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Investigation of defects in SiC_p/A356 composites made by a stir casting method

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A stir casting method is one of the most competitive methods for fabricating SiC particle reinforced aluminum matrix composites because of its low cost with competitive quality. However, defects formed in the composites during the fabrication process will deteriorate their properties. Different kinds of defects such as black inclusions related to agglomerated SiC, silver spots related to Al-Fe-Si phases, white inclusions related to Al_2O_3 and porosity related to gas and SiC agglomeration are investigated in this paper. Based on these investigations, a technique for improving the quality of SiC_p/A356 composites fabricated by a stir casting method is proposed. A SiC_p/A356 composite with few defects and good properties was fabricated with the improved stir casting process.

Key words: SiC_p/A356 composites, Stir casting, Black inclusions, Silver spots, White inclusions, Porosity.

Introduction

Metal matrix composites have potential application in many fields because of their good physical and mechanical properties, such as high specific strength and stiffness, good wear resistance and low thermal expansion coefficient. Among all metal matrix composites, SiC particle reinforced aluminum matrix composites can be fabricated with the stir casting process, which is one of the chief developments in fabricating SiC_p/A356 composites [1]. At present, the stir casting method is one of the most competitive methods for fabricating SiC_p/A356 composites. However, various defects in the composites will occur during the fabrication of SiC_p/A356 composites using the stir casting method, which will deteriorate the properties of the composites. Many investigations for improving the wetting ability between SiC and the metal matrix and interface bonding strength have been made in order to improve the quality of the SiC_p/A356 composites [2]. Few studies have been carried out on the causes of the defects and on improving the fabrication method. Different types of casting defects in SiC_p/A356 composites made by a stir casting method and their formations are discussed in this paper. An improved stir casting technique is developed to improve the quality of SiC_p/A356composites.

Experiment Details

An electrical resistance furnace with a steel crucible was used to fabricate the SiC_p/A356 composite. Aluminum alloy A356 (7.0% Si, 0.42% Mg, 0.20% Ti, <0.12% Fe, <0.10% Cu, <0.05% Mn, <0.05% Zn, Al remainder) was used as the matrix of the composite and SiC particles with an average size of 11.5±0.5 μm were chosen as the reinforcement particles. The SiC reinforcing particles were added on the surface of the molten liquid A356 at 620 °C and then a vacuum was applied to the crucible. An agitator was used to disperse the SiC particles into the melt. The mixed material was stirred strongly in the semi-solid state to make the SiC particles disperse homogeneously in the melt. Finally the composite melt was heated to 700 °C and poured into a steel mould. The microstructures and fracture surfaces were investigated with an optical microscope and a scanning electron microscope (JSM 5800) equipped with an energy dispersive X-ray spectrometer.

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Results and Discussion

The main defects formed during the fabrication of the composite were identified on the basis of experiments. It was found that there were four kinds of casting defects existing in the composite including black inclusions, silver spots, white inclusions and pores.

A sample with black inclusions and its microstructure are shown in Fig. 1 and Fig. 2. It can be seen from Fig. 1 that the black inclusions (marked with an arrow) appear black on the macroscopic view and are dispersed non-uniformly in the sample. The black inclusion has a recessed shape as shown in Fig. 2. Because the recessed shape scatters light, this kind of casting defects appears black on the macroscopic view. The EDAX composition analysis of black inclusions marked in Fig. 2 indicates that they are mainly composed of Si and C elements,

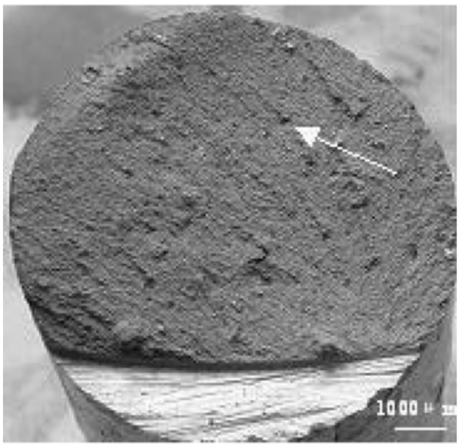

Fig. 1. Black inclusions.

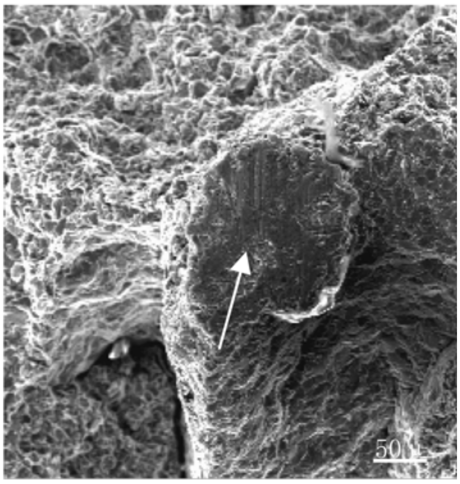

Fig. 2. Microstructure of a black inclusion.

Fig. 3. Silver spots.

