2010, TILLOVÁ E. 2011, ULEWICZ R. 2013).

The present study is part of a larger research project which was conducted to evaluate the heat treatment of an AlSi7Mg0.3 cast alloy used in the manufacture of engine blocks and cylinder heads. The study was conducted on as-cast and heat treated samples that were cut from the bulk-heads of cylinder heads. These samples were tested either in the as-cast and heat treated conditions.

## 2. Experimental procedure

For the experimental work cylinder head castings (Fig.1) that were produced from the most popular A356 alloy were used. Chemical composition of AlSi7Mg0.3 (wt. %) is 7.1 Si; 0.38 Mg; 0.095 Ti; 0.12 Fe; 0.005 Mn; 0.001 Cu; 0.025 Sr; 0.0008 Na; 0.0001 Sb; 0.002 Ca; 0.003 Zn; base of Al.

The structure refinement is one of the most important methods for improving the strength and ductility of Al-Si castings (ROMANKIEWICZ R. 2014). Melt was grain refined with Tiboral 6 masteralloy. Modification was achieved with AlSr 90/10 masteralloy. An addition of strontium can cause a transition of the eutectic silicon phase from

coarse flakes to fine fiber and consequently improve the mechanical properties, especially the ductility.

A standard heat treatment used for engine blocks is solution heat treatment lasting 7 hours at the temperature of 530°C, quenching in water at 20°C and precipitation hardening for 4 hour at 160 °C. Experimental samples were solution treated by different solution time (2, 3, 4, 5, 6 and 7 hours) at 530°C ± 5°C, quenched in water at 20°C ± 2°C and precipitation hardened for 4 hour at 160 °C ± 5°C.

Experimental samples for a tensile test were cut from the bulkheads of engine blocks (Fig. 1). The tensile test were carried out on a tensile machine ZDM 30 at 21 °C following the STN EN ISO 6892-1 in as-cast state and after heat treatment; these specimens were of 14 mm in diameter by 120 mm in gauge length. Values of ultimate tensile strength in dependence on heat treatment were determined by the average value of three test bars. Hardness measurement was performed by a Brinell hardness tester with the load of 62.5 kp, 2.5 mm diameter ball and the dwell time of 15 s according to standard STN EN ISO 6506-1. The Brinell hardness value at each state was obtained by the average of at least six measurements.

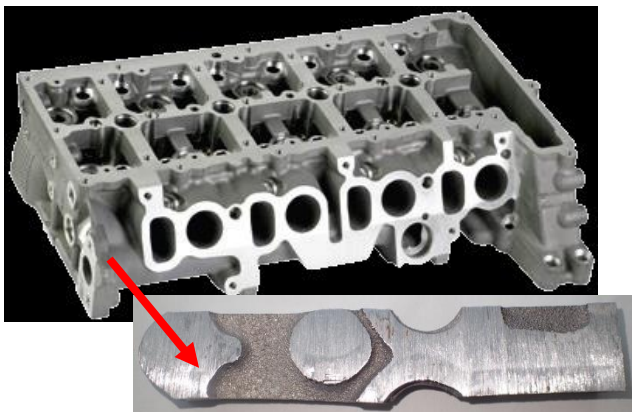


Fig. 1. The experimental cylinder head casting and part of casting for tensile test bar

Metallographic samples were sectioned from the tensile test bars (after testing), standard prepared for metallographic observations (wet ground on SiC papers, DP polished with 3 µm diamond pastes followed by Struers Op-S) and etched by 0.5 % HF (TILLOVÁ E. 2011). The microstructures were studied using an optical microscope (Neophot 32). Some samples were also deep-etched for 30 s in HCl solution in order to reveal the three-dimensional morphology of the silicon phase and observed on SEM. The silicon particle characteristics (average Si particle area (µm<sup>2</sup>)) were measured using a Nis Elements 3.0 image analyser.

### 3. Results and discussion

Alloys of the A356 type (AlSi7Mg0.3) are usually heat treated in order to develop higher mechanical properties. The influence of heat treatment parameters on solution heat treatment and artificial aging was investigated in terms of changes in the eutectic silicon morphology and in the me-

chanical properties. Magnesium's role is to strengthen and harden aluminium castings. Silicon combines with magnesium to form the hardening phase, Mg<sub>2</sub>Si that provides the strength-hening of this alloy. According to the increase of the strength, the hardness is also improved.

The effect of heat treatment on mechanical properties of the AlSi7Mg0.3 alloy is shown in Fig. 2 and Fig. 3. Utility ultimate tensile strength (UTS) and hardness (HBS) of specimens increase with solution treatment time. Elongation with solution treatment time decreases.

