Morphology of intermetallic phases in Al-Si cast alloys and their fracture behaviour

Lenka Hurtalová1, Eva Tilová 1, Mária Chalupová1, Juraj Belan1

1University of Žilina, Faculty of Mechanical Engineering, Department of Materials Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia, phone: 00421/415132626, e-mail: lenka.hurtalova{eva.tillova, maria.chalupova, juraj.belan}@fstroj.uniza.sk

Abstract Applications of Al-Si cast alloys in recent years have increased especially in the automotive industry (dynamic exposed cast, engine parts, cylinder heads, pistons and so on). Controlling the microstructure of secondary aluminium cast alloys is very important, because these alloys contain more additional elements that form various intermetallic phases in the structure. Therefore, the contribution is dealing with the valuation type of intermetallic phases and their identification with using optical and scanning microscopy. Some of the intermetallic phases could be identified on the basis of morphology but some of them must be identified according EDX analysis. The properties of aluminium alloy are affected by morphology of intermetallic phases and therefore it is necessary to study morphology and its fracture behaviour. The present work shows morphology and typical fracture behaviour as the most common intermetallic phases forming in Al-Si alloys.

Key words – morphology of intermetallic phases, Al-Si alloys, fracture behaviour of intermetallic phases

1. Introduction

Aluminium alloys have been the most common materials in different industries, but especially in the areas of aerospace and automotive, on account of their high stiffness/weight ratio and strength/weight ratio, good formability, good corrosion resistance etc. (XING M. Z., 2013; MILLER W. S., 2000; MATVIA M., 2012, ULEWICZ, R., 2014).

The final microstructure of aluminium material determines the technological and mechanical properties of cast components. Mechanical properties can be affected by casting method, solidification rate, heat treatment or modifying and grain refining (FARAHANYA S., 2013; TIMPEL M., 2012; XIUFANG B., 2001).

Al-Si-Cu alloys usually contain Cu (2 - 4 %), a certain amount of Fe, Mn, Mg and Zn that are present either unintentionally, or they are added deliberately to provide special material properties. These elements partly go into solid solution in the matrix and partly form intermetallic particles during solidification (RIOS C.T., 2003). The influence of intermetallic phases to mechanical and fatigue properties depends on size, volume and morphology of these phases (TILLOVÁ E., 2010). The formation of these phases should correspond to successive reactions during solidification with an increasing number of phases involved at a decreasing temperature. In practice, Bäckerud et al. (BÄCKERUD L., 1986; BÄCKERUD L., 1992) identified these reactions in Al-Si-Cu alloy:

- 602°C: α-dendritic network. The exact temperature depends on the Si and Cu concentration in the alloy;
- 590°C: Liq. → α-phase + Al15(Fe,Mn)3Si2;
- 575°C – 507°C: Liq. → α-phase + Si + Al13FeSi;
525°C – 507°C: Liq. → α-phase + Al2Cu + Al5FeSi + Si. Reduction of temperature allows nucleation of Cu-enriched eutectic (Al + Al2Cu);
507°C: Liq. → α-phase + Al2Cu + Si + Al5Mg8Si6Cu2.
483°C: End of the alloy solidification (solidus temperature).

Suwanpinij et al. (SUWANPINIJ P., 2003) calculated crystallization temperatures of major phases by the Gul-liver-Scheil model in the 380-type alloy (Fig. 1).

The present study is a part of a larger research project, which was focused on a study of secondary Al-Si cast alloy. The purpose of the present article is to investigate the microstructure of recycled AlSi9Cu3 cast alloy with a combination different analytical techniques and valuations of fracture behaviour structure components.

3. Methodology of research

As an experimental material was used secondary AlSi9Cu3 alloy, that contains 9.4 % Si, 2.4 % Cu, 0.9 % Fe, 0.28 % Mg, 0.24 % Mn, 1.0 % Zn, 0.03 % Sn, 0.09 % Pb, 0.04 % Ti, 0.05 % Ni, 0.04 % Cr. The secondary alloy (prepared by recycling of aluminium scrap) was received in the form of 12.5 kg ingots. Experimental material was molten into the metallic mould (chill casting). The melting temperature was maintained at 760 °C ± 5 °C. Molten metal was purified with salt AlCu4B6 before casting and was not modified or grain refined. The microstructure of experimental material was studied using light microscope Neophot 32 and SEM observation with EDX analysis using scanning electron microscope VEGA LMU II linked to the energy dispersive X-ray spectroscopy (EDX analyzer Brucker Quantax). The samples for metallographic observations (1.5 cm x 1.5 cm) were prepared by standard metallographic procedures (wet ground, polished with diamond pastes, finally polished with commercial fine silica slurry - STRUERS OP-U and etched by standard (Dix-Keller, 0.5 % HF) reagent. Some samples were also in order to reveal the three-dimensional morphology of the silicon phase and intermetallic phases deep-etched for 30 s in HCl solution. The fracture surface (and fracture behaviour of structure components) was observed by using scanning electron microscope on Charpy impact specimens after impact bending test.

