ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Special Issue
1/2015

13 – 16

3/1

# Influence of the Mould Material Coatings on the Microstructure of AlSi7Mg Alloy

**B. Dybowski*[a], Ł. Poloczek[b], R. Jarosz[c], A. Kiełbus[a]**
[a] Institute of Materials Science, Materials Engineering and Metallurgy Faculy
Silesian University of Technology, Krasińskiego 8 STR, 40-019 Katowice, Poland
[b] Department of Production Engineering, Materials Engineering and Metallurgy Faculy
Silesian University of Technology, Krasińskiego 8 STR, 40-019 Katowice, Poland
[c] ZM „WSK Rzeszów” Sp. z o.o. Hetmańska120 STR, 35-078 Rzeszów, Poland
* Corresponding author. E-mail address:bartlomiej.dybowski@polsl.pl

Received 28.04.2015; accepted in revised form 05.05.2015

## Abstract

Family of the aluminium alloys with silicon addition is an important group of non-ferrous casting alloys. They exhibit very good technological properties, especially castability. Aluminium alloys are known for their low density, which in connection with high mechanical properties and relatively low price create very good structural material. Magnesium addition to the Al-Si alloys enables their age-hardening, resulting in even better mechanical properties. However, formation of the microstructure of the alloy has to be precisely controlled to avoid formation of massive, brittle silicon crystal. Presence of large, platelet-like particles of silicon, dramatically decreases material mechanical properties. Second factor, which must be taken into consideration is casting porosity, which may significantly decrease fatigue life of the element. Many researches consider effect of modification or refining on the microstructure of the castings made from the Al-Si alloys. However there is lack of detailed investigation on the mould components influence on the microstructure. Such components may be protective coatings applied for the mould sand during the gravity casting of Al-Si alloys. Following paper presents results of the research on the influence of applied mould protective coatings on the microstructure of AlSi7Mg sand cast alloy. Five different protective coatings were applied. Macro observations, qualitative and quantitative microstructure evaluation of the AlSi7Mg alloy was conducted during the researches. Results revealed, that application of the coatings does not influence the size and distribution of the α-Al dendrites, however it influences size of Si particles in a significant way. It was revealed that application of water-based coatings affects the heat flow in the mould material-liquid alloy system, thus causing growth of silicon particles.

**Keywords:** Metallography, AlSi7Mg alloy, Microstructure, Protective coatings, Sand casting

## 1. Introduction

Aluminium alloys are one of the lightest structural materials. They are characterized by a high mechanical properties as well as good corrosion resistance. These properties make from aluminium alloys great structural material for industries, in which weight savings are essential. These are mainly transportation and aeronautical industries. Interesting physical properties (high conductivity) allow application of aluminium alloys also e.g. in power plant industry. Majority of the structural elements are produced mainly by means of casting. Large-sized parts are sand-cast. The most important aluminium casting alloys is the Al-Si family, which possess good technological properties, especially castability. Addition of elements such as Mg, Cu or Zn enables age hardening of the Al-Si alloys, which in turn, results in increase of mechanical properties [1-3].

The main disadvantage of the Al-Si alloys is their tendency for formation of massive, brittle Si crystals during solidification. They significantly affect mechanical properties. Iron is considered to be an impurity in the aluminium alloys, moreover there is no completely effective method of removing this element from the Al-Si alloys [4 - 6]. Iron forms numerous types of phases in these alloys. β-$Al_5FeSi$ phase forms massive, brittle acicular particles, affecting mechanical properties and hindering flow of liquid metal in the mould resulting in increased porosity. Several methods of suppressing formation of this phase are mentioned in the literature. First of all, addition of elements such as Mg or Mn causes formation of relatively harmless π-AlFeSiMg or α-Al(Fe, Mn)Si phases with Chinese-script morphology [7, 8]. Another method may be alloy modification – which may also lead to formation of above mentioned phases or may decrease size of the β-$Al_5FeSi$ precipitates [9].

