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Estimation of thermal expansion properties of quasicrystalline alloys①

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Abstract: By investigating the thermal expansion properties of three quasicrystalline alloys $Al_{65}Cu_{20}Cr_{15}$ quenched, $Al_{65}Cu_{20}Cr_{15}$ cast and $Al_{65}Cu_{20}Fe_{15}$ cast particles reinforced Al matrix composites from 25 ℃ to 500 ℃, the thermal expansion coefficients of three quasicrystalline alloys were theoretically estimated. The results show that the thermal expansion coefficients of the composites are much lower than that of pure Al, and the thermal expansion coefficients of the composites reinforced by Al-Cu-Cr quasicrystalline particles are lower than those of the composites reinforced by Al-Cu-Fe quasicrystalline particles. According to estimating, quasicrystalline alloys have negative thermal expansion coefficients, and the thermal expansion coefficients of Al-Cu-Cr quasicrystalline alloys are lower than those of Al-Cu-Fe quasicrystalline alloys. In the alloys, the more the qusicrystalline content, the lower the thermal expansion coefficient.

Key words: $Al_{65}Cu_{20}Cr_{15}$ alloy; quasicrystalline alloy; composite; thermal expansion coefficients
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1 INTRODUCTION

Quasicrystalline alloys exhibit rotational symmetries, such as 5, 8, 10 and 12 fold symmetries which are not consistent with periodic structures. They are a relatively new class of materials, first discovered in 1982[1]. Some property data indicated that quasicrystalline materials had lower surface energy[2], high hardness[3-5], low frictional coefficient[6], good hydrogen-storage properties[7] and lower thermal conduction[8]. Recent developments have shown that quasicrystals are promising materials for applications as coatings[9], metal matrix composites[10, 11], hydrogen storage materials[7], thermal barriers[8], and other functional materials.

Some studies of quasicrystalline materials for application as reinforcement for soft matrix materials have been reported. Tsai et al[12] first reported the preparation of the quasicrystalline particle-dispersed Al base composite alloys. They produced the composites by hot pressing a mixture of crushed quasicrystalline $Al_{65}Cu_{20}Fe_{15}$ and pure Al powder, investigated the microstructure and distribution in the matrix materials of the quasicrystalline particles and measured their hardness with different volume fractions. Biner et al[13] had a patent on quasicrystal reinforced Al composites in which the composites were prepared by hot isostatic pressing and the Al-Cu-Fe particles were prepared by gas-atomization technique. QI et al[10, 14] synthesized $Al_{65}Cu_{20}Cr_{15}$ quasicrystalline particle reinforced Al matrix composites by hot pressing technique and the particles were prepared by crushing the conventional cast samples and the melt-spun ribbons, studied the microstructure and phase transformation of quasicrystalline particles and Al matrix during the processing of hot pressing and investigated the evolution of hardness and tribological properties with the particle volume fraction and hot pressing temperature. Fleury et al[11, 15] fabricated Al-Cu-Fe gas-atomized quasicrystalline particle reinforced Al composites by conventional cast process and hot extrusion and reported their properties using continuous ball indentation technique and tensile test method. Bloom et al[16] reported that Al-Cu-Fe/PPS and Al-Cu-Fe/PEKK composites showed improved wear resistance and increased storage modulus compared with unfilled PPS and PEKK samples.

Materials for high temperature environment are required to have a low thermal expansion for dimensional stability. The present work was estimating the thermal expansion coefficients of the quasicrystalline alloys by investigating the thermal expansion properties of Al-Cu-Fe and Al-Cu-Cr quasicrystalline particle reinforced Al composites fabricated by hot-pressing.

2 EXPERIMENTAL

One $Al_{65}Cu_{20}Fe_{15}$ master alloy (P_3) and two kinds of $Al_{65}Cu_{20}Cr_{15}$ master alloys were chosen: one in the as-cast condition (P_1), and the other in the as-quenched condition (P_2). The alloys were melted in a magnetic suspension vacuum furnace. Part of the Al-Cu-Cr alloys were left for the as-cast master specimen

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while the others were cast by melt-spinning in a argon atmosphere of 0.45 MPa using a single copper wheel of 345 mm radius rotating at a speed of 1 800 r/min. These melt-spun samples were used as the as-quenched master specimen. The alloy powder was prepared by first crashing the as-cast master samples and then grinding for 3 h in QM-IST ball mill and sieving them through the 300 mesh sieve with the size of 50 μm. The P_1, P_2 and P_3 powder and commercial pure Al (99.99%) powder with size of 75 μm were mixed in 15%, 20%, 25% and 30% (volume fractions), respectively, and were milled in the ball mill for 30 min. The mixtures were hot-pressed into 25 mm diameter discs of 5 mm in thickness at 550 ℃ under the pressure of 40 MPa for 90 min.

