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Oxidation of liquid Al-7Si alloys containing strontium and magnesium

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Abstract: Oxidation behaviour of small and large amounts of Al-7Si alloys containing strontium and magnesium has been investigated. The results showed that Sr and Mg-additions increase the oxidation rate of the small amount of Al-7Si alloys melt significantly. The noticeable amount of SrO and MgO was found in the oxidised surfaces. The oxidation behaviour of the large melts was also studied by analysing the melts surface layer. The surface oxide layers consisted of Al₂O₃ and Al₂O₃.MgO but was found to contain no detectable SrO. Also, in contrast with the small melts, the relatively slow rate of Sr-loss during the oxidation period of showed that in the large melts strontium has no considerable tendency for oxidation.

Keywords: Al-Si alloys, Oxidation, Strontium, Modification, Magnesium

1. INTRODUCTION

The modification treatment of Al-Si alloys is associated with an increase tendency to porosity formation [1-5]. To explain this tendency, many authors have suggested that Sr-modification increases the oxidation rate and/or the melt inclusion content of Al-Si alloys [6-10]. Contrary, Miresmaeili et al [3-4], have suggested that the strontium oxide can not be responsible for the increase in porosity content. They have found that in both modified and unmodified alloys, oxide films of Al₂O₃ and Al₂O₃.MgO play a significant role in pore formation and the Sr-containing oxides do not take part in pore formation [3-4].

Despite widespread researches, the only investigations to quantify the effect of Sr-modification on the melt oxidation rate of Al-Si alloys are those carried out by Gruzleski et al [11-12]. Emadi and Gruzleski [11] found that Sr-modification increases the rate of oxidation of binary Al-7Si alloy at 740°C by three times. Conversely in another work, Gruzleski and Yuen [12] have reported that Sr-modification decreased the rate of oxidation of Mg-containing Al-Si alloys.

The literature shows that there is no agreement about the effect of Sr-modification on the oxidation rate of Al-Si alloys. In the present study, the oxidation behaviour of small and large amount of liquid Sr-modified Al-Si alloys is studied.

2. EXPERIMENTAL PROCEDURE

2.1. Oxidation of Small Al-Si Alloys Melts

Melting and alloying was carried out in a 3kg capacity silicon carbide crucible using an electrical resistance furnace. Binary Al-7Si, ternary alloys Al-7Si-0.35Mg (A356), Al-7Si-

0.03Sr and Al-7Si-0.1Sr, and quaternary alloys Al-7Si-0.35Mg-0.03Sr (0.03Sr-modified A356) and Al-7Si-0.35Mg-0.1Sr (0.1Sr-modified A356) were used, prepared by adding pure silicon, magnesium and Al-10%Sr master alloy to 99.7% aluminium. In facilitating detection of the heavy Sr-rich compounds in Al-Si alloys microstructures (either intermetallics or oxides), using BSE image that emphasises the differences in atomic weight of elements, the alloys contained very low concentration of other heavy elements Fe, Cu, Mn and Cr. The cast samples of the alloys were machined to a truncated cone shape weighing about 47g. Thermo gravimetric analysis (TGA), was used to study the oxidation behaviour of the liquid Al-alloys. In measuring the weight change due to oxidation, an AP250D series OHAUS-ANALYTICAL PLUS recording balance was used. It was capable of measuring weights up to 62g with a resolution of 10 μ g.

2.2. Oxidation of large Al-Si Alloys Melts in a 3kg-Capacity Crucible

Melting and alloying of 2.5kg weight of the alloys were carried out in the 3kg capacity silicon carbide crucibles using the electrical resistance furnace. This amount of melt is regarded as the large melt, in comparing with the 47g melts samples. Since the TGA method is not capable to study precisely the oxidation rate of the large quantity of melts, in such a case the effect of Sr-addition on the oxidation behavior of the large melts was carried out by analyzing the melt surface oxide layer. In analysing the oxidized surfaces, samples of the melt surface layers were taken just 20 minute Sr-addition at 730°C. The melts were then held for another 300 min period at 730°C and the sampling from the melts oxide layers were made every 60 minutes using preheated metallic meshes.