Formation of massive Si crystals during the binary eutectic mixture solidification is retarded by Al-Si alloys modification or increasing cooling rates. In the case of large-sized, sand cast elements, the cooling rate is low, so the modification is the only method of eutectic refinement. Addition of Na, Sr, Ti or so on leads to formation of fibrous eutectic mixture, resulting in enhanced mechanical properties [10].

Precise control of solidification process is essential for achievement of castings with acceptable microstructure and free from casting defects. Application of mould elements such as chills and feeders has a significant influence on the alloys microstructure. However influence of the protective mould coatings was not preciously investigated. As the industrial practice shows, application of different protective coatings may lead to increased porosity and disturbed heat flow in the mould cavity. Following work presents results of the research on the influence of mould protective coatings on the AlSi7Mg alloy microstructure.

## 2. Material for the research and methodology

Material for the research consisted of AlSi7Mg aluminium casting alloy. The chemical composition of the alloy is shown in the table 1. Six 100x50x20mm specimens were cast for the research (Fig. 1). The alloy was poured at 710±5°C into the furan moulds. The mould cavities of five plates were covered with the different protective coatings: Koalid 2290 – alcohol-based coating for sand moulds; WV-Coating 401 200 - water-based coating used for cores produced by a ColdBox method; PV-Coating W220 – water-based coating used for cores produced with HotBox method; Dimanol Al – alcohol-based coating used for cores and moulds, creates overcooling effect; Tellurschlichte 813 – alcohol-based coating containing tellurium, creates overcooling effect. Sixth plate was cast as a reference specimen, without any coating.

Specimens for the macro- and microstructure investigations were cut from the centres of the plates. Each plate was cut in the same place. Specimens for the macrostructure observations were prepared with following procedure: grinding on the SiC abrasive papers and polishing on the diamond suspensions with mean grain size 6μm, 3μm and 1μm. Macrostructure was observed on the Olympus SZX9 stereoscope. Specimens for microstructure observations were also polished on the colloidal silica with grain size 0.05μm. Observations were conducted on un-etched specimens. Quantitative evaluation of the Si and Fe-bearing phases parameters was done at 20 images recorded with 1000 times magnification. α-Al dendrites parameters were evaluated on 8-10 images recorded with 50 times magnification. The researches were conducted both on the edge of the specimens, as well as within the plates interiors.

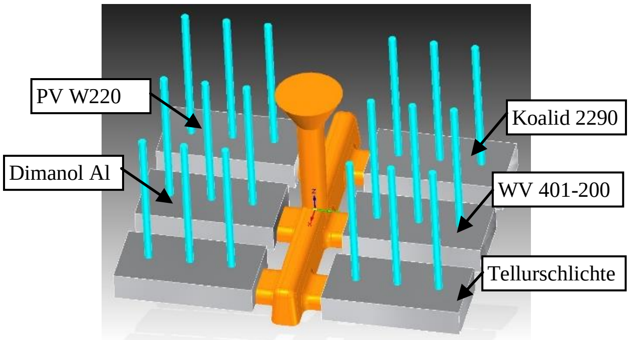


Fig. 1. Casting pattern and description of the specimens

## 3. Research results

### 3.1. Macroscopic observations

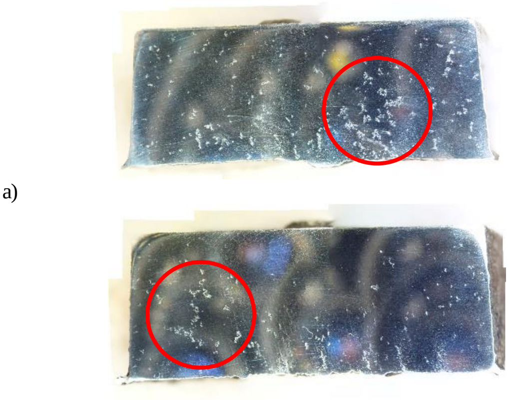
Surface of the plate cast without any protective coating is characterized by a uniformly distributed roughness. In another cases, little holes and surface punctures were distributed non uniformly. What is more, geometrical defects were observed in the plate cast with PV-Coating W220. The edges in this case were significantly curved (Fig. 2), top and bottom surfaces were not completely flat. Similar defects were observed in plate cast with WV-Coating 401-200.