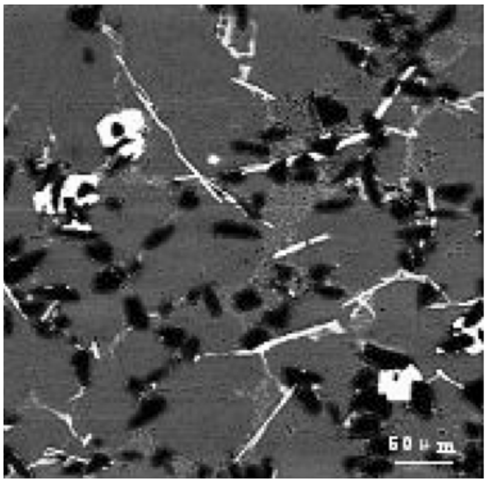

Fig. 4. Microstructure of Al-Fe-Si phases.

which means that the black inclusions are agglomerated SiC. If the shear force was not strong enough to break up the agglomerated SiC particles during the stirring process, they would gather together and form black inclusions. These black inclusions will deteriorate the properties of the composite, therefore an effort should be made to avoid the occurrence of black inclusions.

A silver spot on a specimen is shown in Fig. 3. Its microstructure is shown in Fig. 4. It can be seen that they appear white with needle-like and block-like shapes. EDAX analysis in Table 1 shows that they are Al-Fe-Si phases. Coarse grains will promote the formation of Al-Fe-Si phase particles because more Fe will segregate around the grain boundaries. The needle-like phase existing in the composite will be the source of stress concentrations and create cracks during the application of the composites. Figure 5 showed the typical cleavage fracture generated around the Fe-rich phase. The ex- istence of a needle-like phase will reduce the material properties significantly. Therefore, it is vital to reduce Fe-rich phase formation in order to obtain composites of good quality. Fe in composites mainly comes from the crucible and stirring agitator that contact directly with the aluminum melt. It is necessary to control the stir casting process to reduce the amount of Fe entering into the aluminum melt. Based on many experiments, it was found that there were no obvious silver spots on the specimen fracture surfaces if the Fe content is less than 0.2%. Mechanical property tests show that the lower the Fe content is, the better will be the properties.

White inclusions on a fracture sample are shown in

Table 1. Chemical compositions of needle-like and block-like phase (wt.%)

	Al	Si	Mg	Fe	Ti	Cu	Zn	Cr	Ni	Mn
block–like	53.46	6.71	0.00	28.20	0.12	0.00	0.16	9.63	0.15	1.16
needle-like	56.81	21.02	0.00	21.02	0.16	0.08	0.00	0.09	0.49	0.23

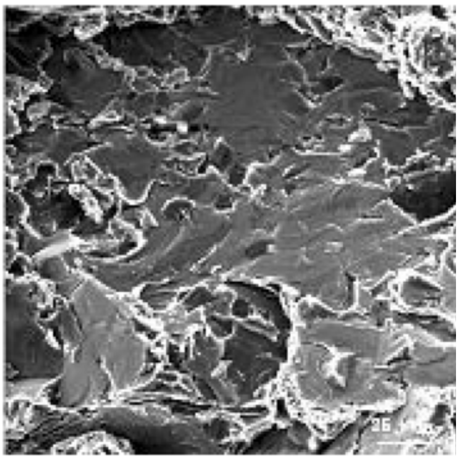

Fig. 5. Cleavage fracture of Al-Fe-Si phase.

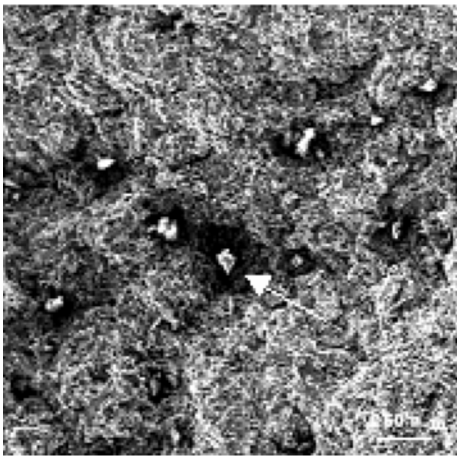

Fig. 6. Fracture with oxygen inclusions.

Fig. 6. EDAX analysis of the white inclusion marked in Fig. 6 shows that it is mainly composed of oxygen and aluminum. It can be concluded that the white inclusions are Al_2O_3. During the fabricating process of the composites, aluminum oxide particles, Al_2O_3, caused by oxidization on the surface of the melt are stirred into the melt. Al_2O_3 may adhere to the SiC particles, and the white inclusions will be formed. It is necessary to reduce the amount of Al_2O_3 formed by oxidization in order to reduce the white inclusions.