3. RESULTS AND DISCUSSIONS

3.1. The Small Melts

The weight gains of Al-7Si alloys containing different amounts of the elements Sr and Mg versus time at 730°C is plotted in Fig.1. As can be seen, Sr and Mg-additions increase noticeably the oxidation rate of the liquid Al-7Si alloy although the effect of even 0.03%Sr on the increased melt oxidation rate is higher than 0.35%Mg. Figure 2 shows the variation of concentration of Sr dissolved in the 47g A356 alloy samples versus time at 730°C. More than 75% of strontium faded during the 1000min holding period at 730°C, revealing that in a small Al-Si alloy melt which has a high ratio of oxidation surface area to melt volume (surface modulus), Sr is very active, probably for oxidation.

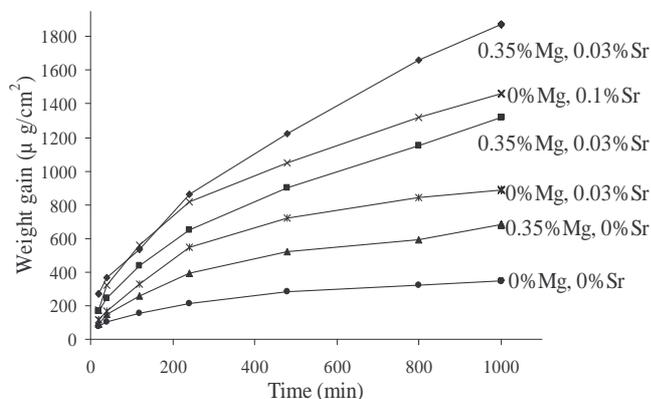


Figure 1. The effect of Sr and Mg-addition on the oxidation rate of Al-7Si alloy at 730°C

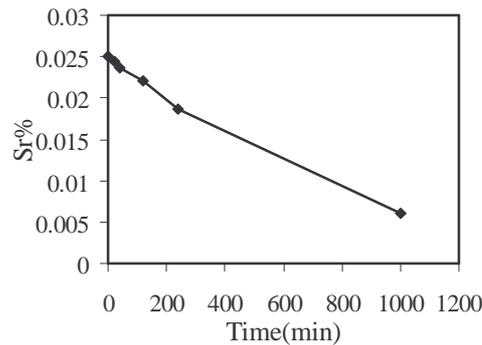


Figure 2. Variations of concentration of Sr in Al-7Si-0.35Mg-0.03Sr alloy versus time at 730°C

The SEM-EDS microanalysis pattern obtained from the upper surface film of an Al-7Si-0.35Mg-0.03Sr alloy melt, which held for 240min at 730°C is shown in Fig.3. As seen, the oxidised surface consists of complex of SrO.MgO.Al₂O₃ oxides, showing the high activity of Sr and Mg for oxidation in a small melt. The quantitative SEM-EDS analyses were also used to estimate the composition of the oxidised surfaces. Consequently, by doing mass balance calculations, the composition of the oxidised surfaces in liquid 0.03%Sr-modified A356 alloy at different periods of oxidation at 730°C has been determined as in Fig.4. Again it shows that in the small melts, the elements Mg and Sr were both reactive for oxidation.

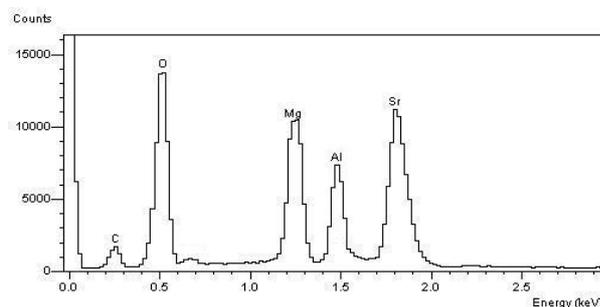


Figure 3. SEM-EDS microanalysis pattern obtain from the oxide film of Al-7Si-0.35Mg-0.03Sr alloy after 240 min oxidation at 730°C

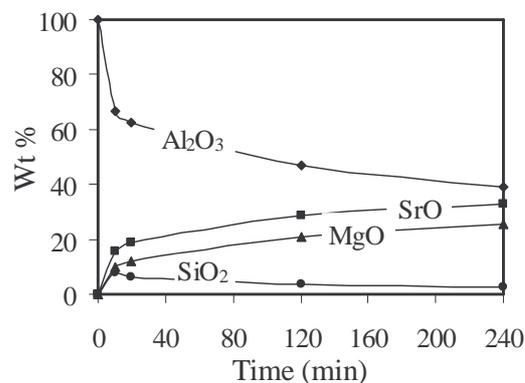


Figure 4. Variations of composition of the oxidised surface of the Al-7Si-0.35Mg-0.03Sr alloy with time at 730°C