The hot-pressed sample was machined into 5 mm × 5 mm × 15 mm to test the thermal expansion properties with a DIL402C type of thermal expansion coefficient tester. During the test process, the specimen was heated from room temperature to 500 ℃ with the rate of 10 K/min, stayed at 500 ℃ for 10 min, then cooled to room temperature with the same rate. The test data were recorded by computer and the analysis of data was finished with the NETZSCH-Geratebau GmbH thermal analysis.

3 RESULTS AND DISCUSSION

Microstructure of the composites were analyzed by X-ray diffractometry, transmission electron microscopy and electron probe microanalyzer. Quasicrystal contents (volumn fraction, φ_q) in the quasicrystalline particles of the composites are listed in Table 1. The microstructure of the composites is shown in Fig. 1. It is clear that the quasicrystalline particles are uniformly dispersed in Al matrix.

Table 1 Magnitudes of components with quasicrystalline microstructure of three quasicrystalline materials

Alloy	Symbol	φ_q/ %
$Al_{65}Cu_{20}Cr_{15}$ as-cast	P_1	> 60
$Al_{65}Cu_{20}Cr_{15}$ as-quenched	P_2	> 95
$Al_{65}Cu_{20}Fe_{15}$ as-cast	P_3	> 70

The coefficients of thermal expansion (CTE, α) of the three composites as a function of temperature and particle volume fraction gotten from the experimental results of the thermal expansion using NETZSCH-Geratebau GmbH thermal analysis program are shown in Fig. 2. Figs. 2 (a)-(c) show that the variant curves of CTE values of the three composites with

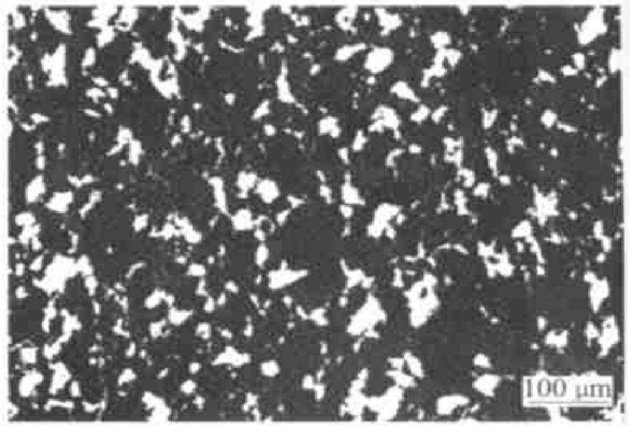

Fig. 1 Microstructure of composites

temperature and particle volume fraction are similar. They are all lower than the CTE value of aluminum, and increase with increasing temperature, but the increasing rate with temperature under 200 ℃ is more rapid than that above 200 ℃, which means that these composites have more stable dimension at elevated temperature. In addition, they all decrease with increasing particle volume fraction, but for $Al_{65}Cu_{20}Cr_{15}$ as cast reinforced composites, the decreasing magnitude of the CTE value is very obvious. For $Al_{65}Cu_{20}Cr_{15}$ as quenched reinforced composites, the CTE values lower obviously when the particle volume fraction is increased from 20% to 25%, almost have no change when from 25% to 30%. For $Al_{65}Cu_{20}Fe_{15}$ as cast reinforced composites, the decreasing magnitude of the CTE value is very little. The variance of CTE values of the three composites with 25% particle volume fraction with temperature is shown in Fig. 2(d), from which it can be seen that above 200 ℃, $Al_{65}Cu_{20}Cr_{15}$ as quenched reinforced composites have the lowest CTE values and $Al_{65}Cu_{20}Fe_{15}$ as cast reinforced composites have the highest CTE values. Therefore, quasicrystalline particles improve greatly the thermal expansion property of aluminium, and $Al_{65}Cu_{20}Cr_{15}$ quasicrystalline materials have better thermal property than $Al_{65}Cu_{20}$- Fe_{15} quasicrystalline materials. The more quasicrystals there are in the particles, the lower CTE values the composites have.

