# On the Preparation and Properties of Al-7Si-0.4Mg Matrix Composites Reinforced by In-situ Intragranular $Al_3Ti$ and Intergranular $TiB_2$

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**Abstract:** In particulate reinforced Al matrix composites (PRAMCs), the micro-sized ceramic particles tend to segregate at the α-Al grain boundary, resulting in a sharp drop in the ductility of the composite and thus restricting its application. It is promising to improve the ductility of the $TiB_2$-containing composites while maintaining high strength by introducing the intragranular $Al_3Ti$ particles to replace part of $TiB_2$ particles. In the present work, ($Al_3Ti$+$TiB_2$)/Al-7Si-0.4Mg composites were prepared by using the ultrasound assisted in-situ casting. The results showed that most of modified $Al_3Ti$ particles were inside the α-Al grains while $TiB_2$ particles were mainly located at the α-Al grain boundaries. Under the ultrasonic stirring, both particles were uniformly distributed in the Al alloy matrix. Compared with Al-7Si-0.4Mg alloy, the ($3Al_3Ti$+$2TiB_2$)/Al-7Si-0.4Mg composite exhibited the best comprehensive mechanical properties, and its yield strength, ultimate tensile strength, and elongation (254MPa, 310MPa, and 3.8%) were improved by 21.0%, 21.6%, and 111%, respectively. This work provides a novel composite design approach to achieve a strength-ductility synergetic improvement.

**Keywords:** $Al_3Ti$; $TiB_2$; Hybrid reinforced particles; Microstructure; Mechanical properties

## 1 Introduction

PRAMCs have been widely used in the automotive and aerospace industries due to its specific lightweight and high strength characteristics [1]. The reinforced particles of PRAMCs include ceramic ($TiB_2$ [2], TiC [3], etc) and intermetallic compound ($Al_3Ti$ [4], $Al_3Zr$ [5], etc). $TiB_2$ particles in as-cast PRAMCs tend to aggregate together in the Al melt, resulting in the microstructure with the agglomerated $TiB_2$ particles at the α-Al grain boundary, which is detrimental to the mechanical properties of PRAMCs and thus restricts their application [6]. In contrast, during the cooling and solidification process of $Al_3Ti$-containing Al melt, the peritectic reaction occurs, in which $Al_3Ti$ particles are used as the heterogeneous nucleation sites of α-Al grains [7]. In this case, $Al_3Ti$ particles are located within the α-Al grains, which will not significantly deteriorate the ductility of PRAMCs.

Hence, in order to achieve the superior strength-ductility synergy of $TiB_2$-containing PRAMCs, it is necessary to replace part of $TiB_2$ particles with $Al_3Ti$ particles. Moreover, ultrasound treatment contributes to promote the uniform dispersion of small-sized particles [4,8]. In the present work, the dual-phase particles ($Al_3Ti$+$TiB_2$) with different rations were introduced into the Al-7Si-0.4Mg matrix (wt.% unless otherwise noted) to prepare the composites by the ultrasound assisted in-situ casting. Furthermore, the phase, microstructure and tensile properties of T6-composites were investigated.

## 2 Experimental procedure

The ($xAl_3Ti$+($5-x$) $TiB_2$)/Al-7Si-0.4Mg composites (Table 1) were fabricated by using Al-7Si-0.4Mg matrix (pure Al (99.7%), Si (99.9%) and Mg (99.9%)), Al-10$Al_3Ti$ (Al-$K_2TiF_6$ system) and Al-10$TiB_2$ (Al-$K_2TiF_6$-$KBF_4$ system) master composites as raw materials. The detailed fabricating process of the master composites can be referred to our previous research [4,8]. Al-10$TiB_2$, pure Al and Si were initially melted at 750℃ for 30min within a graphite crucible in a high-frequency induction furnace. Then Al-10$Al_3Ti$ and pure Mg were added into the melt when the temperature was stabilized at 700℃. After that, the ultrasound probe (1.6kW, 20kHz) was immersed into the melt for 5min with the aim of making $Al_3Ti$ and $TiB_2$ particles distribute uniformly in the melt. Finally, the composite melt was poured into a graphite mold to obtain an ingot. Then all ingots were T6-heat treated: solution treatment (540℃ 4 h, 60℃ water quenching) + aging treatment (170℃ 7 h, air cooling).

**Table 1. Composition of the composites (wt.%)**

| Samples | $Al_3Ti$ | $TiB_2$ | Matrix |
|---|---|---|---|
| 0-0# | 0 | 0 | Si: 7<br>Mg: 0.4<br>Al: Bal. |
| 5-0# | 5 | 0 | |
| 4-1# | 4 | 1 | |
| 3-2# | 3 | 2 | |
| 2-3# | 2 | 3 | |
| 1-4# | 1 | 4 | |
| 0-5# | 0 | 5 | |

The phases and microstructure of samples were examined by X-ray diffractometer (XRD, Bruker D8 ADVANCE) and scanning electron microscopy (SEM, SU3500). Flat specimens (gauge length×width×thickness: 20×4×3.5mm) were tensile tested by using a testing machine (CMT5305, MTS, USA) equipped with an extensometer at a constant cross-head speed of 0.5mm/min.

