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Improvement of yttrium on the hot tearing susceptibility of $6TiB_2$/Al-5Cu composite

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Abstract: To improve the severe hot tearing susceptibility of TiB_2 reinforced Al-5Cu matrix composites, the present research investigated the influence of Y on the hot tearing susceptibility of $6TiB_2$/Al-5Cu composite. For the composite added with Y, the solidification temperature range was shortened, which was caused by the novel τ_1-Al_8Cu_4Y phase. The grain size of $6TiB_2$/Al-5Cu composite was 39.8 μm. The addition of Y promoted the grain refinement, and the grain sizes were 36.33, 33.42 and 26.77 μm for $6TiB_2$/Al-5Cu with 0.2 wt.%, 0.5 wt.% and 1 wt.% Y, respectively. The decrease of solidification temperature range and grain size was beneficial to the hot tearing susceptibility improvement. Furthermore, the hot tearing initiation force increased from 44 to 288 N, when 1 wt.% Y was added in $6TiB_2$/Al-5Cu. For the above significant influence, the hot tearing susceptibility values were reduced by 12.2 wt.%, 57.7 wt.% and 66.8 wt.% for $6TiB_2$/Al-5Cu with 0.2 wt.%, 0.5 wt.% and 1 wt.% Y, accordingly.

Keywords: metal matrix composites; microstructure; hot tearing susceptibility; rare earths

The cast aluminum-copper metal matrix composites and Al-Cu alloys have found significant application in areas, where the high strength and light weight are of primary consideration owing to their excellent strength to weight ratio[1–3]. However, their practical applications are often restricted due to the severe hot tearing susceptibility (HTS), which renders them manufacturing failure[4,5]. As a result, there is a considerable attention on the research of HTS improvement in Al-Cu alloys[4,6,7].

For the aluminum alloy, the addition of element was a useful method to improve the HTS. Nabawy et al. found that the addition of Si reduced the HTS of Al-2Cu-Si alloy[4]. The reduction was ascribed to the increase of the eutectic. Lin et al. reported that the addition of Ti refined the grain size and reduced the HTS of aluminum alloys[7]. The grain refining addition was another important approach to lowering the HTS. Nabawy et al. found that the addition of Ti-B or Zr-Ti-B effectively improved the hot tearing of Al-2Cu alloy due to the grain size refinement[8]. The study made by Viano et al. indicated that the addition of Al5Ti1B reduced the HTS value of Al-5Cu alloy[9].

For the TiB_2 reinforced Al-5Cu composite, the TiB_2 particles served as nucleation cores, which was beneficial to the grain refinement and mechanical properties improvement. However, more TiB_2 caused serious hot tearing. In our former research, it was found that TiB_2 particles reinforced aluminum-copper metal matrix composites also had serious hot tearing problem, especially when the high mass fraction of TiB_2 was added into the Al-Cu alloy matrix. The HTS indexes of $4TiB_2$/Al-5Cu and $6TiB_2$/Al-5Cu were 24.6 and 33.4, which were greater than the Al-5Cu matrix alloy (HTS=22.9). Therefore, the hot tearing improvement of Al-5Cu metal matrix composites was a necessary issue. Nevertheless, there are rare reported works about the hot tearing of metal matrix composites. Hence, the current research focused on improving the HTS of composites through the addition of Y.

Yttrium (Y), one of the important rare earth elements, has been widely employed in lightweight materials to improve the comprehensive mechanics performance[10–15]. Moreover, the rare earth elements also have beneficial influence on the casting process, including the decrease of gases, impurities and grain size[11,16]. Y is an important alloying element to aluminum alloys, which can improve casting characteristics. Furthermore, it was found that Y can improve the phases distribution of microstructure. The purpose of this work is to report the mechanism of the HTS improvement of Al-5Cu matix composites.

1 Experimental

In an attempt to improve the HTS of Al-5Cu metal matrix composites, the present work investigated the effect of Y addition on the HTS of the $6TiB_2$/Al-5Cu composite. The experimental Al-5Cu based alloy contained 5.3 Cu, 0.22 Ti, 0.45 Mn, 0.05 B, 0.22 V, 0.22 Cd, 0.18 Zr and 0.05 Fe (all in wt.%), and the $6TiB_2$/Al-5Cu

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composite was fabricated with a chemical reaction between the molten aluminum and mixed salts[17]. In the reaction, K_2TiF_6 and KBF_4 salts were added in proper Ti:B ratio to the molten aluminum-yttrium alloy and Al-5Cu based alloy liquid at 850 ºC[17,18], stirred for 30 min at regular intervals and cast in a constrained rod casting (CRC) mold at 750 ºC[19,20]. In the research, the $6TiB_2$/Al-5Cu composites with different levels of Y were prepared, including 0.2Y-$6TiB_2$/Al-5Cu, 0.5Y-$6TiB_2$/Al-5Cu and 1Y-$6TiB_2$/Al-5Cu (all in wt.%).

The composites were characterized using scanning electron microscopy (SEM; NOVA NanoSEM 230), energy dispersive spectrometer system (EDS; Oxford Instruments AZtec X-Max 80) and transmission electron microscopy (TEM; JEM-2100F). The phase compositions of the composites were determined by X-ray diffraction (XRD; Smart Lab, Cu Kα radiation).

