

# Influence of Cooling Rate on Intergranular Corrosion in Al-Si7-Mg Alloy

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## Abstract

The use of aluminium cast alloys in automotive industry results from a tendency to considerably lower vehicle mass. Subject to working conditions, silumin casts may show occurrence of intergranular corrosion that reduces mechanical properties of the parts produced. The paper presents the influence of cooling rate – R of a plate cast of aluminium alloy EN AC-AlSi7Mg0,3 on the depth of appearance of intergranular corrosion. Samples were exposed to corrosive medium by immersion for 2,5; 12; 24 and 48 hours in an aqueous solution of NaCl+HCl+H<sub>2</sub>O. The study demonstrated that cooling rate – R and subsurface porosity significantly influence on distribution and depth of intergranular corrosion in casts of subeutectic silumin.

**Keywords:** Al-Si-Mg alloys, Intergranular corrosion, Cooling rate

## 1. Introduction

Casting alloys of aluminium with silicon find numerous applications in various industries, in particular in automotive industry. The advantageous relation of mechanical properties to density of the cast material as well as the ease of forming the material in mould cavity made it possible to use silumins in construction of such elements as: steering wheel columns, gearbox casings, cylinder heads, suspension elements, etc.

A characteristic feature of casts of aluminium and silicon alloys is moderate/good corrosion resistance in natural environments (air, water), whereas highly acidic or alkaline environments significantly accelerate corrosion process [1 - 3].

Intensity of corrosion process is correlated to elements such as corrosive environment, thermochemical treatment of the cast, content of elements such as: Fe, Cu, Mn, Mg in the cast as well as the magnitude of microstructure and intermetallic phases, connected with intensity of solidification process of the cast. [4 - 10].

Pitting and/or intergranular corrosion most commonly occurs in silumin casts and results from a difference in electrode potentials between matrix materials and intermetallic phases present in the cast. A problem in this type of corrosion is the absence of visual signs of its occurrence as corrosive processes progress into the cast material.

## 2. Methodology

The studies on the influence of cast cooling rate on the depth of intergranular corrosion were carried out on casts of plate of technological silumin EN AC-AlSi7Mg0,3 of 150 mm height, 120 mm width and 22 mm thickness, and its chemical composition is presented in Table 1.

Table 1.

Chemical composition of alloy AlSi7Mg0,3

Si	Mg	Cu	Fe	Ti	Mn	Zn	Ni	Pb	Al
7,37	0,34	0,01	0,1	0,17	0,01	0,01	0,01	0,01	rest

The process of melting metallic charge was carried out in a laboratory resistance furnace Nabertherm K4/13. The alloy was modified with titanium boron Ti5B1 and strontium at 250 ppm (each) in relation to charge mass.

Moulds for plates were made of quartz sand, bentonite clay and dextrin, and repeatability of casts was achieved by pouring sets of three moulds placed at equal distances from the axis of the gating system (Fig. 1a).

Before pouring the sets of moulds, liquid alloy was subject to refining process in order to remove the suspension of  $Al_2O_3$  oxides and dissolved hydrogen by bubbling (nitrogen) the liquid alloy with use a graphite lance for 5 minutes. The alloy temperature at pouring the mould cavity was  $720 \pm 10^\circ C$ .

Variability of conditions at plate cast solidification was obtained by placing a cooper chill in a lower part of mould.

Temperature measurements were made with thermoelements NiCr-Ni with a diameter 1 mm and recorded with EURO THERM 6100V recorder at casting points as presented in Fig. 1b. Thermoelement 1 was placed on the cast-chill interface.

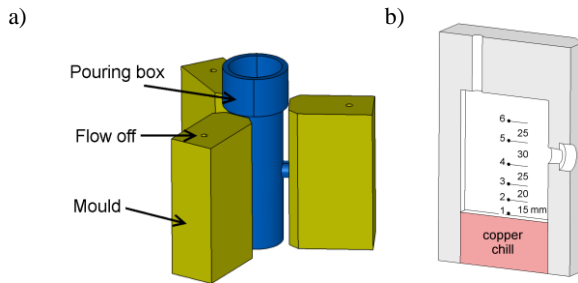


Fig. 1. a) set of moulds and their placement, b) distribution of thermoelements in mould

The obtained curves for temperature change were used to calculate the averaged cooling rate – R. The parameter of cooling rate was determined for the range of growth of dendrite phase  $\alpha_{Al-Si}$ , which better describes the kinetics of cast solidification process [11].

