Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

# Study of low pressure die casting AlSi11 alloy solidification

Zdenka Zovko Brodarac[1], Josip Kalinić[2], Tamara Holjevac Grgurić[1]
[1] University of Zagreb Faculty of Metallurgy, Aleja narodnih heroja 3, Sisak, Croatia
[2] Jajce Alloy Wheels Ltd, Divicani bb, Jajce, Bosnia and Herzegovina

Aluminium alloys possess an excellent mechanical, physically-chemical and technological properties which have found an extensive application in the automotive industry. Alloy AlSi11 belongs to a group of eutectic alloys, which are characterized by high castability, low pouring temperature and narrow solidification interval which makes it suitable for low pressure casting technology (LPDC).

In addition to chemical composition, the structural and mechanical properties of alloys depend on many factors that act during solidification. Study of AlSi11 alloy solidification sequence has been accompanied by calculation of equilibrium phase diagram, and simultaneous thermal analysis, all in correlation to microstructure development. Thermodynamic calculation revealed solidification sequence with corresponded temperatures in equilibrium state. Differential scanning calorimetry enables determination of exact temperatures of phases' transformations. Metallographic investigation comprehends fractography, as well as optical and scanning electron microscopy. Microstructural examination performed on scanning electron microscope equipped by EDS revealed development of following constituents: primary aluminum ($\alpha_{Al}$), high temperature intermetallic phases on the iron basis ($Al_5FeSi$ and/or $Al_{15}(Fe,Mn)_3Si_2$), binary eutectic ($\alpha_{Al}+\beta_{Si}$) and secondary eutectic ($Mg_2Si$ and $Al_5Mg_8FeSi_6$) as a last solidifying phases'.

Synergy of performed thermodynamic and microstructural investigation, as well as obtained mechanical properties enables an evaluation of material quality and management of solidification process.

***Keywords:*** *AlSi11 alloy, solidification sequence, mechanical properties, microstructure.*

## 1. Introduction

The automotive industry is forced to apply advanced materials and technologies in order to overcome the mutual competition, but also for compliance with environmental regulations requiring reduction of emissions, and fuel consumption. One of main component for achieving this goal is weight saving by downsizing of components using advanced materials and production technologies. Average car containing 140 kg of aluminium exceeds a driving distance of 200.000 km (15.000 km / year). Aluminium component is on average 40% lighter than the replaced component (direct weight saving) and that 25% additional weight reduction is obtained by downsizing other components (weight savings) [1]. The widest production of aluminum component refers to wheels as the most safety-critical part, which has been produced by low pressure die casting technology. "Eutectic" AlSi11 alloy (EN AC 44000) is characterized with relatively low melting point and narrow solidification interval which both brought to the uniformly distributed eutectic microstructure indicating superior mechanical and technological properties [2]. Silicon is one of the most important alloying elements which comprehend to good castability of aluminium alloys. Addition of silicon improves resistance to hot cracks and feeding capability [2,3]. Synergy of influenced alloying and trace elements effect comprehend to different intermetallic phase evolution. The content of secondary alloying elements (Mg, Cu) and trace elements (Fe, Mn, Cr, Zn) significantly influence on solidification manner of an AlSi11 alloy [4-6].

## 2. Materials and methods

Investigation of an AlSi11 alloy comprehends modelling of equilibrium phase diagram (CALPHAD method-TCW 5.0), simultaneous phase analysis (Netzch STA-DSC) and microstructural investigations performed: optical (Olympus GX51) and scanning electron microscope (Tescan, JEOL).

## 3. Results and discussion

Chemical composition of produced sample, given in Table 1, corresponds to those prescribed by norm (EN 1706:2010, [7]).

Table 1. Chemical composition of AlSi11 alloy (wt.%).

| Si | Fe | Cu | Mn | Mg | Al |
|---|---|---|---|---|---|
| 10.6276 | 0.0905 | 0.001 | 0.0017 | 0.1808 | Bal. |

Modelling by CALPHAD method enables overview of solidification sequence AlSi11 alloy in polythermal section of phase, as shown in Figure 1.

