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Effects of extrusion deformation on mechanical properties of sub-micron Si_3N_{4p}/2024 composite

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Abstract: Si_3N_{4p}/2024Al composite was fabricated by squeeze casting method and treated by extrusion deformation. Microstructure analyses indicate that Si_3N_4 particles in the composite are in cylindrical polyhedron shape. Extrusion deformation is beneficial to uniform distribution of Si_3N_4 particles and improves the relative density of Si_3N_{4p}/2024Al composite. Tensile strength of Si_3N_{4p}/2024Al composite increases by 76.6% after T6 treatment, and after extrusion and T6 treatment it is by 57.6% more than T6 treatment only. Elastic modulus of Si_3N_{4p}/2024Al composite increases a little after T6 treatment but increases by 33.5% after extrusion deformation.

Key words: Si_3N_{4p}/2024Al composite; extrusion deformation; mechanical properties

1 Introduction

Si_3N_4 particles reinforced light metal (Al, Mg, Ti) composites, which have excellent properties such as low cost, high modulus, high specific strength, high wear resistance and easy fabrication[1−3], have been attached much attention. They show important applicable prospects in aerospace, automotive engine and other industries, while have been applied in civil fields by American and Japan, such as piston-connecting rod of automobile and brake disc[4−6].

Organic precursor infiltration method[5] and pressureless infiltration method[7] were used to fabricate Si_3N_4/Al composite. However, micro-cracks trend to form in Si_3N_4 network structure in organic precursor infiltration method. Moreover, the process of organic precursor infiltration method is complex and the preparation temperature is high (800−1 400 ℃ for precursor fabrication and over 840 ℃ for Al infiltration), which leads to serious burning of alloy. Furthermore, Al_2O_3 or ZrO_2 should be added as sintering agent, which changes the Al alloy components and decreases the composite properties. WANG et al[7] reported fabrication of Si_3N_4/Al-Mg composite by pressureless infiltration method. However, the reactant between Al-Mg alloy and Si_3N_4(AlN) is necessary for Al infiltration, which restrict the selection of Al alloy. Furthermore, similar to organic precursor infiltration method, composite fabrication temperature is also very high (over 1 200 ℃ for better wettability), and addictives are indispensable, which are harmful to composite properties. Fortunately, squeeze casting method is an effective method to fabricate composite when wettablity between matrix and reinforcement is poor, just as Si_3N_4 and Al system[8].

Generally, the application of ceramic particles reinforced metal matrix composites is limited because ceramic particles will cause the plasticity of composites to decrease. Many documents report that the plasticity of composites decreases by 10 times compared with metal matrix, which is unfavorable to safety. Fortunately, hot-extrusion, which is easy in process, could improve relative density and interface bonding between particles and matrix, leading to improvement in strength and plasticity. The composite was subjected to three direction press stress, which can prevent crack formation and improve plasticity of composites and formation properties[9−11].

In this work, the authors fabricated 36% (volume

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fraction) Si_3N_{4p}/2024Al by squeeze casting method, and the effects of T6 treatment and extrusion deformation on its mechanical properties were discussed.

2 Experimental

High-purity Si_3N_4 ceramic particles (0.2 μm, 36%) were used to reinforce 2024Al alloy by squeeze casting method. The morphologies of Si_3N_4 particles are in cylindrical polyhedron shape, as shown in Fig.1. The composite was extruded with an extrusion ratio of 10:1.