The required mechanical properties for a typical aluminium engine block includes an ultimate tensile strength of 245 MPa, yield stress of 215 MPa, and fatigue strength of 60 MPa. These values meet all experimental heat treated samples.

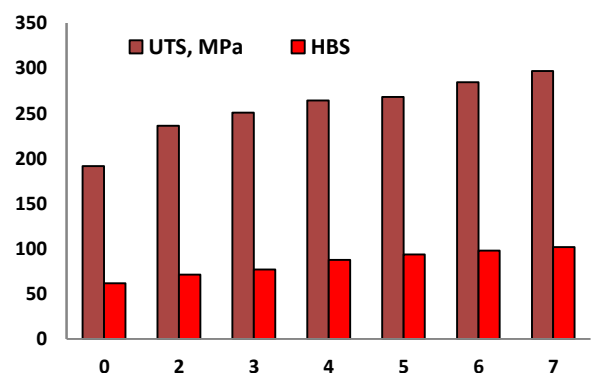


Fig. 2. Effect of solution treatment time on utility tensile strength and Brinell hardness of AlSi7Mg0.3 alloy

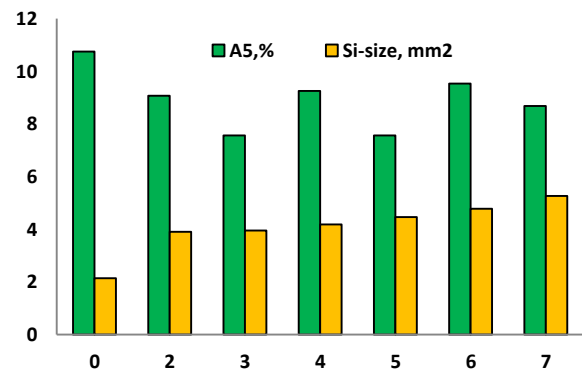


Fig. 3. Effect of solution treatment time on elongation and Si-particle area of AlSi7Mg0.3 alloy

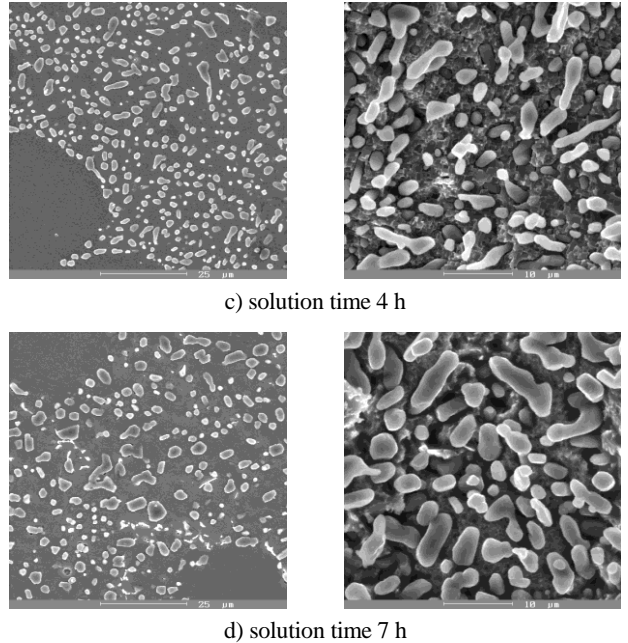
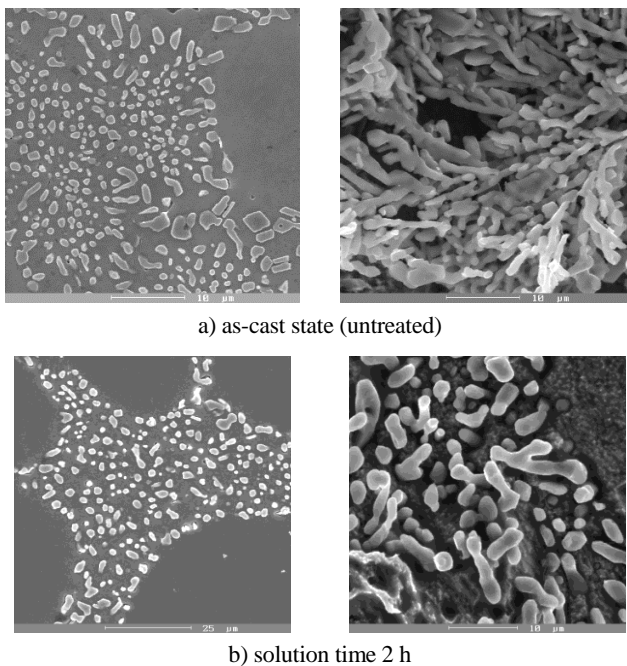
Higher strength but lower elongation accounts the specimens for 3 and 5 hours solution heat treatment, next increases. This uncorrelated trend between strength properties and elongation can be attributed to the following three factors: 1) effect of dissolved Mg<sub>2</sub>Si; 2) effect of Si content dissolved in the Al-matrix; and 3) effect of Si morphology. The trend of increase in UTS and decrease in elongation observed in this study is in good agreement with other researcher (CACERES C.H. ET AL. 1999, SJÖLANDER E. 2010).

