FRACTURE MODE AND PROCESS OF SiC_w+ B_4C_p/ MB15 MAGNESIUM MATRIX COMPOSITE ①

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ABSTRACT The mechanical properties of the SiC_w+ B_4C_p/ MB15 extruded composite made by liquid infiltration technique were tested. It is concluded that the strength and E-modulus of the composite are much higher than those of its matrix alloy by analysing its fracture appearance and fracture process observed with SEM; the fracture mode is the combination of cleavage and fibrous mode; cracks pass through whiskers in the fracture process which can be divided into three stages: void initiation, second critical elongation and crack buckling expansion.

Key words magnesium composites SiC whiskers B_4C particles fracture

1 INTRODUCTION

Discontinuously reinforced magnesium composites are drawing more attention owing to their good properties[1-4], such as high strength, low density, wear-resistance, high temperature resistance and good secondary workability. A series of SiC_p reinforced magnesium composites developed by Dow Chemical Co. have much higher strength and E-modulus than its matrix alloy. In addition, SiC particles improve wear resistance and high temperature properties of the matrix. Compared with fiber reinforced composite, the discontinuously reinforced composite is isotropic. The company has also made oil pump parts such as shells, case covers and pressure reducing valves.

Thus, this kind of composite opens up a new field of applications. However, the fracture of this kind of material is rarely studied, in addition, the fracture process has become more complicated due to the different matrix alloy, interfacial reactions and precipitated phases. Therefore it is necessary to further study the problems in order to manufacture the materials of both good property and safety.

2 TESTING METHOD

2.1 Testing materials and fabrication

Matrix alloy: MB15(5% ~ 6% Zn, 0.3% ~ 0.9% Zr) with 1.83 g/cm^3, higher strength and modulus, and used widely as aerospace structural material.

Reinforcements: SiC whiskers and B_4C particles were mixed at the volume ratio of 1∶1, and their volume fraction is 24% in the composite. The basic properties are shown in Table 1. SiC whisker is needle-shaped single-crystal with very high strength, B_4C particle is rhombic, and has high hardness and stable chemical property under high temperature.

Table 1 Properties of SiC_w and B_4C_p

Fiber or particle	Length /μm	Diameter /μm	Ratio of l/d	Density /g·cm^{-3}	Strength /GPa	E-modulus /GPa
SiCw	30~ 100	0.1~ 1	20	3.2	3~ 14	400~ 700
B_4C_p	-	7	-	2.51	≤0.9	35~ 45

The manufacturing process of the composite is that, first, the reinforcements should be

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mixed evenly, so that the preform can be made with certain strength and uniform pores; second, the finished preform is preheated and infiltrated with the melting magnesium alloy under certain pressure, the composite is made by vacuum pressure infiltration process. After extrusion (the extrusion ratio is 16∶1), the composite is tested and studied.

2.2 Testing method

The metallographic specimen of the composite is burnished and polished by using alcohol as lubricant for protecting specimens from easy oxidation. Testing samples are taken from the extruded material with the direction parrellel to the extrusion. DCS 2000 device was used. The fracture surface was observed on Philips 515 SEM after the gold-spraying protection.

In situ tensile experiments on S-570 which has drawing table are made to observe the tensile fracture process under the quasi-static state tension. When the sample is loaded, the loading speed should be controlled by hand screw to approach the quasi-static state; besides, loads are recorded and the expanding crack is observed in the fracture process.

3 RESULTS AND ANALYSES

The SEM appearances of SiC_w and B_4C_p are shown in Fig. 1, SiC_w is slender with different thickness, B_4C_p is hard black crystal with irregular polygon.

Compared with magnesium alloy ZM5, cast-MB15 and extruded-MB15, the average bending strength of the composite increases by 41.2%, 93.4% and 49.8% respectively, it has been up to 642 MPa; simultaneously, E-modulus rises from 44 GPa for the matrix alloy, to 80.2 GPa for the composite (Table 2). Fig. 2 shows that the unreinforced matrix alloy MB15 is characterized by $MgZn_2$ precipitates on the regular equiaxed grain boundaries after extruding recrystallization; additionally, the excellent properties of the composite were related to the evenly-distributed particles and whiskers parallel to the extrusion direction (Fig. 2(b)).

