IN-SITU SYNTHESIS OF SPINEL WHISKERS REINFORCED ALUMINUM COMPOSITE

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Abstract

$MgAl_2O_4$ whisker reinforced Al matrix composite was prepared by in-situ synthesis method after high-energy ball-milling pretreatment. The distribution and combination of the whiskers were characterized, and the microstructure and mechanical properties of the whisker reinforced Al matrix composite were systematically studied. The results indicate that a large number of $MgAl_2O_4$ whiskers were in-situ generated in the Al matrix. The $MgAl_2O_4$ whiskers break through the Al matrix and exhibit excellent distribution and interfacial bonding with the matrix, so the hardness and the compressive strength of the composite were improved effectively.

1 General Introduction

Ceramic one-dimensional material with high elastic modulus, tensile strength and low thermal expansion properties could be used as reinforcements in composites to increase the wear resistance and strength of metal matrix [1-4]. In general, the metal matrix composites (MMCs) [5-7] reinforced with whiskers is synthesized by either powder metallurgy or casting, but it is difficult to obtain well wettability between the ceramic reinforcement and the metal matrix by externally adding and mechanically mixing, because some inevitable problems arise, such as the agglomeration, poor interfacial reaction and dispersion. Therefore, exploring a new technology that can make the whiskers reinforcement uniformly dispersed and strongly bonded with the matrix is needed for improving the performance and realization of industrialization application of the composites.

Recently, the in-situ generated reinforcement inside the matrix has been applied in some MMCs [8-10], such as Ti and Mg matrix composites, and has shown good results for improving the wettability with the matrixes. However, the research of in-situ growth of whisker reinforced aluminum matrix composites were less reported. In this work, the single crystal spinel ($MgAl_2O_4$) whiskers were synthesized by in-situ method in aluminum matrix, and the composite was prepared by powder metallurgy method. The microstructure and the mechanical properties have been conducted, and the hardness and compressive strength of the composite are investigated. The SEM images show that the $MgAl_2O_4$ whiskers generate inside the matrix during the calcination process. The whiskers have a well combination with the Al matrix, and form a net structure, resulting in the effective enhancement in properties of the composite.

2 Preparations

Aluminum powders, magnesium powder and boric acid were used as raw materials, mixed with a mass ratio of 9:2:2. The mixture was then homogenized in a stainless steel grinding chamber and milled in a planetary ball mill.

The Mg content in the mixed powders is about 15.38% after the milling pretreatment, and the additional pure Al powder was added to control the amount of whiskers formed during sintering. With the change of Al powder mass in the total mixture, the $MgAl_2O_4$ whiskers generated in the matrix is about 1.5~15%.

Subsequently, the green samples were obtained by pressing the composite powders in a steel mold at room temperature, and sintered in argon atmosphere at 800 °C for 1 h. After the growth process of the $MgAl_2O_4$ whiskers, the samples were hot-extruded to obtain the rod samples with 5 mm diameters. As a comparison, the pure Al and Mg-Al alloy samples were prepared under the same process.

The phase identification was conducted using a Rigaku D/max 2500V/pc automated X-ray diffractometer in Cu Kα radiation. The morphology of the composites was characterized by a JEOL S4800 scanning electron microscope (SEM).

3 Results and discussion

After sintered at 800 °C, a large number of whiskers were generated in the Al matrix, and the Al composite was obtained. The whiskers can be observed in the fracture after the samples is broken. The typical morphologies of the whisker products are shown in Fig.1. It can be seen that the straight whiskers with diameter of 0.2 to 2 μm dispersing in the aluminum matrix, and all the whiskers have a flat top and six smooth sides. Every whisker has uniform size from top to the end, and crystallizes well.

To identify the phase of the whiskers, the composite was grinded to collect the whisker. The XRD pattern of the products is shown in Fig.2. The diffraction peaks in the pattern exhibit a good agreement with the standard spectra of the spinel (JCPDS 21-1152) and aluminum (JCPDS 04-0787) in both the reflection profile and intensity, and no peaks related to by-products was detected.

During the sintering process, the $MgAl_2O_4$ whisker generation process is probably as follows.

$$H_3BO_3 \rightarrow B_2O_3 + H_2O \quad (1)$$

$$B_2O_3 + Al + MgO \rightarrow MgAl_2O_4 + B \quad (2)$$

$$B_2O_3 + Al + Mg \rightarrow MgAl_2O_4 + B \quad (3)$$

The molten B_2O_3 involved in chemical reactions and supplied a liquid-phase reaction environment for the nucleation and generation of the whiskers. The $MgAl_2O_4$ ceramic whiskers were generated in the semi-molten Al matrix, so it is easy to grow into the soft matrix. The Fig.3 shows the whiskers in the Al matrix, which indicated a well combination and wettability between the whiskers and the matrix. Because the $MgAl_2O_4$ whiskers were in-situ synthesized in the matrix, and a matching between whisker and Al matrix interface at atomic level could be achieved. So the $MgAl_2O_4$ whiskers can be covered tightly by the parts of Al matrix, and it shows a small contact angle at the interface between the whiskers and the matrix in Fig.3. The well wettability between the reinforcement and the matrix is important for the composite as the matrix need transfer the stress to the reinforcement through the interface under load and the well combination promotes the transfer efficiency. The in-situ generated $MgAl_2O_4$ whiskers have excellent distribution and interfacial bonding with the matrix, so the hardness and the mechanical properties of the composite were improved effectively.