Turner's model assumes homogeneous strain throughout the composite, and uses a balance of internal average stresses to derive the α_c of a two-component composite, which is expressed as follows:

$$\alpha_c = \frac{\alpha_1 \varphi_1 K_1 + \alpha_2 \varphi_2 K_2}{\varphi_1 K_1 + \varphi_2 K_2} \tag{1}$$

where φ is volume fraction; K is the bulk compression modulus; α is the CTE. The subscript 1 designates the quasicrystalline particle and the subscript 2, the matrix.

It is reported that the elastic modulus of Al-

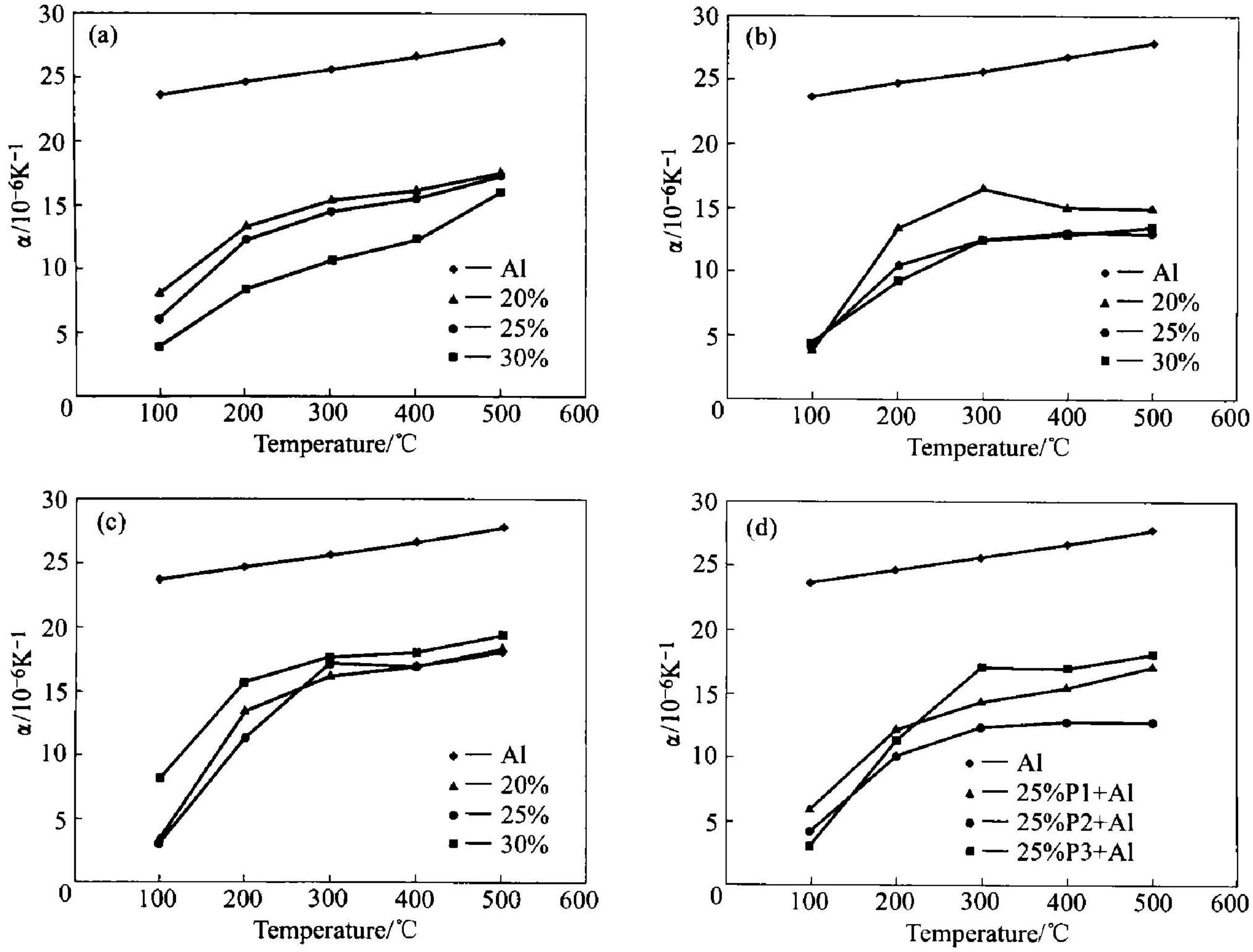

Fig. 2 Variation of coefficient of thermal expansion with temperature
(a) —$Al_{65}Cu_{20}Cr_{15}$ as-cast+ Al composites; (b) —$Al_{65}Cu_{20}Cr_{15}$ as-quenched P2+ Al composites;
(c) —$Al_{65}Cu_{20}Fe_{15}$ as-cast P3+ Al composites; (d) —25% partcles+ Al composites

Cu-Fe quasicrystal is almost the same as that of pure Al metal. So it is assumed that the bulk compression modulus K_1 of Al-Cu-Cr and Al-Cu-Fe quasicrystal equals approximately the K_2 of the Al matrix. Then Eqn. (1) is simplified as follows:

$$\alpha_c = \alpha_1 \varphi_1 + \alpha_2 \varphi_2 \qquad (2)$$

The CTE α_1 of quasicrystal alloy is derived as follows:

$$\alpha_1 = \frac{\alpha_c - \alpha_2 \varphi_2}{\varphi_1} \qquad (3)$$

From Eqn. (3), in which $\alpha_2 = 23.6 \times 10^{-6}$/K. The CTE values of the three quasicrystals alloys for the composite with 25% particle (volume fraction) under different temperatures are calculated and are shown in Fig. 3.