Fig. 2. Plates surfaces; 1 - Koalid 2290, 2 - WV-Coating 401 200, 3 - PV-Coating W220, 4 - Dimanol Al, 5 - Tellurschlichte 813

The biggest porosity at the plates flat sections was observed in case of castings made with water-based WV-Coating 401 200 and PV-Coating W220. It was distributed less uniformly than in plates cast with overcooling coatings as well as in the plate without any coating (Fig. 3).

Table 1.
Chemical composition of the investigated alloy (wt. %)

| | **Si** | **Fe** | **Cu** | **Mn** | **Mg** | **Cr** | **Ni** | **Zn** | **Ti** | **Na** | **Zr** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PN EN 1706 | 6.5-7.5 | 0.19 | 0.05 | 0.10 | 0.25-0.45 | - | - | 0.07 | 0.25 | - | |
| Melt No.: 1519004 | 7.38 | 0.13 | 0.02 | 0.024 | 0.25 | 0.003 | 0.04 | 0.017 | 0.124 | 0.0049 | 0.0013 |

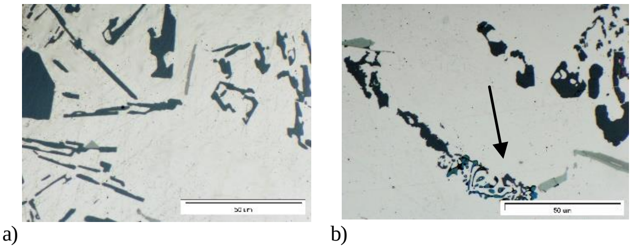

a)

b)

Fig. 3. Porosity at the plates sections; a) Plate cast with WV-Coating 401 200; b) Reference plate

## 3.2. Microstructure of AlSi7Mg alloy

The microstructure of the AlSi7Mg alloy in the as-cast condition was investigated previously [11]. The investigations revealed that AlSi7Mg alloy microstructure consists of α-Al + β-Si eutectic mixture between the α-Al solid solution dendrites. What is more, some Fe-bearing intermetallic phases are observed. These are: blocky $\alpha$-$Al_{17}(Fe_{3.2}Mn_{0.8})_3Si_2$ phase, acicular $\beta$-$Al_5FeSi$ phase and Chinese-script like $\pi$-$Al_9FeMg_3Si_5$ phase. Also $Mg_2Si$ phase may be observed. In the specimens cast for the research, α-Al + β-Si eutectic possess mainly fibrous morphology, however some coarse, platelet like Si crystals are observed, especially near the specimens edges (Fig. 4a). Morphology of the iron-bearing phases suggest presence of all, above mentioned phases. Even though Mg content is low in the alloy, some $Mg_2Si$ particles are observed (Fig. 4b).



a) b)

Fig. 4. AlSi7Mg alloy microstructure, LM; a) Coarse β-Si crystals; b) $Mg_2Si$ phase

## 3.3. Quantitative microstructure evaluation

α-Al dendrites quantitative measurements results are shown in the table 2. Their volume fraction is similar in each plate, regardless of analysed area. In each case it is equal about 60%. What is more their distribution is quite homogenous. Mean length of the chord transecting the flat section of the dendrites is higher far from the casting edges in each plate. This means that α-Al dendrites are coarser within the plates interiors, regardless of the specimen. There were not noticed any differences in the size of dendrites in each plate.

