Effect of Process Factors on Viscosity of In-situ Particulate Reinforced Aluminum Matrix Composites

Zhi-Hong JIA[1,a,*], Dao-Cun XIE[2,b], Lan-Lan XIONG[3,c], Chi ZHANG[3,c], Yu-Tao ZHAO[3,c]

[1,2,3]School of Material Science & Engineering, Jiangsu University, Zhenjiang 212013, China

[a]jia_zh@163.com, [b]1057426394@qq.com, [c]1176583168@qq.com

* Corresponding author

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Abstract. Viscosity of aluminum matrix composites reinforced by TiB_2 particle has been studied systematically by using the rotating cylinder method. The results show that the viscosity of melt decreased with the increase of temperature, and the changes are abnormal when the temperature is between 710℃ to 730℃. In high superheat, the viscosity of melt decreased with the increase of Si content. It is more then 11% Si content that the viscosity of the melt increased in low superheat.

Introduction

In-situ preparation of TiB_2 particle reinforced aluminum composite was a new composite preparation technology which has been developed in recent decades[1]. Composite of stable performance can be obtained because of good interfacial compatibility between reinforced particle and substrate material[2-3]. TiB_2 has the properties of high melting point, high hardness, high elasticity modulus, good corrosion resistance and abrasive resistance etc[4], that makes TiB_2 /Al composite become an excellent structural material[5].

Viscosity is a physical property of liquid metal which describe the melt structure change[6-8]. The information of distribution, aggregation, and sediment of melt particles can be obtained by studying the composite melt particles, thus improving the preparation process of particulates reinforced composites. It provides theoretical basis for making composites which have uniformly distributed and fine grained particulates[9-11]. Containing reinforcing particles makes the metal liquidity worse and influences the mold filling capacity of the melt. The impact of different factors on melt viscosity of TiB2 reinforced composites was studied in this paper.

Experimental Procedures

Al(better than 99.9%) and Al-20%Si alloy were used to produce Al, Al-1%Si, Al-3%Si, Al-5%Si, Al-11%Si alloy by the mass fraction. According to precious study [12-14] ,K2TiF6、KBF4 and Ti were used as reactant to prepare 3% TiB2 aluminum matrix composites by resistance furnace.

The prepared Al, Al-1%Si, Al-3%Si, Al-5%Si, Al-11%Si samples were taken into clay crucible. The samples were smelted in 30kw well resistance furnace(SG2-5-10 model Well type) ; the liquid metal was refined with slag removal in 850℃, and let stand for 10 minutes. K_2TiF_6 and KBF_4 were added to the melt in a certain proportion, and the melt was stirred well by carbon rod. After 30 minutes, the liquid metal with degassing and slag removal was poured in copper mold in 750℃. Then as-cast composite can be obtained.

The reaction of producing in-situ TiB_2 particulate reinforced aluminum matrix composites is:

$$3K_2TiF_6+6KBF_4+10A1\rightarrow 2TiB_2+6AlF_3+12KF+TiAl_3+A1B_2+6F_2 \quad (1)$$

$$TiAl3+AlB2\rightarrow TiB2+4Al \quad (2)$$

Viscosity measuring instrument: GNDJ high temperature melt viscosity instrument, NDJ-5S digital Viscometer, the structure is shown in Ref.15.

Results and Analysis

Relationship between Temperature and Viscosity

Metal melt viscosity usually keep declining with the increase of temperature[11] . Figure 1 shows the relationship between temperature and melt viscosity of 3% (mass fraction) TiB_2 composites.

Adding 3%TiB_2 particles, apparent viscosity of the four different constituents composites has the same change trend in 620℃～800℃. Viscosity-temperature curve shows that, with the increase of temperature, viscosity decreased firstly then increased rapidly, afterwards decreased slowly. In 775℃～800℃temperature interval viscosity continue to increase.

For pure aluminum and 1%Si sample, the melt temperature interval (630℃～800℃) can be divided into three section, they are: 660 ℃ ~ 730℃ low temperature area; 730 ℃ ~ 750℃medium temperature area; 775 ℃ above high temperature area. For 5%Si and 11%Si sample, the same interval (630℃～800℃） can also be divided into three section: 660 ℃ ~ 715℃ low temperature area; 715 ℃ ~ 775℃medium temperature area; 775 ℃ above high temperature area.