The fracture surface of bending samples is shown in Fig. 3, fracture begins from flat cleavage plane and reaches the plane with dispersed dimples, then keeps on to the last buckling failure. This indicates that the studied composite has a certain toughness and its fractographic

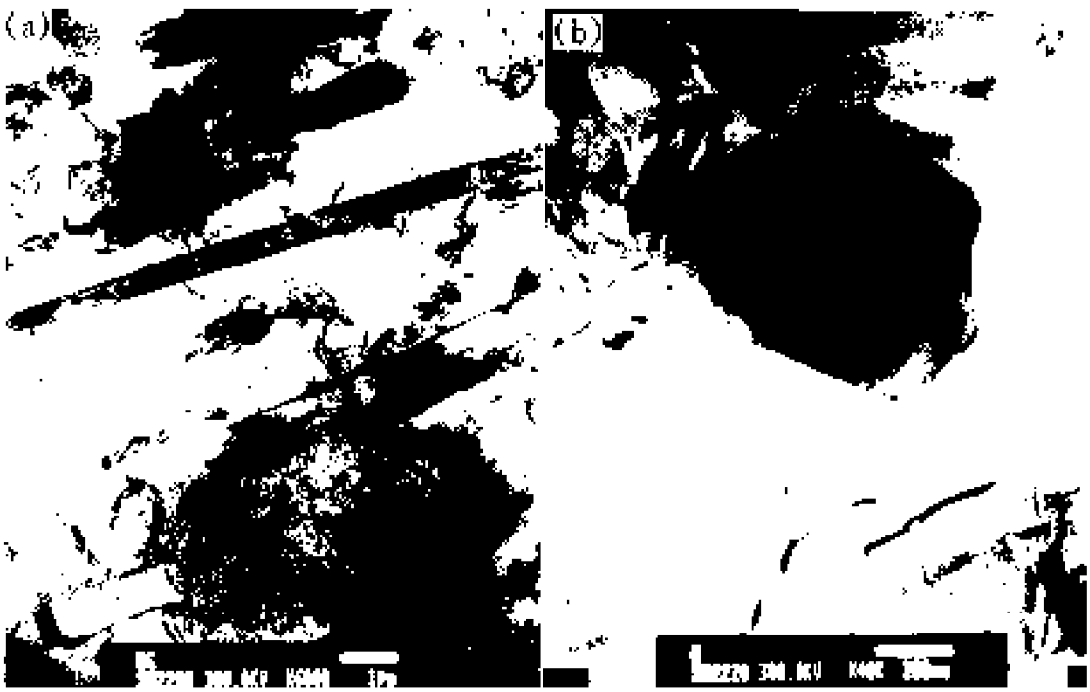

Fig. 1 SEM appearances of reinforcements

(a) —SiC_w; (b) —B_4C_p

Table 2 Mechanical Properties Comparison of several materials

Material	Bending strength / MPa	E-modulus / GPa
ZM5	454.8	43.1
Cast-MB15	332.0	44
Extruded-MB15	428.8	44
SiC_W+ B_4C_P /MB15	642.2	80.2

mechanism is the combination of cleavage and fibrous modes.

Additionally, whisker ends can be seen from the tensile fracture surface while their other ends stay in the base alloy, particles fall and holes exist as well as the dimples. The above phenomena indicate that there is a moderate bonding between the whiskers and the matrix, and it makes the load transfer effectively from the matrix to the whiskers through their interface and leads to the last fracture of the whiskers. Holes and dimples observed in the material are related to the particles and short whiskers' failing. Due to the mismatch of expansion coefficients of the phases, particles or short whiskers debonded from matrix and voids form and grow with increasing stress, as a result, dimples are formed and can be observed on the fracture surface.