Table 2.
α-Al dendrites metallographic parameters (E – edge of the plate, I – interior of the plate)

| Specimen | Koalid 2290 | | WV-Coating 401 200 | | PV-Coating W220 | | Dimanol Al | | Tellurschlichte 813 | | Reference | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | E | I | E | I | E | I | E | I | E | I | E | I |
| Volume fraction $V_V$ [%] | 63.1 | 63.5 | 60.5 | 61.1 | 60.4 | 61.2 | 59.5 | 57.0 | 63.0 | 58.7 | 59.9 | 60.3 |
| Variability factor $\upsilon(V_V)$ [%] | 3.14 | 2.69 | 1.29 | 2.36 | 1.2 | 1.53 | 1.96 | 2.51 | 1.41 | 4.38 | 2.19 | 2.73 |
| Mean chord d [mm] | 0.054 | 0.062 | 0.050 | 0.059 | 0.053 | 0.059 | 0.050 | 0.057 | 0.054 | 0.058 | 0.050 | 0.059 |
| Variability factor $\upsilon(d)$ [%] | 63.2 | 84.8 | 84.9 | 80.2 | 80.9 | 81.4 | 82.5 | 80.1 | 87.1 | 83.7 | 82.8 | 82.2 |

Metallographic parameters of the eutectic Si are shown in the table 3. Volume fraction of the eutectic silicon decrease far from the plates edges. Similarly to the dendrites fraction, it does not depend on the applied protective coating. The mean area of the Si particle flat section decreases within the plates interior. In this case definitely the finest particles were observed in the plates coated with overcooling coatings and in the reference plate. However, this may be stated only for the plates interiors. At the edges, this dependency is opposite. Finer Si particles are observed in the plates cast with water-based coatings and with the Koalid 2290 coating.

Table 3.
Eutectic Si metallographic parameters (E – edge of the plate, I – interior of the plate)

| Specimen | Koalid 2290 | | WV-Coating 401 200 | | PV-Coating W220 | | Dimanol Al | | Tellurschlichte 813 | | Reference | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | E | I | E | I | E | I | E | I | E | I | E | I |
| Volume fraction $V_V$ [%] | 7.25 | 6.58 | 6.23 | 5.39 | 7.5 | 6.41 | 6.55 | 5.56 | 7.46 | 7.45 | 6.68 | 5.94 |
| Variability factor $\upsilon(V_V)$ [%] | 38.6 | 47.5 | 28.5 | 31.4 | 28.1 | 30.4 | 17.8 | 40.7 | 34.1 | 39.2 | 33.9 | 39.8 |
| Mean area A [mm] | 4.46 | 5.20 | 8.04 | 4.08 | 5.81 | 4.02 | 7.45 | 1.43 | 9.44 | 2.05 | 15.6 | 2.32 |
| Variability factor $\upsilon(A)$ [%] | 221 | 194 | 152 | 294 | 165 | 291 | 186 | 276 | 169 | 293 | 180 | 281 |

## 3.4. Discussion

Eutectic Si precipitates in each case are finer within the plates interiors. The silicon crystals near the castings edges possess unmodified morphology. The most evident case is the reference specimen, in which Si crystals are more than six times bigger at the plate edges. Application of the mould protective coatings does not affects size and distribution of α-Al dendrites. However, application of water based coatings and Koalid coating seem to cause slight increase of silicon particles size within the plates interiors. Distributions of the Si particles size is shown in the figures 5 and 6. While the distributions are similar at the plates edges (Fig. 5), within the plates interiors higher volume fractions of the smallest particles are observed in casts with applied overcooling coatings and in reference specimen (Fig. 6). This is probably caused by higher heat abstraction rates in these cases. It seems that water-based coatings and Koalid coating affect heat flow at the moulding sand/liquid metal interface. Moreover, the plates cast with application of these mould coatings are characterized with increased non-uniformly distributed porosity and some geometrical defects.