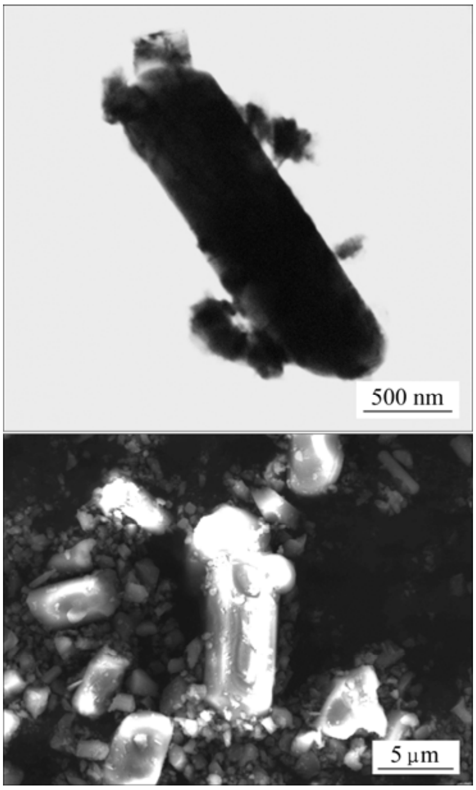

Fig.1 Morphologies of Si_3N_4 ceramic particles

Rod specimens after hot extrusion were chosen for tensile test using INSTRON 5569 universal test machine. The standard distance was 15 mm. In order to ensure reliable results, every group contained 5 specimens, and obtained the average result was obtained. The morphology of particles and fractured surfaces of tensile specimens was observed using an S-2570 scanning electron microscope (SEM). The further observation is conducted by Philips CM12 transmission electron microscope (TEM) with an accelerate voltage of 120 kV.

3 Results and discussion

Optical microstructures of as-cast and extruded Si_3N_{4p}/2024Al composites are shown in Fig.2. The light area is lack of Si_3N_4 particles while the dark area is enriched. Si_3N_4 particles are nonuniformly distributed in

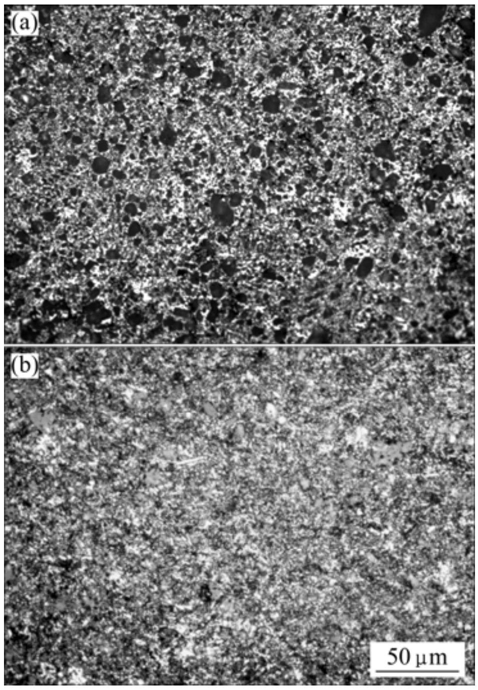

Fig.2 Microstructures of as-cast and extrusion Si_3N_{4p}/2024 composite: (a) As-cast composite; (b) Extruded composite

as-cast composite. Extrusion improves the distribution of Si_3N_4 particles in composite and decreases “island clusters” existing in as-cast composite.

Improving matrix mechanical properties via heat treatment is an effect way to strengthen composite [12−14]. Precipitations in matrix, which impede dislocation movement, would improve the composite strength. Aging process for two main precipitation phases $Al_2CuMg(S')$ and $CuAl_2(\theta')$ in 2024Al is as follows:

$\alpha \rightarrow \alpha$+GP zone$\rightarrow \alpha+S'' \rightarrow \alpha+S' \rightarrow \alpha+Al_2CuMg$ (flake)

$\alpha \rightarrow \alpha$+GP zone$\rightarrow \alpha+\theta'' \rightarrow \alpha+\theta' \rightarrow \alpha$+Cu Al_2 (massive)

Firstly, GP zone, which is completely coherent with Al matrix, forms through the segregation of quenched-in vacancies. Then, S' phase, which is still coherent with Al matrix, forms based on the GP zone or other defect zone and grows up to form stable S phase which is semi-coherent with matrix. Orthorhombic S', which is trend to nuclear at dislocations or low angle grain boundary, is the main strengthening phase in Al alloy. The formation process of θ phase is similar to S phase. These transition phases retain a coherent lattice relationship (S'' and θ'') or semi-coherent lattice relationship (S' and θ'), and generate coherent strain regions in matrix, leading to lattice elastic distortion, impeding dislocation movement and finally strengthening matrix and composite.