The cast plates were subjected to thermal treatment T6 ( $540^\circ C/12$  h; cooling in water;  $160^\circ C/4$  h)

In order to determine the distribution and depth of intergranular corrosion the plates were divided and sectioned as in the diagram in Fig.2.

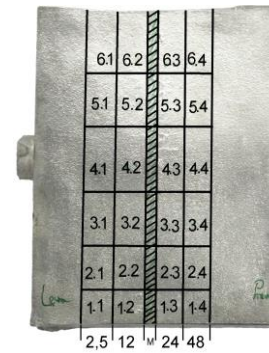


Fig. 2. Diagram of plate division for corrosion testing where: 2,5; 12; 24; 48 – duration of sample exposure to corrosion medium in hours, and M – samples subjected to microstructure testing

Samples for corrosion testing were polished with abrasive papers of granularity of 240, cleaned with spirit, then exposed to corrosive medium by immersion in a chemical solution of: 1000 ml  $H_2O$ , 20g NaCl, 100 ml HCl (33%). Samples immersed in the solution were kept for 2,5; 12; 24 and 48 h for each series separately. Six samples, not touching each other, were examined at the same time, and the study part was directed upwards. Following each series (duration of how long samples were immersed in the solution) the solution was replaced with a new batch. The temperature throughout the study was  $22 \pm 1^\circ C$ . When the exposure to corrosive medium was finished the samples were placed in an ultrasonic cleaner (8 minutes), and then washed with spirit and dried.

The extent of corrosion of the analysed surfaces was evaluated under stereo zoom microscope MOTIC SMZ-168 in areas presented in Fig. 3a. When most corroded areas were selected (Fig. 3b) the sample was cross-sectioned (Fig. 3c) and metallographic microsection was made. Microstructure observations were carried out under optic microscope NIKON Optiphot-100; the depth of intergranular corrosion was determined for each sample by averaging results of five measurements (Fig 3d).

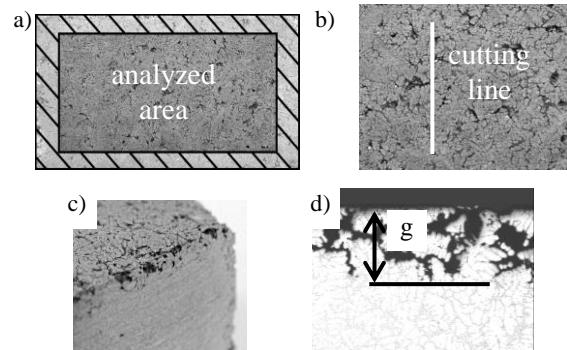


Fig. 3. Procedure for measuring depth of intergranular corrosion: a) analysed area, b) microsection spot, c) cross-sectioned sample, d) measurement of corrosion depth

### 3. Results

The parameter of cooling rate– R for the increase in growth of phase  $\alpha_{Al-Si}$  in six places of a plate cast was determined based on cooling curves as presented in Fig. 4

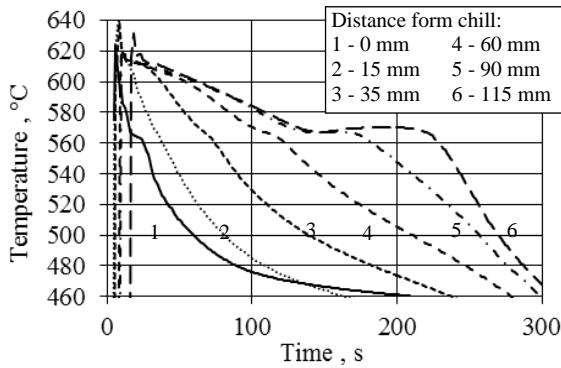


Fig. 4. Cooling curves of a plate cast

The calculated values of cast cooling rate as a function of distance from base of plate are presented in Fig. 5.