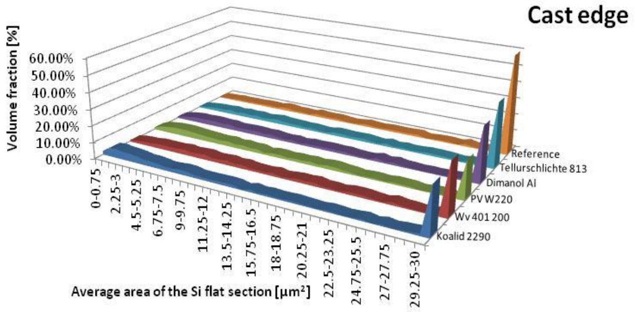


Fig. 5. Si particles size distribution at the plates edges

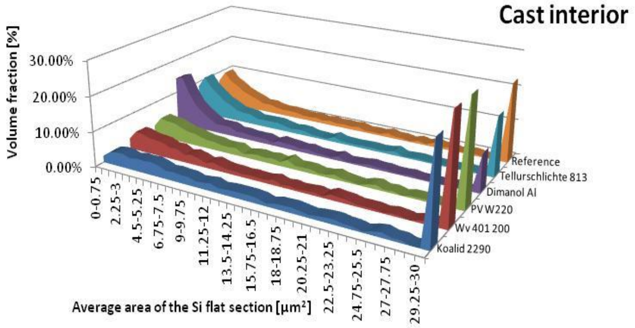


Fig. 6. Si particles size distribution within the plates interior

## 4. Conclusions

1. Application of mould protective coatings may result in surface and geometrical defects in the castings.
2. Application of cores water-based coatings result in increased porosity of the casting. It may be the result of reduced heat conductivity at the mould material/liquid metal interface.
3. The distribution of the Si particles sizes is similar in reference specimen and in the specimens with applied overcooling coatings. This indicates that these coatings do not affect heat flow in the mould material-liquid metal surface.

## Acknowledgments

The present work was supported by the Polish National Centre for Research and Development under the research project No PBS2/B5/28/2013.

## Referances

[1] Davis, JR. (1990). ASM handbook. ASM, Metals Park, OH, ISSN: 978-0-87170-657-7, 123–151

[2] Cais, J., Weiss, V. & Svobodova, J. (2014). Relation between Porosity and Mechanical Properties of Al-Si Alloys Produced by Low- Pressure Casting, *Archives of Foundry Engineering*, V14 - SI1 20, ISSN 1897-3310

[3] Sha, G., Möller, H., Stumpf, W.E., Xia, J.H., Govender, G. & Ringer, S.P. (2012). Solute nanostructures and their strengthening effects in Al–7Si–0.6Mg alloy F357, *Acta Materialia* 60 ISSN: 1359-6454

[4] Cao, X. & Campbell, J. (2006). Morphology of β-$Al_5FeSi$ Phase in Al-Si Cast Alloys, *Materials Transactions* 47, ISSN 1347-5320

[5] You Kim, H., Young Park T., Won Han, S. & Mo Lee, H. (2006). Effects of Mn on the crystal structure of α-Al(Mn,Fe)Si particles in A356 alloys, *Journal of Crystal Growth* 291, ISSN 0022-0248

[6] Sanna, F., Fabrizi, A., Ferraro, S., Timelli, G., Ferro, P. & Bonollo, F. (2013). Multiscale characterisation of AlSi9Cu3(Fe) die casting alloys after Cu, Mg, Zn and Sr addition, *La Metallurgia Italiana* 4, ISSN 0026-0843, 13-24

[7] Bolibruchová, D. & Richtárech, L. (2015). Elimination of Iron Based Particles in Al-Si Alloy, *Archives of Foundry Engineering*, V15 - I1 02, ISSN 1897-3310

[8] Kral, M.V. (2005). A crystallographic identification of intermetallic phases in Al–Si alloys, *Materials Letters* 59, ISSN 0167-577X, 2271-2276

[9] Suarez-Pena, B. & Asensio-Lozano, J. (2006). Influence of Sr modification and Ti grain refinement on the morphology of Fe-rich precipitates in eutectic Al–Si die cast alloys, *Scripta Materialia* 54. 1543-1548 ISSN: 1359-6462

[10] Dahle, A.K., Nogita, K.S., McDonald, D., Dinnis, C. & Lu, L. (2005). Eutectic modification and microstructure development in Al–Si Alloys, *Materials Science and Engineering* A 413-414. 243-248 ISSN: 0921-5093

[11] Dybowski, B., Adamczyk-Cieślak, B., Rodak, K., Bednarczyk, I., Kiełbus, A. & Mizera, J. (2015). The microstructure of AlSi7Mg alloy in as cast condition, *Solid State Phenomena* 229. 3-10 ISSN: 1662-9779