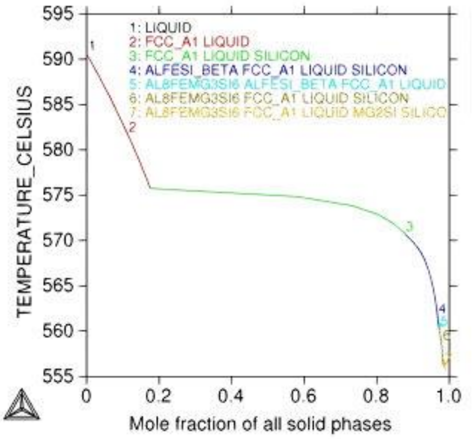


Fig. 1. Solidification sequence of AlSi11 alloy modelling by CALPHAD method.

Since liquid is stable till 566 °C, and secondary eutectic phases evaluate below this temperature which indicate limited sources and positions for its precipitation: evaluation of $\alpha_{Al}$, precipitation of high temperature intermetallic phases on iron base, silicon (primary and eutectic) evaluation, and precipitation of complex secondary eutectic intermetallic phases $Al_8FeMg_3Si_6$ and $Mg_2Si$.

Simultaneous thermal analysis performed at heating / cooling rate of 10 (K/min) enabled exact identification of characteristic temperatures of phase transformations and precipitation. Comparison of CALPHAD (TCW) and STA temperatures is shown in Table 2.

Table 2. Comparison of TCW and DSC phase transformation temperatures

| Reaction No. | Temperature, °C | | Reaction |
|---|---|---|---|
| | TCW | DSC | |
| 1 | 590 | 589,2 | Dendrite network development |
| 2 | 575 | - | Primary silicon evolution |
| 3 | 572 | 564,6 | Precipitation of $Al_5FeSi$ phase |
| 4 | 502 | 563,2 | Eutectic reaction |
| 5 | 439 | 558,1 | Precipitation of $Al_8FeMg_3Si_6$ phase |
| 6 | 394 | 525,9 | Precipitation of $Mg_2Si$ phase |

Metallographic analysis resulted in following microstructural constituents: primary aluminium $\alpha_{Al}$, main eutectic $\alpha_{Al} + \beta_{Si}$, high temperature iron phase and intermetallic phases in form of secondary eutectic $Mg_2Si$ and $Al_8FeMg_3Si_6$, as shown in Figure 2.

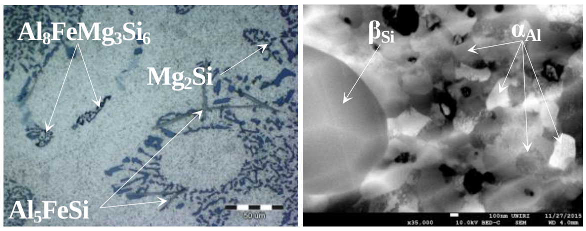


Fig. 2. Microstructure analysis of AlSi11 alloy.

Higher magnification enabled an overview of primary aluminium nucleation correlated with dislocation movement, as well as twinning mechanism of eutectic silicon.

## 4. Conclusions

An AlSi11 alloy, as a commonly used alloy in automotive applications reveals specific solidification sequence due to amount of secondary alloying and trace elements. Also thin-wall casting geometry and LPDC ensures rapid cooling and solidification. Modelling of equilibrium phase diagram, simultaneous phase analysis and microstructural investigations resulted in determination of manner and solidification sequence of AlSi11 alloy.


## Acknowledgements

Company Jajce Alloy Wheels Ltd for samples and University of Rijeka, Department of physics for help are greatly acknowledged. Investigation was done in the frame of Financial support of investigation of University of Zagreb (5.10.1.1, TP1.79, TP167)


## References


[1] EAA-Aluminium-in-Cars-Unlocking-the-light-weighting -potential, 2013, www.european-aluminium.eu

[2] J. R. Davis, Aluminim and Aluminum Alloys (ASM Specialty Handbook, Ohio, USA, 2002)

[3] J. Campbell, Metal quality studies in secondary remelting of aluminum, Technical Paper, 47(2004), 78-81.

[4] K. Krone, Aluminiumrecycling (Vereinigung Deutscher Schemlzhütten, Düsseldorf, 2000)

[5] H. Baker, Alloy Phase Diagrams, ASM Handbook – Vol. 3, (ASM International Ohio, USA, 1992.)

[6] L. Bäckerund, G. Chai, J. Tamminen, Solidification Characteristics of Aluminium Alloys, Foundry Alloys, Vol. 2, (AFS/Skanaluminium, Stockhlom, 1999).

[7] EN 1706:2010 Aluminium and aluminium alloys – Castings – Chemical composition and mechanical properties