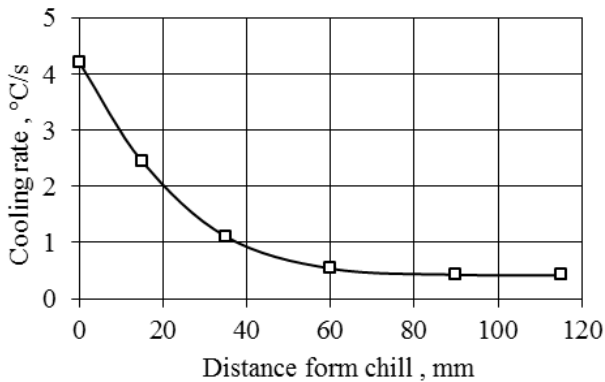


Fig. 5. Values of cast cooling rate as a function of distance from chill

The highest value of cast cooling rate was achieved on the contact between cast and chill and was 4,21°C/s. Along with increasing distance from the chill, the intensity of heat absorption from a solidifying cast is lower, and at a distance of 60 mm, which is where the operating range of the chill ends (66 mm), cast cooling rate was approximately 0,55°C/s. Beyond that distance cast cooling rate is stabilized and is about 0,42°C/s.

The correlation between the measured depth of intergranular corrosion and the length of time of sample immersion in corrosive medium is presented in Fig. 6.

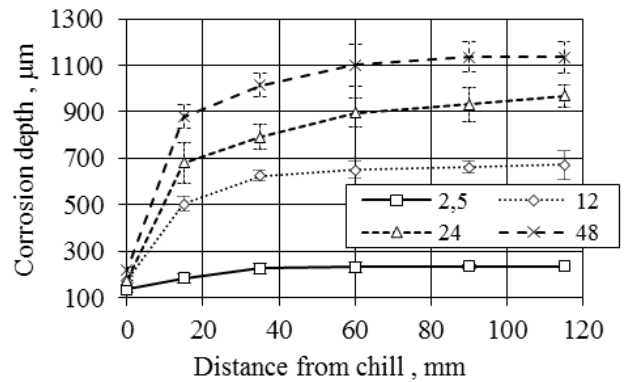


Fig. 6. Correlation between depth of intergranular corrosion as a function of distance from the chill including length of time of sample immersion in corrosive medium

The lowest value of measured depth of intergranular corrosion for various lengths of time of sample immersion in corrosive medium was observed in samples that were in contact with the chill. At a distance from the chill of 15 mm the depth of intergranular corrosion increased, particularly in samples that were immersed in corrosive medium for a minimum of 12 hours. Further increasing the distance from the chill did not cause significant increase of corrosion in the samples studied.

The correlation between the measured depth of intergranular corrosion as a function of cast cooling velocity – R and length of time of sample immersion in corrosive medium is presented in Fig.7.

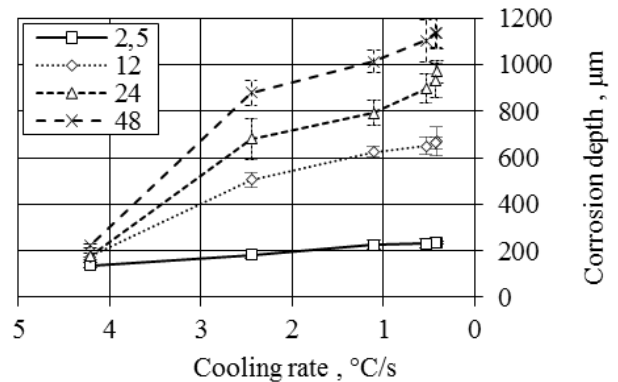


Fig. 7. Correlation between corrosion depth as a function of distance from chill including sample immersion in corrosive medium

It was found that the lowest increase in intergranular corrosion, regardless of length of sample immersion in corrosive medium, occurred at the highest values of cast cooling rate ( $R \approx 4,2^\circ\text{C/s}$ ).

After 2,5 hours of sample immersion in the solution the depth of corrosion was approximately 137  $\mu\text{m}$  (Fig. 8a). Extending the length of exposure to the corrosive medium to 12 hours resulted in increase in corrosion depth by 27%, to the value of approx. 174  $\mu\text{m}$  (Fig. 8b), whereas for the sample immersed for 48 hours

corrosion depth increased by approx. 61% and was 221  $\mu\text{m}$  (Fig. 8d).