Fig.4 shows tensile strength of Si_3N_{4p}/2024Al

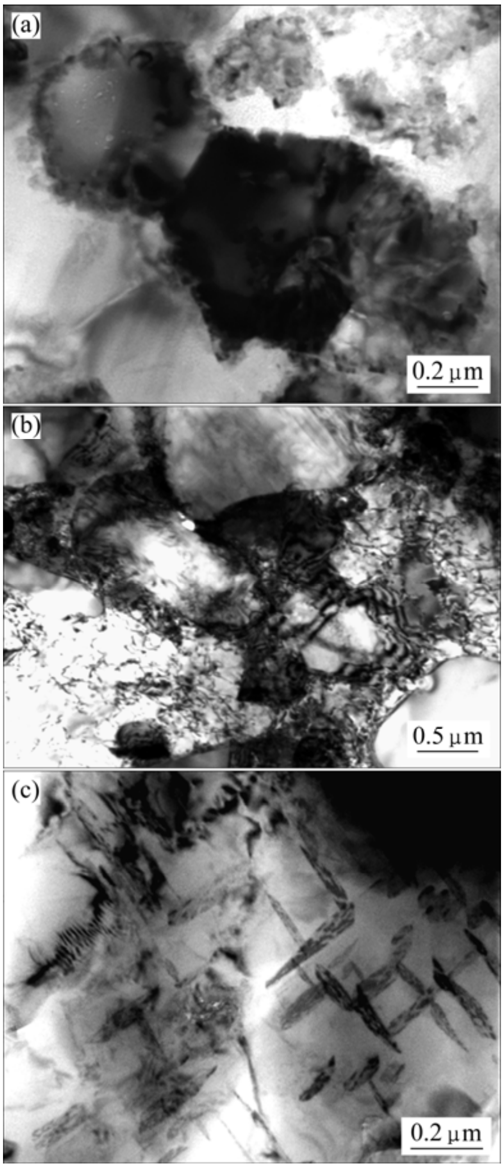

Fig.3 TEM images of as-cast and extruded Si_3N_{4p}/2024 composite: (a) As-cast composite; (b) Extruded composite; (c) Extrusion and T6 treated composite

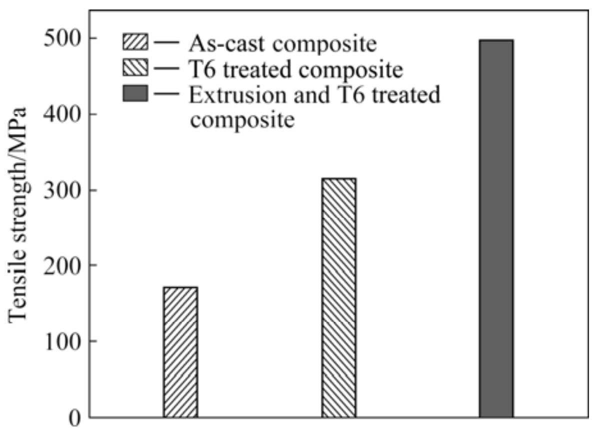

Fig.4 Tensile strength of composite

composites by different treatments. The tensile strength of as-cast composite is 178.7 MPa, and increases by 76.6% to 315.5 MPa after T6 treatment, which should be attributed to precipitation strengthening after T6 treatment. While after extrusion deformation and T6 treatment, it improves by 57.6% compared to T6 treatment. Generally, mechanical properties of composite depend on matrix reinforcement and their interface. The interface plays very important role in load transferring, while the mechanical properties of composite are unsatisfactory when the interfacial bonding is too weak or too strong[15−16]. Due to poor wettability between Si_3N_4 particles and Al matrix, the interfacial bonding is weak in as-cast composite. However, extrusion deformation improves the interfacial bonding, which leads to improvement of mechanical properties.

Fig.5 shows elastic modulus of Si_3N_{4p}/2024Al composites by different treatments. The elastic modulus of as-cast Si_3N_{4p}/2024Al composite is 113.6 GPa, and increases a little to 115.1 GPa after T6 treatment. The study of aluminium borate whisker reinforced Al matrix composite by FEI et al[17] has shown that a little interfacial reaction could improve composite elastic modulus by reinforcing interfacial bonding. The study of SiC_p/Al composite by FAN et al[18] has confirmed that the effect of load transferring by interface could influence composite elastic modulus. The extrusion can improve interface bonding of particles and matrix, and elastic modulus increases obviously to 151.7 GPa after extrusion and T6 treatment.