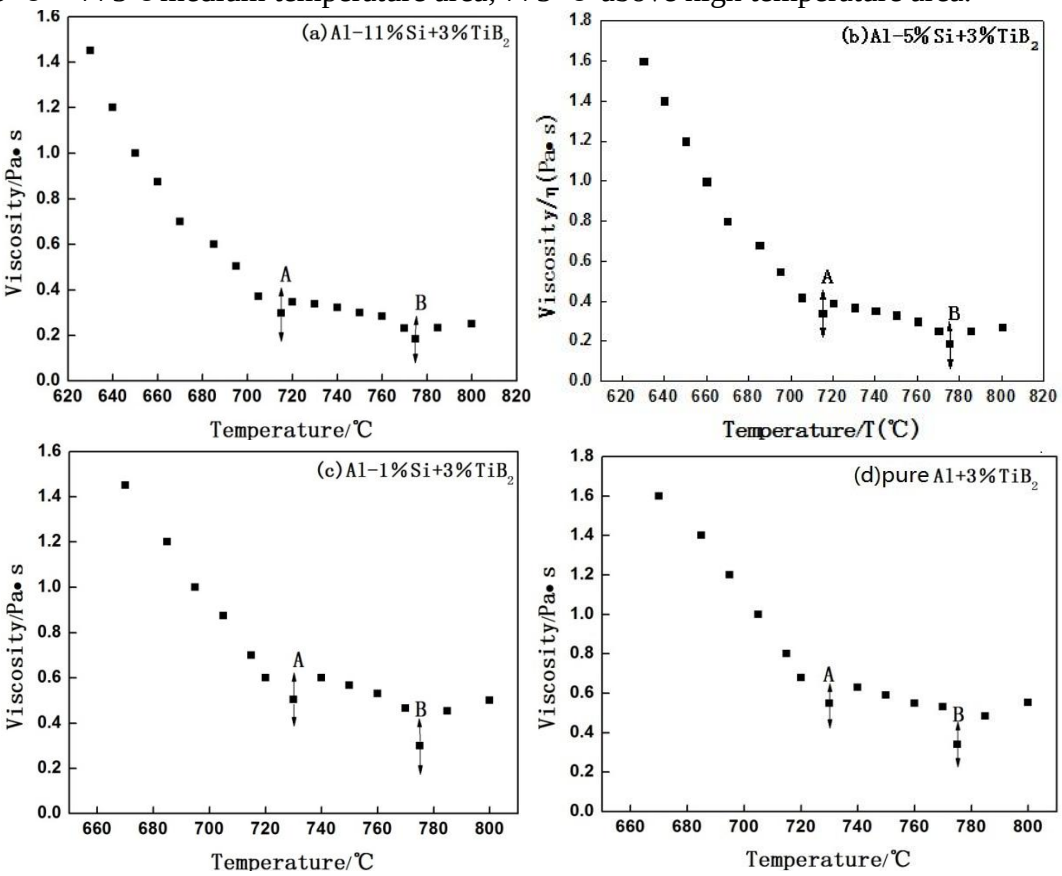


Fig.1 Relationship between viscosity of composite melts and temperature

In low temperature area, microscopic particles activity was more vigorous with increasing temperature. The force of substrate atoms and TiB_2 particles gradually weakened, so viscosity decreased. TiB_2 particles can be seen as “atomic cluster”. With the increasing temperature and the continually stirring rotor, the distribution of melt atoms and TiB_2 ceramic particles is more uniform, and the micro non-uniformity of melt is reduced. Therefore, average energy of viscosity flow interaction increases, it shows up as less melt stickiness on a macroscopic scale[16], that is, the viscosity presents an ascending trend in medium temperature area. This factor had more impact on viscosity than temperature, thus the first discontinuous change of viscosity happened. Literature[17]

find that, melt viscosity increased with the increasing temperature by adding 3%TiB_2 into Al and rising temperature to 780℃. It is considered that Al atoms reacted with oxygen in the air to form Al_2O_3 particles due to thermal motion of Al is fierce.

Effect of Si Content on Melt Viscosity

As seen in Fig.2, with the increase of Si content, four different kinds of melt viscosity decreased in the same temperature. According to Doolittle's formula about viscosity and free volume:

$$\eta = Ae^{B/(v_f/v_0)} \tag{3}$$

In the formula, η is viscosity coefficient; v_f/v_0 represents relative free volume ratio; A and B are constant for simple melt.

Cohen inheritance and development the theory about free volume in the liquid which has been presented by Eyring and Doolittle. According to Cohen's theory, it's 50 degrees lower of superheat in melt of pure Al and 3%Si sample than in 11%Si and 5%Si sample under the same temperature. So hole concentration of atomic cluster increased in higher superheat melt, and size of atomic contraction increased. Combining formula (3), viscosity of 5%Si and 11%Si sample is lower.