A typical example of porosity is shown in Fig. 7. It has the appearance of the agglomerated particles without metal in it. When SiC particles are added into the melt, gas and water on the surfaces of SiC particles enter into the melt at the same time. When the gas pressure p_g in the melt meets the condition of $p_g \geq p_e + \rho h + 2\sigma/r$, where p_e is the gas pressure in P_a, r is the gas pore radius in metres, h is the melt height in metres in the furnace, σ is the surface energy in N/m, the gas bubbles will be formed [3]. If the radius r of the gas bubble is great enough, it will easily escape from the melt. The contact angle between SiC and air is the complementary angle between SiC particles and the

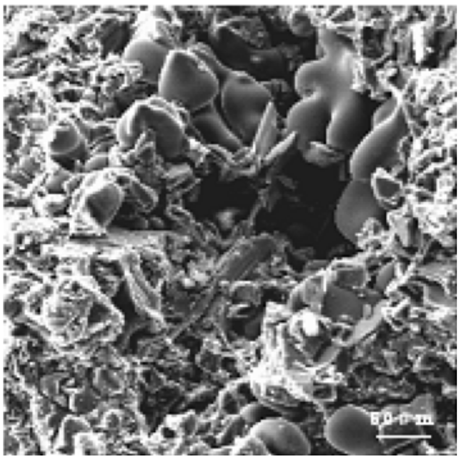

Fig. 7. Fracture with porosity.

melt, which means that SiC can not be wetted by the melt but by air. Then the gas bubbles formed in the melt will absorb SiC particles easily. The gas bubbles have a trend to rise from inside the melt to its surface. During process by which the gas bubbles rise, they will continue to absorb SiC particles and the weight of the bubbles will be increased. When the weight is equal to or larger than the buoyancy, the bubble will stay in the melt and porosity will be formed [4]. It is then necessary to reduce the amount of air and water entering into the melt.

Improvements in technique for fabricating SiC_p/A356 composites

Based on investigations of the formation of different defects, an improved stir casting process is proposed in order to reduce the defects.

The improved technique is described as follows. The melting process of the aluminum ingots proceeds in a vacuum atmosphere in order to avoid the molten metal being exposed to air, and therefore the oxidation of aluminum can be prevented. The gas and water on the surface of the SiC particles are removed by heating the SiC particles at 500 ^oC for 1 hour before they are added into the melt. The stirring process starts when the crucible has been evacuated for half an hour after which the SiC particles are added on the surface of melt in order to further remove the air and water absorbed on the SiC particle surfaces. The equipment and tools that contact directly with the molten aluminum are coated with a firm layer of zinc oxide protective material to avoid Fe entering into the melt. The thickness of the coating is 0.2-0.4 mm. The stirring speed is 700-900 rpm for 25 minutes in the semi-solid state of 575-585 ^oC.

A SiC_p/A356 composite with 20 Vol.% SiC was fabricated using the improved stir casting process. Its microstructure is shown in Fig. 8. It can be seen that SiC is distributed homogeneously in the composite and no obvious Al-Fe-Si phase is found. Figure 9 shows

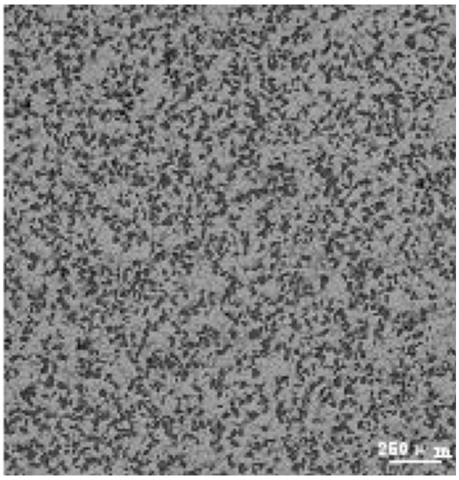

Fig. 8. Microstructure of the improved SiC_p/A356 composite.

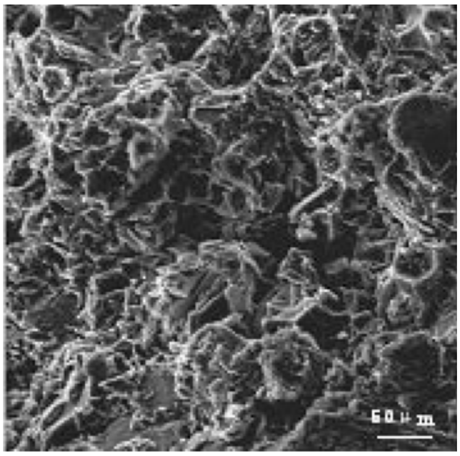

Fig. 9. Fracture of the improved SiC_p/A356 composites.

the fracture of this composite specimen. No obvious oxide inclusions and agglomerated SiC particles are apparent. The porosity of the fabricated composite is between 0.2%-0.4% with mechanical properties of 330 Mpa tensile strength, 1.0% elongation and 106 Gpa Young's modulus.

Conclusions

There mainly exist four kinds of defects in SiC_p/A356 composites if an unsuitable stir casting process is used. Black inclusions are SiC agglomerates, silver spots are Al-Fe-Si phase particles, white inclusions are SiC particles adhering to Al_2O_3 and the pores are caused by gas bubbles and agglomerated SiC particles. An improved stir casting process is established for fabricating SiC_p/A356 composites with good mechanical properties and less defects.

Acknowledgements

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