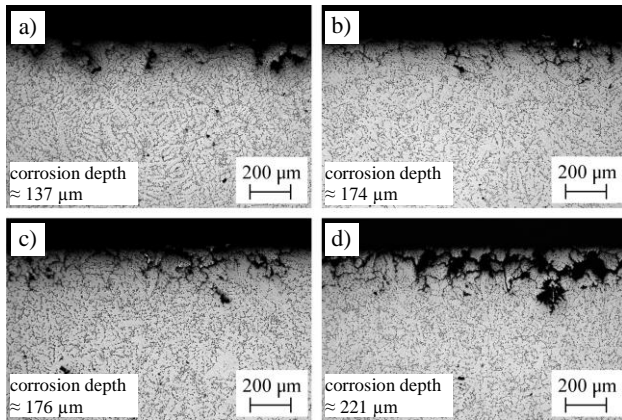


Fig. 8. Depth of corrosion for  $R=4.21^\circ\text{C/s}$ , at sample immersion in corrosive medium for: a) 2,5 h, b) 12 h, c) 24 h, d) 48 h

The samples where cooling rate was  $R=2.45^\circ\text{C/s}$  there was a significant increase in the depth of intergranular corrosion (Fig. 9).

In comparison to samples close to the chill the highest corrosion growth was observed for periods of 24 and 48 hours (Fig. 9c, d) of immersion in corrosive medium. In those samples, depth of corrosion increased almost fourfold in comparison to samples where cast cooling rate was about  $4.2^\circ\text{C/s}$ .

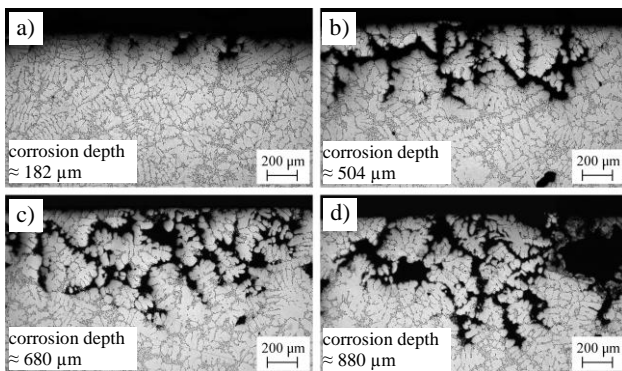


Fig. 9. Corrosion depth for  $R=2.45^\circ\text{C/s}$ , at sample immersion in corrosive medium for: a) 2,5 h, b) 12 h, c) 24 h, d) 48 h

When the distance from the chill was 115 mm cast cooling rate was  $R\approx 0.42^\circ\text{C/s}$ . Comparison of the values of intergranular corrosion in those samples (Fig. 10) with more slowly cooling samples ( $R\approx 2.45^\circ\text{C/s}$ ) can demonstrate that corrosion growth for various time periods of sample immersion in corrosive medium is at the level from 30%, for 2,5 hours and 12 hours (Fig. 10a, b) to about 40% for 24 and 48 hours (Fig. 10c, d). The analysis of the extent of corrosion in samples where heat is absorbed at low intensity ( $R\approx 0.42^\circ\text{C/s}$ ) in relation to samples situated close to the chill ( $R\approx 4.2^\circ\text{C/s}$ ) demonstrates that the increase in corrosion depth is fivefold higher for periods of 24 and 48 hours of sample immersion in corrosive medium.