This type of alloy is characterized by dendrite structure with a homogeneous distribution of eutectic silicon see Fig. 4.

By the addition of appropriate elements such as strontium in the liquid metal, it is possible to modify silicon morphological structure from lamellar to globular during the solidification. This modification treatment improves the mechanical properties of the Al-Si alloy by reducing the notching effect of needle shaped natural eutectic silicon (TILLOVÁ E. 2011).

The as-cast microstructure of AlSi7Mg0.3 consists of  $\alpha$ -phase (Al-matrix), eutectic (mixture of: eutectic silicon and  $\alpha$ -matrix) and various types of Fe- and Mg- rich intermetallic phases. The effects of solution treatment time on eutectic silicon morphology are shown in Fig. 4b-d. Solution treatment causes a substantial degree of spheroidisation and coarsening in modified eutectic phases. Eutectic silicon in as-cast state (Fig. 4a) has undergone necking and separated into segments. During the first hour of solution treatment (Fig. 4b) Si particles gradually fragmented, rapidly spheroidised, and undergo coarsening. Prolonged solution treatment leads to a significant coarsening of the Si particles (Fig. 4c, Fig. 4d). Due to the presence of Sr, the particles in the modified material are already fine and rounded, and they coarsen with an area increasing from  $2.14$  to  $5.27 \mu\text{m}^2$  (Fig. 3).

In Fig. 3, Fig. 4b, Fig. 4c and Fig. 4d we can see that prolonged solution treatment time (more than 5 hours) leads to a coarsening of the Si particles, while the numerical Si density decreases.



**Fig. 4.** Effect of solution treatment time on microstructure of AlSi7Mg0.3 alloy, etch. 0.5 % HF and deep etch. HCl, SEM

Solution treatment causes substantial degree of spheroidisation and coarsening modified eutectic phases. Spheroidisation process of the silicon through heat treatment takes place in two stages: fragmentation or dissolution of the eutectic branches and spheroidisation of the separated branches. The former has the greatest effect on the time required to complete spheroidisation and is strongly affected by the morphology of the Si particles. The rate of spheroidisation depends on the size of the fragmented segments.

Heat treatment of Al-Si-Mg alloy causes precipitation hardening ( $\text{Mg}_2\text{Si}$ ), spheroidisation of silicon crystals, increased bonding between the hard second phase silicon particles and aluminium.

#### 4. Conclusions

Heat treatment improves mechanical properties of the engine block casts from AlSi7Mg0.3 (A356) alloy. Tensile strength and hardness of specimens increase with solution treatment time. The hardness is a reflection of solution strengthening and silicon particle distribution in matrix.

Solution temperature  $530^\circ\text{C}$  and 5 hours solution time is appropriate to obtain better morphology and distribution of Si particles in microstructure of the engine block casts.

Solution treatment blunts the sharp edges of Si particles and promotes fracture resistance. Prolonged solution treatment (more than 5 hours) leads to a coarsening of the Si particles, while the numerical Si density decreases. As the particle density decreases, a fewer number of sites are available for crack nucleation, hence, the fracture properties are improved.

The data obtained from this study will be used to improve process control, and to help the selection of the heat treatment for future products.

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## 氣缸蓋鑄件質量控制

### 關鍵詞

AlSi鑄造合金,  
熱處理,  
質量控制,  
微觀結構,  
機械性能

### 摘要

用於生產汽車發動機部件鑄件的鋁合金的新挑戰來自內燃機朝向更高比功率輸出的演變趨勢。特別地，氣缸蓋必須承受更高的操作溫度和應力水平。目前的工作描述了缸蓋鑄件的微觀結構（Si-形態和Si-尺寸）和機械性能（UTS，伸長率，布氏硬度）的質量控制作為不同T6熱處理（固溶熱處理時間-2, 3, 4, 5, 6, 7小時）。從該研究獲得的數據將用於改進過程控制，並且幫助選擇用於未來產品的鑄件的熱處理。