

Enhanced microhardness of Al - 5 wt.% TiC composite by alloying with Cu

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ABSTRACT

Aluminum (Al) - based materials are highly demanded for automobiles, transportation, and aerospace etc. In this research, Al - based TiC composites were fabricated using powder metallurgy (P/M) technology from Al, Cu, and TiC powders with the compositions of Al - 5 wt.% TiC, and Al - 5 Cu/ 5wt.% TiC. The composite powders were well mixed and compacted using cold pressing technique with an applied pressure of 500 MPa. The compacted samples were sintered at 550 °C in Ar atmosphere for 1 h. The distribution of TiC particles in the Al matrix was observed using scanning electron microscopy (SEM). The phase formation of sintered composite was characterized using X-ray diffraction (XRD). The results showed that TiC particles homogeneously distributed in the Al matrix. The density of Al -5 wt.%TiC and Al - 5 Cu/ 5 wt.%TiC composites achieved 96.7 and 98.0 % of theoretical density, respectively. The microhardness of pure Al increases from 27 HV to \approx 38 HV when reinforcing with 5 wt.% TiC, whilst that of the Al - 5TiC composite increase to \approx 55 Hv when alloying with 5 wt.% Cu.

Keywords: Al-TiC composite, powder technology, mechanical properties, strengthening mechanism

1. INTRODUCTION

Al - based materials are among the most extensively used as light-weight materials for structural applications due to their high specific strength, superior corrosion resistance and machineability. Most of the industrial sectors, especially the automotive and aerospace industries, are focusing on the reduction of weight of the structures, which is aim to improve the fuel efficiency and reduce climate changing and environmental damage. The greatest weight reduction approach can be achieved by decreasing density, which resulting in a direct weight reduction [1]. Vazuzan reported the possibility of substituting Al for cast iron offers a considerable weight reduction of 12 % for a small economy car (about 100 kg in total) and 15 to 17 % for a diesel truck, which consists of cast iron [2]. Typically, Adebisi et al., [3] calculated that in automobile applications, a 7 kg cast iron brake rotor replaces by an Al - based composites (AMCs) can reduce of 50 wt.%, which can result in a savings of \$1.23 - \$12.25.

Pure Al is a light-weight, soft and ductile metal.

However, mechanical properties of Al can be enhanced by reinforcing with hard materials such as TiC, SiC, B₄C, and Al₂O₃ etc. The strengthening mechanisms of the metal matrix composites (MMCs), in particular AMCs, can be direct or indirect effects. The direct strengthening effect is obtained by transferring load from the soft matrix to the hard reinforcements, whilst indirect strengthening effect is due to the variation of the matrix microstructures such as Orowan strengthening mechanism, grain refinement, dislocation multiplication, etc. by the addition of the reinforcements [4]. TiC is an attractive reinforcement due to its low density, high hardness, melting point, and wear resistance, excellent wettability with molten Al and low chemical reactivity. The improved mechanical properties of Al - based TiC composites depend on the amount and homogeneous distribution of TiC particles [5, 6].

P/M technique is commonly used for the manufacturing of MMCs because it offers several advantages compared to casting technique, such as reduction the possibility of chemical reaction

between the matrix and reinforcement phases, as the fabrication process takes place at low temperatures [6, 7]. In addition, the homogeneous distribution of reinforcements in the MMCs can be achieved by P/M [8]. Finally, the products of P/M are near-net shape, which minimizes the consequence machining process [7, 9 -11].

In this research, Al - based composites were fabricated using P/M technique from Al, Cu and TiC powders. The formation of new phases, microstructure of the composite was investigated after sintering. Effects of Cu alloy element and TiC particles on the mechanical properties of the composites were characterized.

2. EXPERIMENTAL

The starting materials used in this research were Al powder (99.7 % purity, particle size $\leq 44 \mu\text{m}$; Alfa Aesar, U.S), Cu powder (99.5 %, particle size $\leq 149 \mu\text{m}$; Alfa Aesar, U.S), and TiC powder (99.6% purity, particle size $\leq 5 \mu\text{m}$; China). The composition of fabricated composites was corresponding to Al - 5 wt.% TiC and Al - 5 Cu/ 5 wt.% TiC. The mixtures of Al, Cu and TiC powders were homogeneously mixed for 4 h before pressing.

Al based composites powders were compacted at 500 MPa in a stainless-steel die with a diameter of 10 mm. The compacted samples were sintered at 550 °C for 1 h in Ar atmosphere in Nabertherm tube furnace.

After sintering, the phase formation and microstructures of samples were characterized by X-ray diffraction (Bruker D8 Advance diffractometer with Cu K α radiation wavelength of 1.54059 Å), and a field-emission scanning electron microscope (FE-SEM, S4800, HITACHI), respectively. Densities and microhardness of sintered samples were measured using Archimedes' principle and microhardness tester Axiovert 250 with a load of 4.9 N for 10 s, respectively.

3. RESULTS AND DISCUSSION

3.1. Investigation of phase formation

The XRD pattern of the Al - based TiC composites after sintering at 550 °C is given in Figure 1. The XRD pattern of the composite gives only peaks of Al and TiC. The addition of Cu leads to the formation of intermetallic CuAl₂ (θ) in the Al - 5 Cu/ 5 wt. % TiC composite. The θ phase was formed due to the reaction between Cu and Al dur-

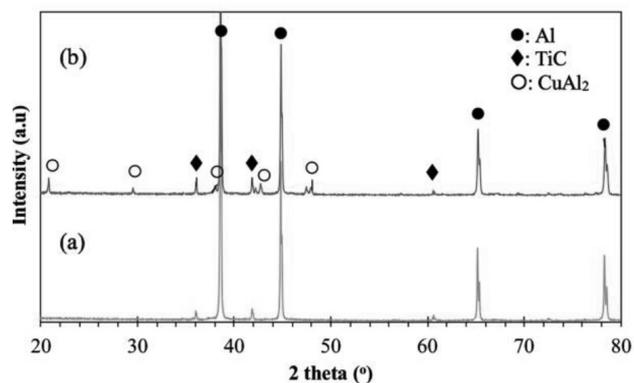


Figure 1. XRD patterns of Al - based TiC composites (a) Al - 5 wt.% TiC composite and (b) Al - 5Cu/ 5 wt.% TiC composite.

ing sintering [12, 13]. No oxidations can be found in the composites. This indicates a good protection against oxygen from the sintering atmosphere.