8. Results and discussions

According to the theory above, the four main types of intermetallic phases occurring in this AlSiCu alloy are Al5FeSi; Al15(Mn,Fe)3Si2; Al2Cu; and Al5Cu2Mg8Si6 (RIOS C.T., 2003; TAYLOR J. A., 2004; SEIFEDDINE S., 2007). In experimental recycled AlSi9Cu3 cast alloy that contains less than 0.9 % of Fe and 0.24 Mn it was found:
- very short and little Al5FeSi needles (Fig. 2a) - in a small volume;
- long Al15(FeMn)3Si2 skeleton like (Fig. 2b - red) - these phases were dominant from Fe-rich;
- small Al2Cu particles (Fig. 3a);
- and eutectic Al15Cu2-Si phases (Fig. 3b).

Al5FeSi phases precipitate in the interdendritic and intergranular regions as platelets (appearing as needles in the metallographic microscope). Long and brittle Al5FeSi platelets (more than 500 µm) can adversely affect mechanical properties, especially ductility, and also lead to the formation of excessive shrinkage porosity defects in castings (RIOS C.T., 2003; TAYLOR J. A., 2004). The β platelets appeared to be the main nucleation sites for the eutectic Si, eutectic Al2Cu and Cu-rich phase. Excess Mn may reduce Al5FeSi phase and promote formation Fe-rich phases Al15(FeMn)3Si2 (known as alpha- or α-phase) in the form „skeleton like“ or in the form „Chinese script“. Phase Al15(FeMn)3Si2 is considered less harmful to the me-
mechanical properties than β phase (RIOS C.T., 2003; TAYLOR J. A., 2004; SEIFEDDINE S., 2007).

The Cu-rich intermetallic phases observed in experimental material are important when material is heat treated. These phases led to formation Θ and Θ' precipitates with body centered-tetragonal crystal structure with the stoichiometry Al$_2$Cu in substructure and improve mechanical properties of materials (BISWAS A., 2014).

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The fracture surface was influenced very significantly by structural components (α-phase, eutectic silicon, intermetallic phases) and their distribution in the cross section. The overall appearance of the fracture surface is not only a violation of the matrix (α-phase), but also the shape and size of eutectic Si and intermetallic phases.

The matrix is characterized by high plasticity while the crystals of eutectic silicon and Fe-rich intermetallic phases have higher values of hardness and so almost zero values of plastic properties. Therefore, the fracture surface of AlSi9Cu3 cast alloy composed of matrix and Cu-rich intermetallic phases ductile fracture and cleavage fracture of hard and brittle structural components (eutectic Si and Fe-rich intermetallic phases).
9. Summary and conclusions

In the present study, the morphology and fracture behaviour of intermetallic phases in AlSi9Cu3 cast alloy was investigated. From the analysis of the results the following conclusions can be drawn:

In AlSi9Cu3 cast alloy two Fe-rich phases were observed - Al5FeSi needles; skeleton-like Al15(FeMn)3Si2 and two Cu-rich intermetallic phases - Al2Cu and Al-Al2Cu-Si.

Al15(FeMn)3Si2 phase was dominant thanks to the presence of Mn. The morphology and size of iron phases are undesirable.

The morphology of structural components (eutectic silicon, intermetallic Fe-rich and Cu-rich phases) significantly affects the fracture surface of Al-alloy.

The fracture surface of as-cast state is forming of transcristalline cleavage and ductile fracture. On the fracture surface, transcristalline cleavage fracture is dominant. Transcristalline cleavage fracture is related to the presence of large hexagonal plate-Si particles in the structure and also brittle iron intermetallic phases. The transcristalline ductile fracture of Al matrix (α-phase) and Cu rich intermetallic phases is observed in the smaller surface.

10. Additional information

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