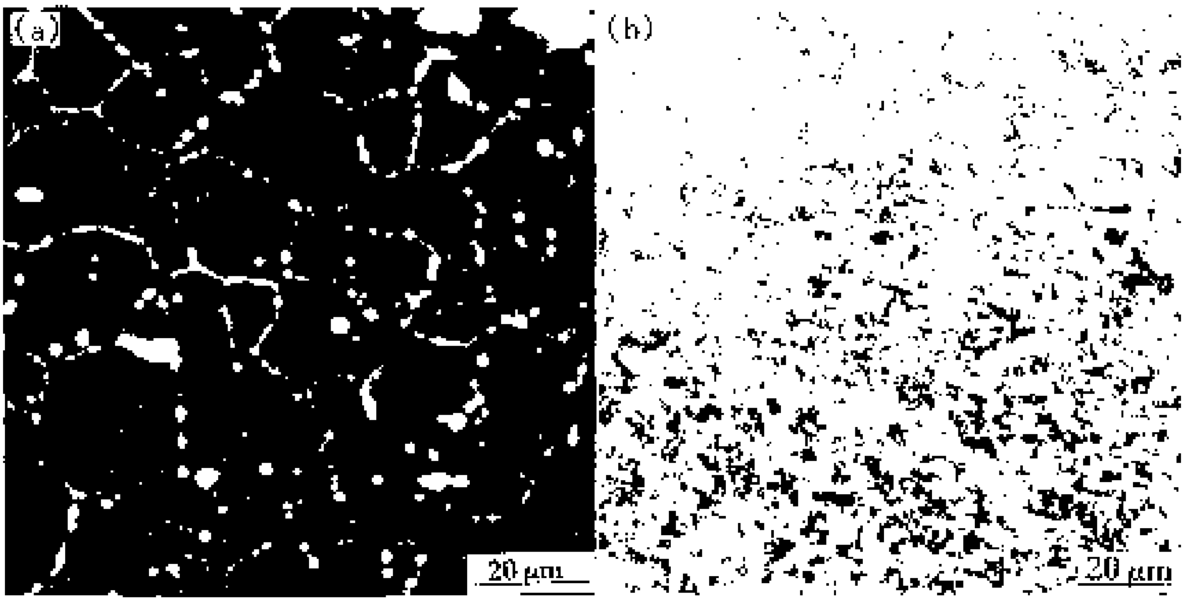

Fig. 2 Metallographs of matrix alloy and composite
(a) —Extruded-MB15; (b) —Composite

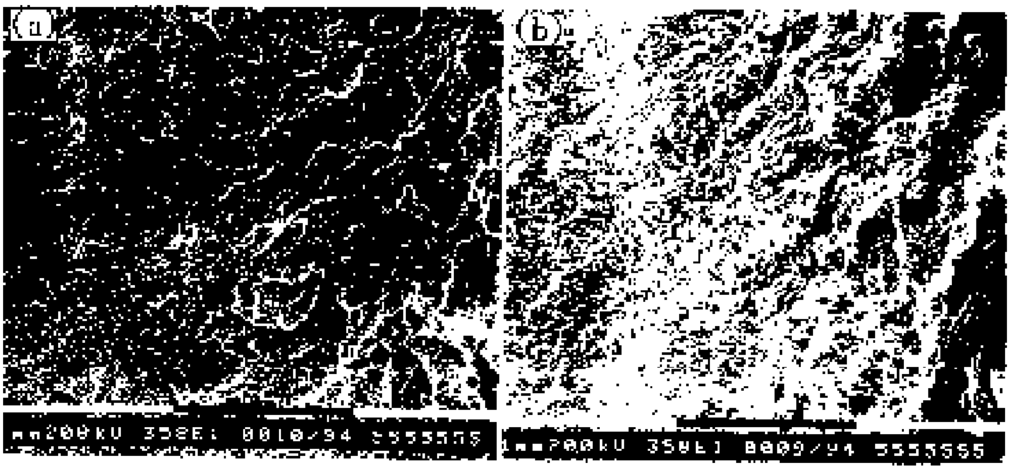

Fig. 3 Fracture appearance of bending samples

In situ scanning electron microscopy fracture studies were also performed (Fig. 5). In the fracture process, the cracks elongate passing through (but not going around) the whiskers and fewer whiskers debond from matrix along the interface, that is, the interfacial bonding strength between whiskers and matrix is higher than the shearing strength of the matrix. It can be inferred from the pictures that voids initiate on the microsplits of the whiskers which are caused by the composite's extrusion, with the expansion and cohesion of the voids, cracks are formed and developed into a passageway of the main crack. In addition, many second-cracks are induced in front of or on both sides of the main crack and they also gather and cohere through the whiskers. From Griffith energy viewpoint, the stress concentration may be relieved with a great number of second-cracks, so this is a secondary critical propagation period during which fracture elastic energy steadily releases to form these new small surfaces, hence the whole fracture speed of the main crack slows down. This shows that the fracture of the composite has the feature of plastic tearing. With the continuing cohesion of the cracks during the last period,