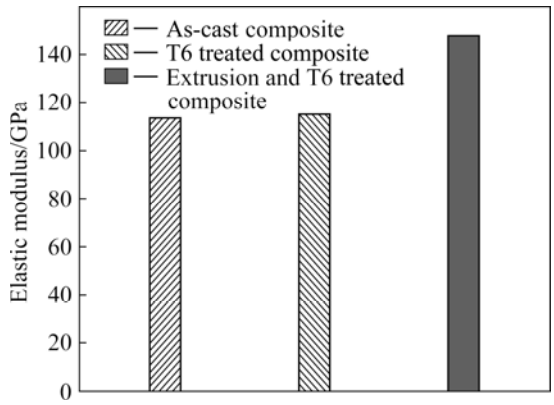

Fig.5 Elastic modulus of composite

SEM analysis is an effective method to investigate the mechanism of composite failure, such as crack generation, extension, material deformation and fracture. The tensile fractured surface morphology of Si_3N_{4p}/2024Al composite is shown in Fig.6. There are large plastic deformations in Al matrix, and plenty of tearing ridges and dimples in fractured surface. Dimples are usually related to the second phase particle in the

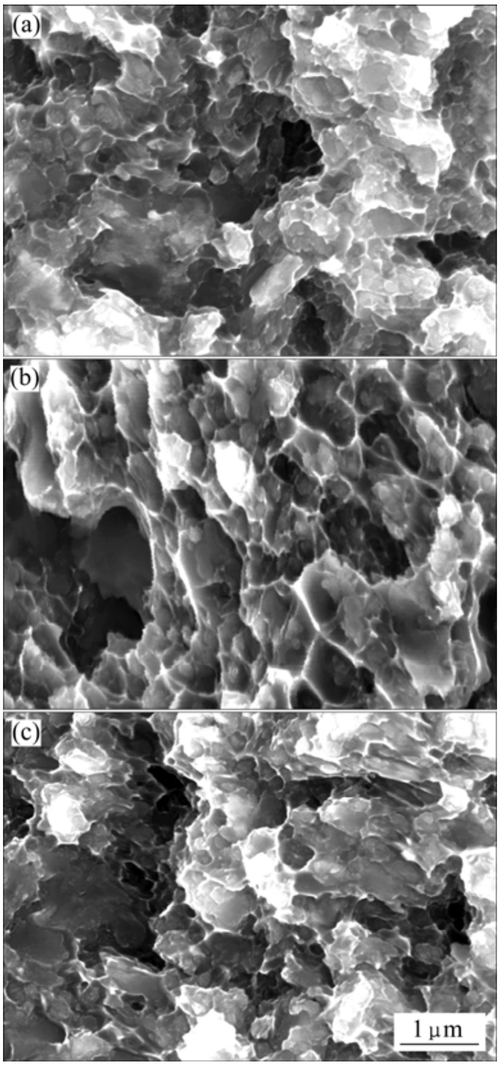

Fig.6 Tensile fractured surface morphologies of composite: (a) As-cast composite; (b) T6 treated composite; (c) Extrusion and T6 treated composite

material. Dislocations movement is hindered by Si_3N_4 particles and form dislocation loops around particles. These dislocation loops are obstacles for subsequent dislocations.

The more the deformation, the more the dislocations pile-up generates around particles. The dislocation is subjected to two kinds of force[9]: one is that dislocation is pushed into particles by the dislocation source; the other is that the leading dislocation is rejected by the particle blocking. When the extra force is strong or the stress of dislocation pile-up around particles is high enough, debonding at interface produces and micropore form. The obstacle of dislocation pile-up group tip disappears because of micropore formation. The front dislocation disappears in cracks, and the behind dislocation moves forward continuously because of losing repulsive force, and finally micropores grow up and form dimples. The tensile fractured surface of composites after extrusion and T6 treatment shows that the better plastic deformation property is shown by more dense fine dimples and tearing edges.

4 Conclusions

1) Ceramic particles are in cylindrical polyhedron shape, and they distribute inhomogeneously in the as-cast composite. However, the reinforcement distributes uniformly in the composite after extrusion, and the “island clusters” decrease obviously.

2) The tensile strength of as-cast Si_3N_{4p}/2024Al composite is 178.7 MPa; and increases by 76.6% to 315.5 MPa after T6 treatment; and further increases by 57.6% to 497.1 MPa after tensile and T6 treatment.

3) The elastic modulus of Si_3N_{4p}/2024Al composite is 113.6 GPa, and increases a little to 115.1 GPa after T6 treatment, and increases greatly to 151.7 GPa after extrusion and T6 treatment.

4) There is great plastic deformation in Al matrix, and a lot of tearing ridges and dimples in fractured surface. The tensile fractured surface of composite shows better plastic deformation after extrusion and T6 treatment.