## 3 Result and discussion

### 1. Phase analysis and microstructure

Figure 1 shows the XRD patterns of T6-samples. As shown in Figure 1, Al, Si, in-situ formed $Al_3Ti$ and $TiB_2$ phases were found in the composites. Owning to the low Mg content (0.4%), the diffraction peak of $Mg_2Si$ cannot be detected in the matrix. The SEM images of the composites are shown in Figure 2(a-f). It can be clearly seen that in $Al_3Ti$-containing composites, the in-situ formed $Al_3Ti$ particles were distributed uniformly in the Al matrix and most of them were located inside the α-Al grains, which showed they could act as heterogeneous nucleating sites [7]. Furthermore, most of $Al_3Ti$ particles were blocky in shape and a few of them had a short rod-like morphology. It should be noted that no large-sized flaky $Al_3Ti$ particles were found in the composites. Here, the formation of modified $Al_3Ti$ particles with uniform distribution in the matrix was attributed to the fragmentation and dispersion of $Al_3Ti$ particles by high-intensity ultrasound [4]. In $TiB_2$-containing composites, small-sized $TiB_2$ particles were uniformly dispersed along the grain boundaries of α-Al grains, which is a result of the particles pushing effect during the cooling and solidification process of the composite melt. Similarly, ultrasonic treatment promoted uniform dispersion of $TiB_2$ particles [8].

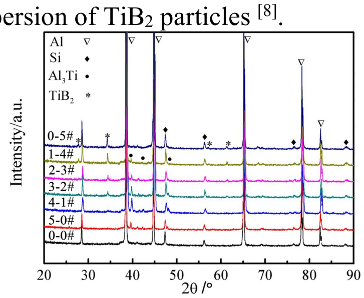


**Fig.1 XRD patterns**

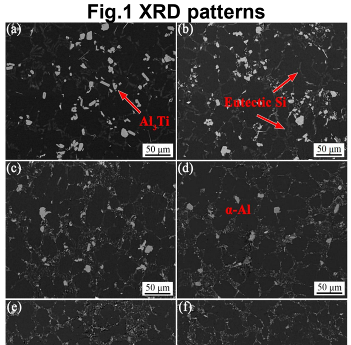


**Fig.2 SEM (BSE) micrographs of the composites: (a) 5-0#; (b) 4-1#; (c) 3-2#; (d) 2-3#; (e) 1-4#; (f) 0-5#**

### 2. Tensile mechanical properties

Figure 3 presents the typical tensile results of T6-samples. As displayed in Figure 3, with the increase of $TiB_2$ content, the values of yield strength (0.2% YS), ultimate tensile strength (UTS) and elongation (El) of T6-samples first increased and then decreased. The mean values of 0.2% YS, UTS and El of the 3-2# composite was 254MPa/310MPa/3.8% (compared to 0-0# matrix alloy, improved by 21.0%/21.6%/111%), which had the best mechanical properties. The improvement of comprehensive mechanical properties of dual-phases reinforced composites was attributed to grain refinement, load-bearing effect, coefficient of thermal expansion mismatch and Orowan strengthening. Furthermore, it can be obviously observed that $Al_3Ti$ contributed to the improvement of the ductility while $TiB_2$ was beneficial for enhancing the yield strength of composites.

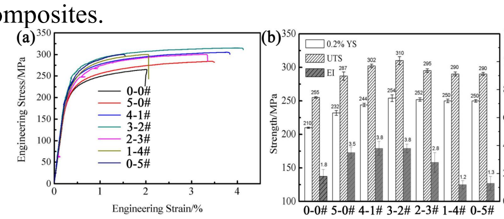


**Figure 3 (a) Engineering stress-strain curves and (b) detailed mechanical properties of T6-samples.**

## 4 Conclusion

In the present work, the dual-phase particles (intragranular-$Al_3Ti$+intergranular-$TiB_2$) reinforced Al-7Si-0.4Mg matrix composites with high strength and good ductility were successfully prepared using the ultrasound assisted in-situ casting. Most of modified $Al_3Ti$ particles were inside the α-Al grains, while $TiB_2$ particles were mainly located at the grain boundaries of α-Al grains. Both particles were uniformly distributed in the Al alloy matrix as a result of the ultrasonic dispersion. Comparing with the alloy matrix, the ($3Al_3Ti+2TiB_2$)/Al-7Si-0.4Mg composite exhibited the best comprehensive mechanical properties, and its 0.2% YS/UTS/El (254MPa/310MPa/ 3.8%) were improved by 21.0%/21.6%/111%. This work provides a novel composite design approach to achieve a strength-ductility synergetic improvement.

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