Fig.2 shows that, in pure Al and 3%Si sample with 3%TiB_2, there is the first discontinuity in 730℃ which is higher point than in 5%Si and 11%Si sample. One possible reason is that melt superheat degree reached 70 ℃ at this point, the size of many Al-Al atom cluster decreased, and the number of free atom increased. Thus melt viscosity came down. For 5%Si and 11%Si sample, Superheat degree of melt has reached above 95 ℃ in 715℃, meanwhile, Si-Si atomic clusters in 11%Si sample melt and a small amount of Si-Si atomic clusters in 5%Si melt became small, so it made the viscosity decreased.

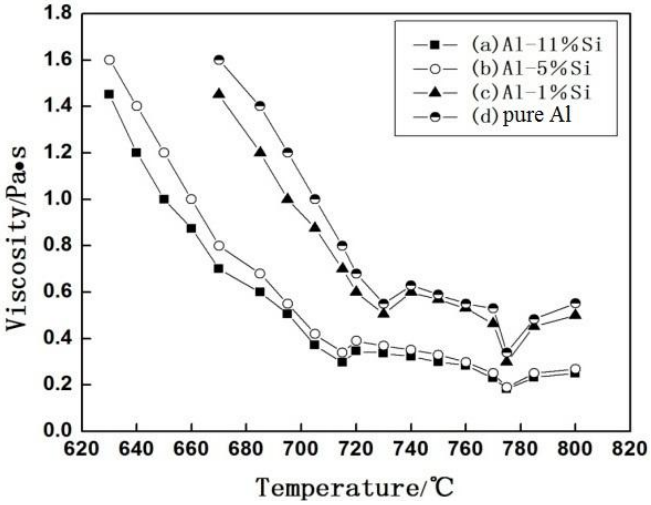


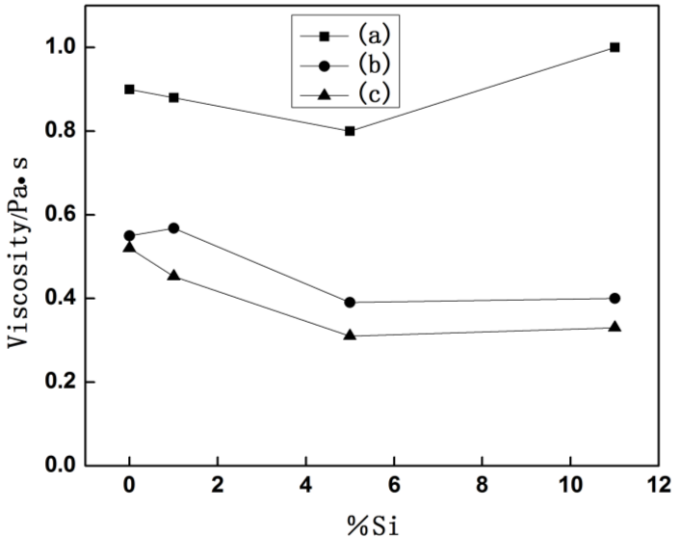
Fig.2 Relationship between viscosity of composites melt and temperature

The viscosity of the four kinds of melt changed suddenly in 775 ℃.One possible reason was that free atoms began to increase when temperature reached 775℃, and they reacted with oxygen to form Al_2O_3 particles which made viscosity increase.

Effects of Superheat on Viscosity

According to Fig.3, when superheat degree was ΔT=50℃ and the Si content was below 5% , with the increase content of Si, viscosity decreased. One possible reason is that relatively few Si atoms led to less amount of Si-Si atomic group. In contrast, viscosity increased when the content of Si was 11%, because more Si-Si atomic group formed in the melt and microscopic non-uniformity

of melt was higher under low superheat. When the superheat degree reached 100℃ or 150℃, atomic motion became more violent, so the interaction between ceramic particle and matrix decreased and homogenized. In this conditions, microscopic distribution was more uniform, it showed that Si content have a smaller impact on melt viscosity in the macroscopic.



（a）ΔT=50℃ （b）ΔT=100℃ （c）ΔT=135℃

Fig.3 Comparison of the viscosities of TiB_2 composite melts at the same superheat temperature

Conclusion

There are two points of discontinuity in TiB2 particle reinforced aluminum matrix composites with the increasing temperature: for pure aluminum or 1%Si composite sample, one discontinuity point existed in 730℃,another existed in 775℃; for 5%Si or 11%Si composite sample, one discontinuity point existed in 715℃ and another existed in 775℃.

For TiB_2 particle reinforced composites, viscosity decreased with the increasing content of Si in the same temperature.

When superheat degree reached 50℃, the viscosity of TiB_2 particle added composites decreased if Si content was below 5%, while it increased if Si content was 11%; when superheat degree was above 100℃, because of more intense atomic motion, viscosity decreased with the increasing Si content.

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