References

[1] HAN I S, SEO D W, KIM S Y, HONG K S, GUAHK K H, LEE K S. Properties of silicon nitride for aluminum melts prepared by nitrided pressureless sintering [J]. Journal of the European Ceramic Society, 2008, 28: 1057−1063.

[2] HUANG H, WINCHESTER K J, SUVOROVA A, LAWN B R, LIU Y, HU X Z. Effect of deposition conditions on mechanical properties of low-temperature PECVD silicon nitride films [J]. Materials Science and Engineering A, 2006, 435/436: 453−459.

[3] CARRASQUERO E, BELLOSI A, STAIA M H. Characterization and wear behavior of modified silicon nitride [J]. International Journal of Refractory Metals and Hard Materials, 2005, 23(4/6): 391−397.

[4] WANG Y W, YU X D, WANG F C. Mechanism of reaction infiltration of pressureless infiltrated Si_3N_4/Al composite [J]. Rare Metal Materials and Engineering, 2007, 8(36): 777−780.

[5] WU R, WANG Y H. Study on material Al-Si_3N_4 infiltration technique [J]. Mining and Processing Equipment, 2007, 8(35): 122−124.

[6] WANG Yang-wei, WANG Fu-chi, YU Xiao-dong. Study of interface reaction in the Si_3N_4/Al composite prepared by pressureless infiltration [J]. Journal of Aeronautical Materials, 2006, 26(1): 55−58. (in Chinese)

[7] WANG S R, WANG Y Z, WANG Y, GENG H R, CHI Q S. Microstructure and infiltration kinetics of Si_3N_4/Al-Mg composites fabricated by pressureless infiltration [J]. Journal of Materials Science, 2007, 42: 7812−7818.

[8] DE LA PEÑA J L, PECH-CANUL M I. Reactive wetting and spreading of Al-Si-Mg alloys on Si_3N_4/Si substrates [J]. Materials Science and Engineering A, 2008: 491(1/2): 461−469.

[9] SARAVANAN R A, SURAPPA M K. Fabrication and characterisation of pure magnesium-30 vol.% SiC_P particle composite [J]. Materials Science and Engineering A, 2000, 276(1/2): 108−116.

[10] BENGTSSON M, BAILLIF M, OKSMAN K. Extrusion and mechanical properties of highly filled cellulose fibre-polypropylene composites [J]. Composite A, 2007, 38(8): 1922−1931.

[11] RAMESH C S, SAFIULLA M. Wear behavior of hot extruded Al6061 based composites [J]. Wear, 2007, 263(1/6): 629−635.

[12] ODESHI A G, OWOLABI G M, SINGH M N K, BASSIM M N. Deformation and fracture behavior of alumina particle-reinforced Al 6061-T6 composite during dynamic mechanical loading [J]. Metallurgical and Materials Transactions A, 2007, 38(11): 2674−2680.

[13] ZHANG Q, WU G H, JIANG L T. Tensile deformation behavior of a sub-micrometer Al_2O_3/6061Al composite [J]. Materials Science and Engineering A, 2008, 483/484: 281−284.

[14] BEFFORT O, LONG S Y, CAYRON C. Alloying effects on microstructure and mechanical properties of high volume fraction SiC-particle reinforced Al-MMCs made by squeeze casting infiltration [J]. Composites Science and Technology, 2007, 67(3/4): 737−745.

[15] KANAGARAJ S, VARANDA F R, ZHILTSOVA T V. Mechanical properties of high density polyethylene/carbon nanotube composites [J]. Composites Science and Technology, 2007, 67(15/16): 3071−3077.

[16] ZHANG X H, XU L, DU S Y. Fabrication and mechanical properties of ZrB_2-SiC_w ceramic matrix composite [J]. Materials Letters, 2008, 62(6/7): 1058−1060.

[17] FEI W D, JIANG X D, LI C, YAO C K. Effect of interfacial reaction on the Young's modulus of aluminum borate whisker reinforced Al composite [J]. Journal of Materials Technology, 1999, 89/90: 513−519.

[18] FAN Jian-zhong, YAO Zhong-kai, DU San-yi. Research on relationship between elastic modules and interfacial bonding in SiCp particle reinforced metal matrix composites [J]. Acta Materiae Composite Sinica, 1998, 15(2): 1−5. (in Chinese).

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