3.2. Microstructure of Al - 5 wt.% TiC composite

The mechanical properties of composite materials can be affected by several factor such as volume fraction, morphology, rearrangement, distribution of the reinforcements, the interface between the matrix and reinforcement and etc [4, 5, 8, 11, 14]. In this research, in order to obtain a good distribution of the TiC reinforcement particles in the matrix, the mixture of Al - 5 wt.% TiC powder was mixed for 4 h. The SEM microstructure of the Al - 5 wt.%TiC composite after sintering is showed in Figure 2. In general, the TiC particles are homogeneously distributed in the Al matrix. Smaller TiC particles can be agglomerated to form a large cluster, as indicated in Figure 2(a) and Fig. 2(b). Thus, a longer mixing duration or other methods need to be applied in order to break this cluster.

3.3. Mechanical properties of Al based TiC composites

The sintered densities of the Al - based TiC composites and pure Al is relatively high (above 96% of theoretical density), as shown in Table 1.

Densities of the Al - based TiC composites, in this research, are comparable to that of Al - 18 vol.% TiC (96.8 % of theoretical density) [14], and Al - 20 vol.% TiC (96.8 % of theoretical density) [15], which were fabricated using hot pressing. These obtained density values indicate that the

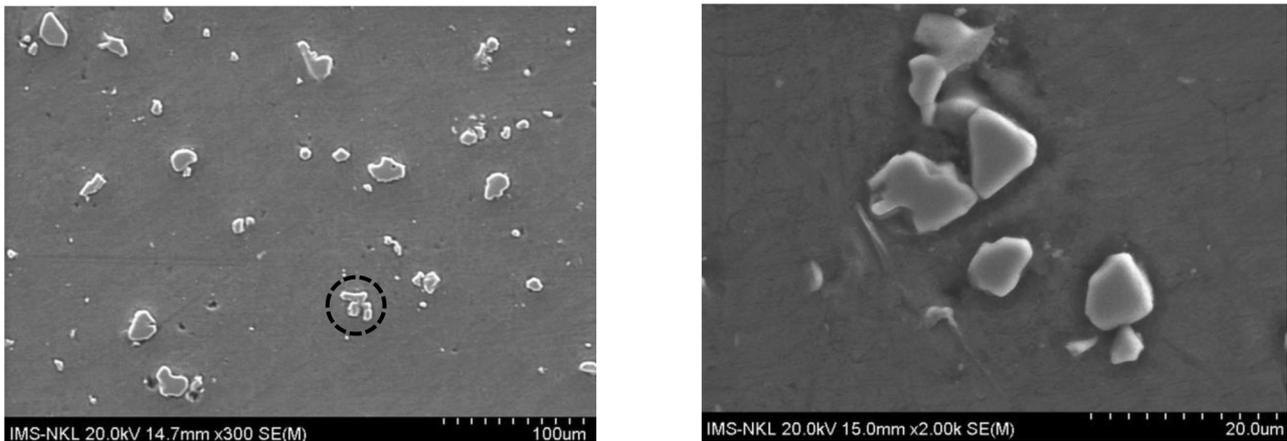


Figure 2. SEM microstructure of Al – 5wt.% TiC composite at different magnifications
 a) X300 and (b) X2000

Table 1. Mechanical properties of Al - based composites

| Samples | Al | Al - 5 wt.%TiC | Al - 5Cu/5 wt.%TiC |
|---------------------------------------|------|----------------|--------------------|
| Relative density (g/cm ³) | 97.0 | 96.7 | 98.0 |
| Microhardness (HV) | 27.0 | 38.2 | 55.2 |

P/M method is a simple technique, which is able to achieve high density for AMCs without the need of expensive equipment such as spark plasma sintering or hot pressing. The microhardness of sintered Al sample is of 27 HV, whilst that of the Al - 5 wt.% of TiC increases to \approx 38 HV. The increase of microhardness can be due to the role of TiC particles in sharing the load from the Al matrix and playing as impedes to the movement of dislocations [16, 17]. The microhardness of the composite further increases when adding 5 wt.% Cu into the composite for alloying the Al matrix. As the results, the microhardness of the Al - 5 Cu/ 5 wt.%TiC composite increases to \approx 55 HV. The

increase of microhardness in this composite can be attributed by the alloying matrix in combination with the formation of hard intermetallic phase. i.e. CuAl₂ [16, 18]. It can be seen that the hardness of the composite significantly enhanced when alloying and reinforcing the Al matrix with Cu and TiC particles.

4. CONCLUSION

High density of Al - based TiC composites can be fabricated by conventional powder metallurgy method in combination with cold pressing at 500 MPa and sintering at 550 °C for 1 h. It found that no reaction between the Al matrix and TiC reinforcement in the Al - 5 wt.% TiC composite. The CuAl₂ intermetallic was formed after alloying the Al matrix with Cu. TiC particles homogeneously distributed in the Al matrix. Microhardness of the Al-based composite reached \approx 38 HV when reinforcing with 5 wt.% TiC, microhardness of the composite further increases to \approx 55 HV when alloying with 5 wt.% Cu.

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