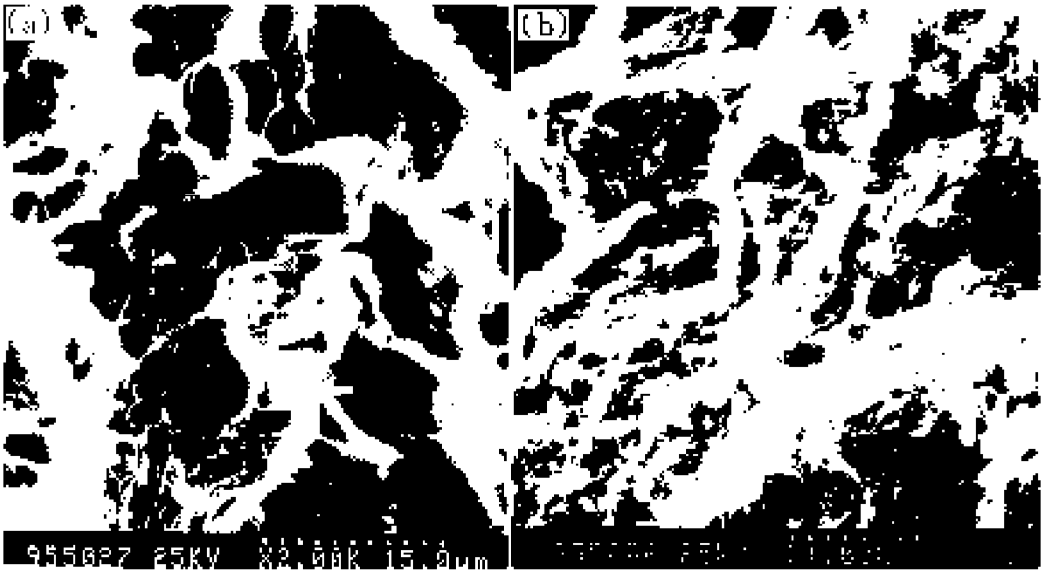

Fig. 4 Fracture appearance of tensile samples

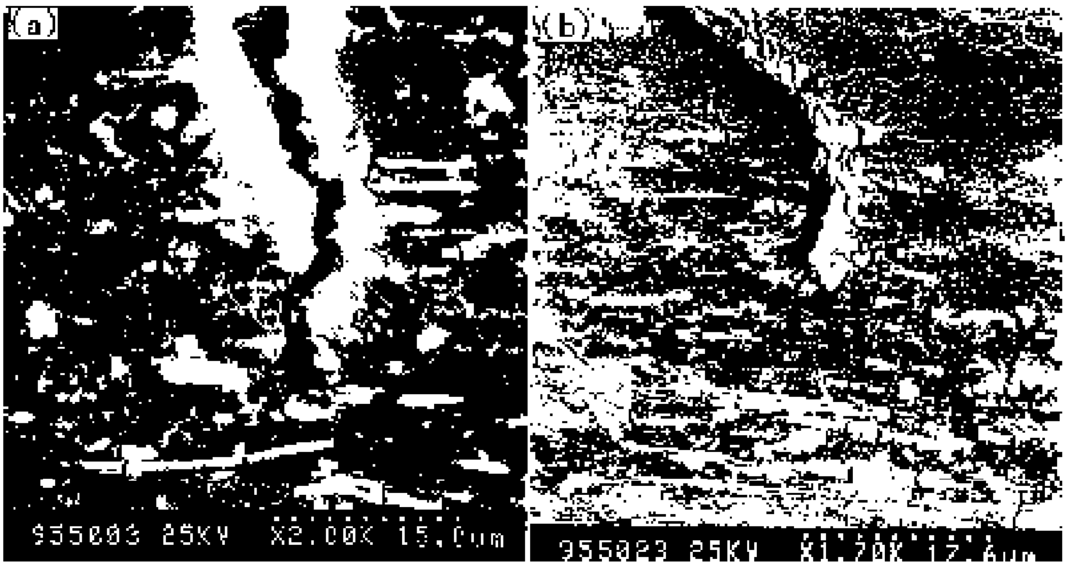

Fig. 5 Fracture process *in situ* tensile experiment

the main crack elongates to the critical size and then completely fails.

In general, the whole fracture process of the composite includes three stages: void initiation, second critical elongation and last buckling fracture of the composite. During the void initiation period, microcracks are induced on the fracture of the whiskers by tensile stress and cohesion of these cracks expand into a passageway of the main crack; During the secondary critical elongation period, the stress ahead of the crack is relaxed owing to the formation of second-cracks and its elastic energy is released with the crack's fracture speed slowing down. In the last period, the expanding speed of the crack increases suddenly and results in the final complete fracture of the composite. However, the first two stages alternate with each other.

Therefore, the fracture strength and the E-modulus of the whiskers are much higher than those of matrix alloy and the whisker plays an important role to bear the load, as a result, the properties of the composite improve greatly.

4 CONCLUSIONS

(1) $SiC_w + B_4C_p/MB15$ extruding composite has higher bending strength and E-modulus than the matrix alloy, evenly-distributed reinforcements in the composite ensure its best properties.

(2) The fracture micromechanism of the composite is a combination of cleavage and fibrousmode; river pattern and dimples appear on the fracture surface. Whisker ends and irregular dimples indicate that bonding between whiskers and matrix is moderate and the composite has certain toughness.

(3) Crack passes through whiskers in the fracture process of the composite in which three stages can be included: void initiation, second critical propagation and last buckling fracture.

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REFERENCES

1 Mikucki B A *et al*. Light Metal Age, 1986, 10: 16 - 20.
2 Mikucki B A *et al*. Light Metal Age, 1990, 6: 12-16.
3 Schroder J *et al*. Mater Sci Eng, 1991, A135: 33-36.
4 Inem B *et al*. J Mater Sci, 1993, 28: 4427- 4434.
5 Badani C *et al*. Mater Sci Eng, 1992, A157: 53-61.

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