3.2. The Large Melts

Variations of concentration of Sr dissolved in 2.5kg liquid Al-7Si-0.35Mg-0.03Sr alloy versus holding time at 730°C is shown in Fig.5. As can be seen, the concentration of Sr did not decrease noticeably and only about 8% of Sr faded after 300min period of oxidation. This shows that strontium has good stability in large Al-Si alloys melt. The systematic analysing of the melt surface layers at different stages of the holding periods at 730°C using SEM-EDS and linescan microanalysis showed that the surface layers of the 0.03 and 0.1%Sr-modified Al-7Si and A356 alloys consisted of Al₂O₃, MgO (only in A356 alloy) and minor amount of SiO₂ but were found to contain no detectable SrO. However, Sr-rich intermetallic compounds were found to be present in the surface layer.

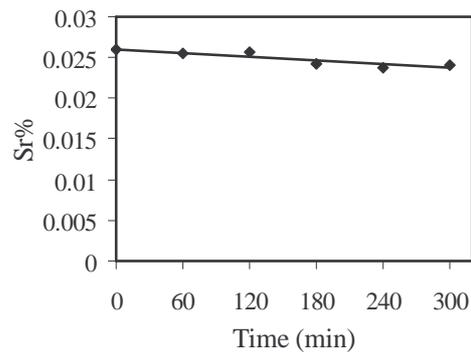


Figure 5. Variations of concentration of Sr in Al-7Si-0.35Mg-0.03Sr alloy versus time at 730°C

The BSE image of a polish section of the surface film of the 0.1%Sr-modified A356 alloy after 300min oxidation at 730°C and an associated linescan microanalysis pattern are shown in Fig.6.

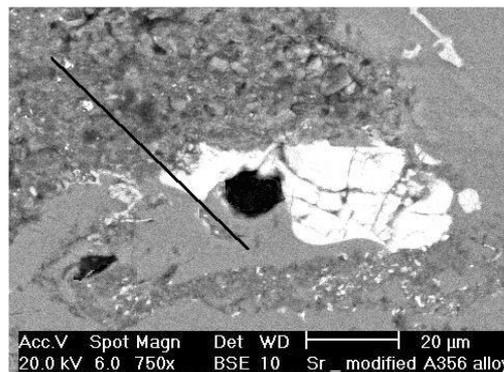


Figure 6-a. BSE image of polished section

The distribution of the elements shows that the porous region is the surface oxide film and the composition of the surface film corresponds to probably Al₂O₃.MgO. There is also a sharp rise in the concentration of the elements Sr and Si in the region of the bright particles and a marked fall in the concentration of Al and O, revealing that the bright particles were Sr-rich intermetallics but not SrO containing oxides. These show that in the large Al-Si alloys melt that has low surface modulus for oxidation, in contrast with small melt, Sr is not an active element for oxidation, indicating that Sr has probably no effect on the oxidation behaviour of the large melt. However Mg is still reactive for oxidation.

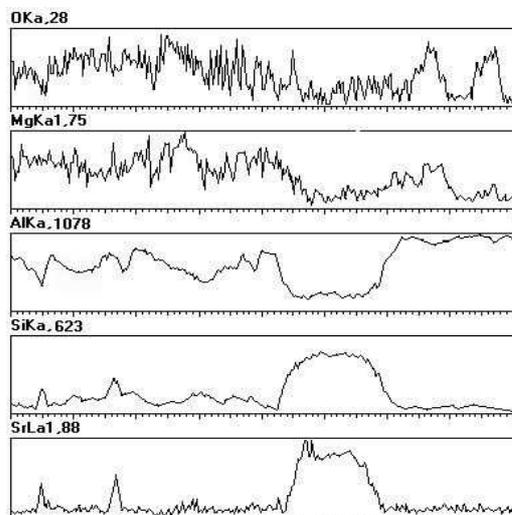


Figure 6-b. line scan microanalysis pattern

Figure 6. SEM images of oxide film of 2.5kg Al-7Si-0.35Mg-0.1Sr alloy melt after 300 min oxidation at 730°C

4. CONCLUSION

1. In a small melt which has high ratio of melt surface area to melt volume, Sr and Mg are both very reactive elements in the Al-Si alloy and increase the melt oxidation rate significantly.
2. In a large melt which has low surface modulus for oxidation, Mg is still reactive for oxidation but Sr has probably no effect on the oxidation behaviour of the melt.

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