2 Results and discussion

2.1 Microstructure analysis

Fig. 1(a) shows the XRD patterns of xY-$6TiB_2$/Al-5Cu (x=0, 0.2, 0.5, 1) composites. The result indicated that $6TiB_2$/Al-5Cu consisted of α-Al, θ-Al_2Cu and TiB_2. In the XRD patterns of the $6TiB_2$/Al-5Cu composites with Y added, the new peaks confirmed the formation of τ_1-Al_8Cu_4Y phase. Meanwhile, the peak amount and intensity of τ_1-Al_8Cu_4Y phase increased with the Y content increasing. Furthermore, Fig. 1(b) exhibits the typical SEM micrograph and EDS maps of 1Y-$6TiB_2$/ Al-5Cu. It was obvious that the microstructure was mainly composed by the α-Al grains, TiB_2 particles, θ-Al_2Cu and τ_1-Al_8Cu_4Y phases. The τ_1-Al_8Cu_4Y phase was rich in Al, Cu and Y elements and existed as lamellar form, as the EDS-map image shown in Fig. 1(b). The TEM characterizations, including the bright field (BF) image, the selected area diffraction (SAD) pattern and the EDS information, were additionally carried out to analyze τ_1-Al_8Cu_4Y phase. As shown in Fig. 1(c), the TEM BF micrograph of τ_1-Al_8Cu_4Y was similar with its SEM feature shown in Fig. 1(b). The τ_1-Al_8Cu_4Y was body- centered tetragonal crystal structure (Mn12Th type structure, *tI*26, *I*4/*mmm*, a=0.8748, c=0.5146)[10,11]. The SAD pattern can be well indexed from [011] zone axis for the τ_1-Al_8Cu_4Y phase. Fig. 1(c) also presents elemental analysis of τ_1-Al_8Cu_4Y, which clearly indicated

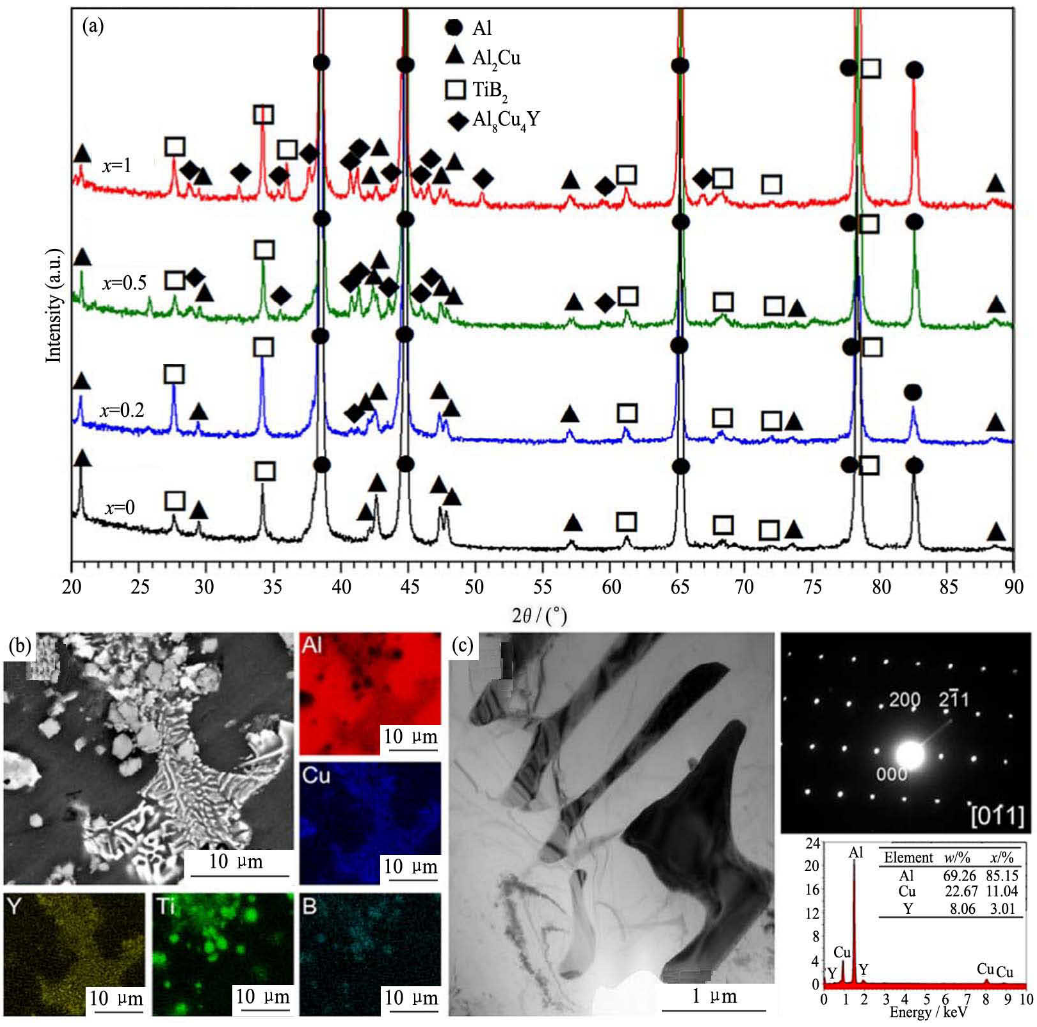

Fig. 1 (a) XRD patterns of xY-$6TiB_2$/Al-5Cu (x=0, 0.2, 0.5, 1) composites; (b) SEM image and EDS-map of 1Y-$6TiB_2$/Al-5Cu; (c) TEM BF-image, SAD pattern and EDS analysis of τ_1-Al_8Cu_4Y phase in 1Y-$6TiB_2$/Al-5Cu composite