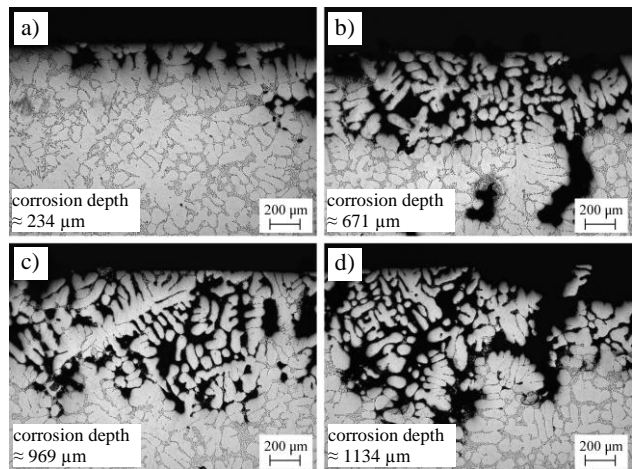


Fig. 10. Corrosion depth for  $R=0.42^\circ\text{C/s}$  at sample immersion in corrosive medium for: a) 2,5 h, b) 12 h, c) 24 h, d) 48 h

An important factor that affects the increase in intergranular corrosion depth in casts is the presence of pitting on the cast surface (Fig. 11) or defects that may initiate corrosion processes.

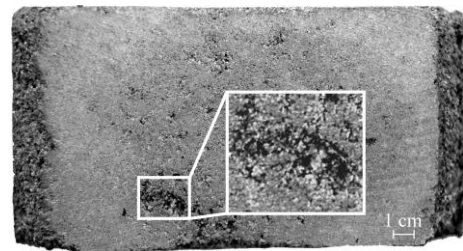


Fig. 11. Pitting on sample surface (at chill) immersed for 48 hours in corrosive medium

In the analysed sample, situated close to the chill and immersed in corrosive medium for 48 hours, in spite of intensive heat absorption from solidifying cast towards the chill ( $R\approx 4.2^\circ\text{C/s}$ ), the depth of intergranular corrosion increased from about 221  $\mu\text{m}$  (surface without pitting) to about 560  $\mu\text{m}$  (Fig. 12), when pitting was present on sample surface, facilitating influx of corrosive solution.

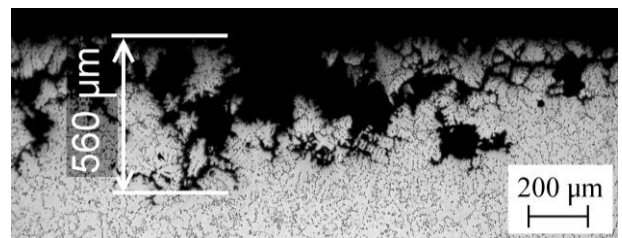


Fig. 12. Corrosion resulting from pitting on sample surface

As factor which may affect the depth of intergranular corrosion in casts (and which should be more closely analysed) is porosity situated directly under cast surface. In the sample where

cooling rate was 4,2°C/s and immersion in corrosive medium was 24 hours, the depth of intergranular corrosion was about 176 µm. Due to subsurface porosity and facilitated influx of corrosive solution into the porosity, the depth of corrosion in this case was about 475 µm (Fig. 13).

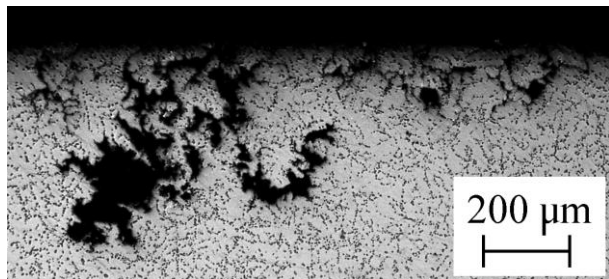


Fig. 13. Corrosion resulting from subsurface porosity (at chill – 24 hours in corrosive medium)

Porosity is particularly important in casts that are to be further machined, which exposes them to loss of tightness and reduces cycle resistance. These defects may be caused by improperly executed refining that removed hydrogen from the solution, core gassing or not completely dried protective layer on the mould gap.

## 4. Conclusions

1. Intensity of heat absorption by the mould significantly influences the depth of intergranular corrosion in casts made from the AlSi7Mg alloy.
2. The lowest corrosion depth occurs in samples where cooling rate – R was approximately 4,2°C/s.
3. Slowing down cooling rate to 2,4°C/s causes nearly fourfold increase in intergranular corrosion in samples immersed in corrosive medium for 24 and 48 hours.
4. Defects on cast surface and pitting may accelerate intergranular corrosion.
5. Subsurface porosity contributes to increased intergranular corrosion.

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