As shown in Fig. 3, the CTE value of quasicrystal alloy is negative and increases with temperature. The CTE value of the $Al_{65}Cu_{20}Cr_{15}$ as-quenched quasicrystal alloy is the lowest and that of the $Al_{65}Cu_{20}Fe_{15}$ as-cast quasicrystal alloy is the highest in the three quasicrystal alloys. The CTE value of the AlCu-Cr quasicrystal alloy is lower than that of the AlCuFe quasicrystal alloy. For the two AlCuCr quasicrystal

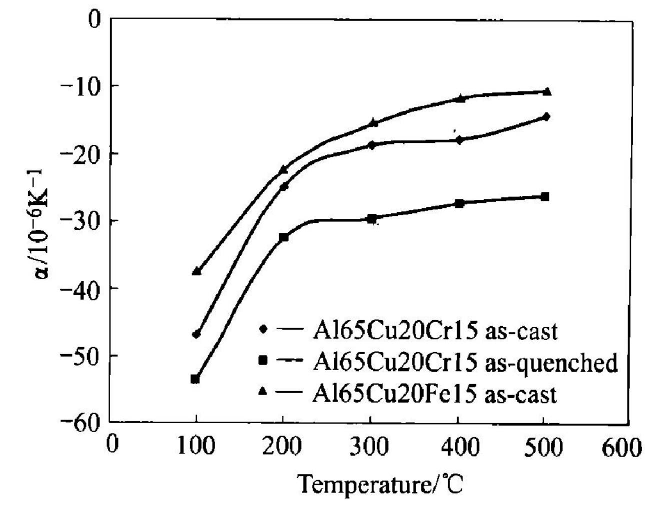

Fig. 3 CTE value of three quasicrystal alloys for composite with 25% particle under different temperature

alloys, the higher the quasicrystal content, the lower the CTE value of the alloy. In fact, the expansionary phenomenon was observed during the cooling of quasicrystal cast. Some physical properties of quasicrystal alloy are different from most crystal alloys such as low thermal conductivity and high resistivity.

4 CONCLUSIONS

1) The thermal expansion coefficients of the composites are much lower than that of pure Al, and the thermal expansion coefficients of the composites reinforced by Al-Cu-Cr quasicrystalline particles are lower than those of the composites reinforced by Al-Cu-Fe quasicrystalline particles.

2) Quasicrystalline alloys have negative thermal expansion coefficients, and the thermal expansion coefficients of Al-Cu-Cr quasicrystalline alloys are lower than those of Al-Cu-Fe quasicrystalline alloys. In the alloys, the more the qusicrystalline content, the lower the thermal expansion coefficient.

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