Fig.4 plots the hardness of the composites containing different amount of $MgAl_2O_4$ whiskers. The hardness of the composite increased linearly with the amount of the whisker rising until the amount of the $MgAl_2O_4$ whisker in the composite achieves 10.5%. Because the $MgAl_2O_4$ whiskers in-situ generated in the Al matrix have a well combination and distribution, the hard ceramic whiskers play an enhanced role in the soft matrix. However, when the content of the whiskers is more than 10.5%, the whiskers tend to form the clusters, and the distribution of the reinforcement becomes uneven, so parts of the enhancement of the hard whisker is ineffective. The curve of hardness of the composite tends to smooth, when the composite contains 15% $MgAl_2O_4$ whiskers, the hardness is nearly 130HV, which reached the highest value.

Fig.5 shows compressive stress-strain curve of the composites. Compared with the pure Al and 5%Mg-Al alloy samples, the addition of whiskers enhanced mechanical properties of the composite significantly. With the increasing of the content of whisker, the strengthen efficiency of the $MgAl_2O_4$ whisker on the Al matrix increased linearly due to in-situ synthesized whiskers having perfect distribution in the matrix. Though the rising of the content of the whisker may lead the whisker to form the clusters, it not affects the enhancement of mechanical properties, and the composite may showed the better performances caused by the effects of the new framework formed by whiskers. The compressive strength of the composite can achieve 400MPa, three times than that of the pure Al, with the content of the $MgAl_2O_4$ whiskers increased to 15%.

4 Conclusions

Homogeneously dispersed $MgAl_2O_4$ whisker reinforcement was in-situ fabricated in Al matrix by powder metallurgy using ball-milled composite powders of metal and boric acid, which provides a new way for in-situ generation of whiskers in the Al matrix. The $MgAl_2O_4$ whiskers have excellent distribution and wettability with the matrix, so the hardness and mechanical properties of the composites were improved effectively. The hardness and compressive strength of the composite contained 15% $MgAl_2O_4$ whiskers can reach 130HV and 400MPa, respectively.

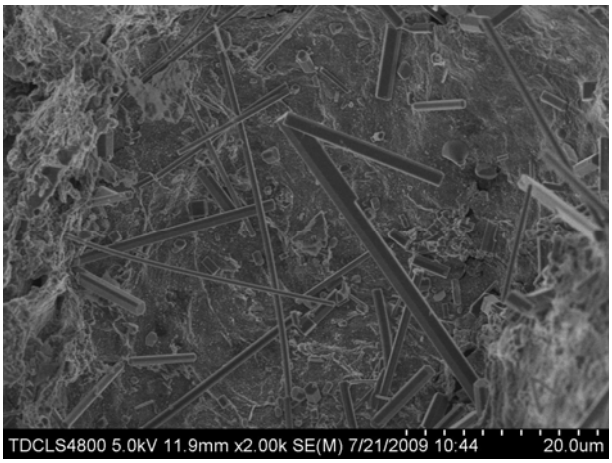

Fig.1 SEM image of the whiskers generated in the Al matrix.

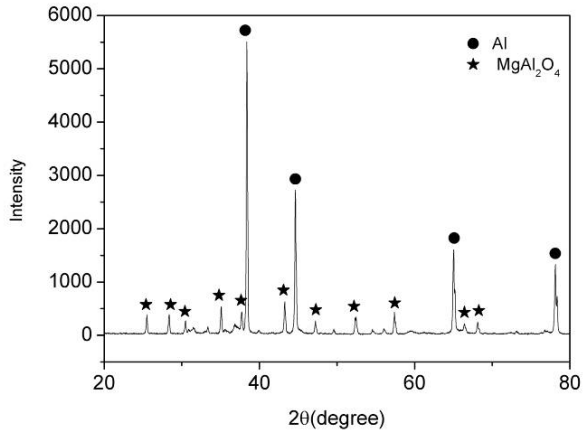

Fig.2 X-ray diffraction pattern of the products obtained after sintered at 800 °C

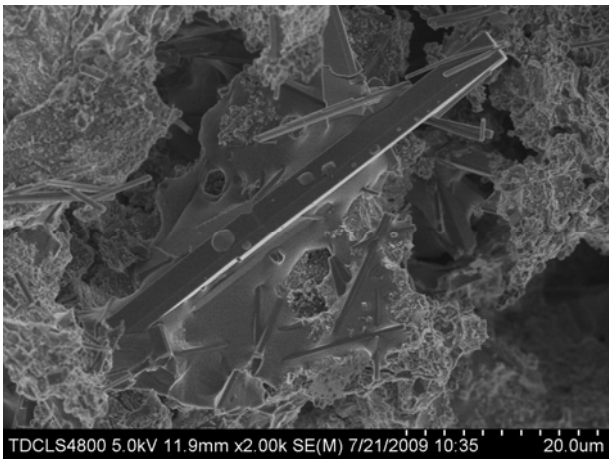

Fig.3 The combination of the $MgAl_2O_4$ whisker and Al matrix.

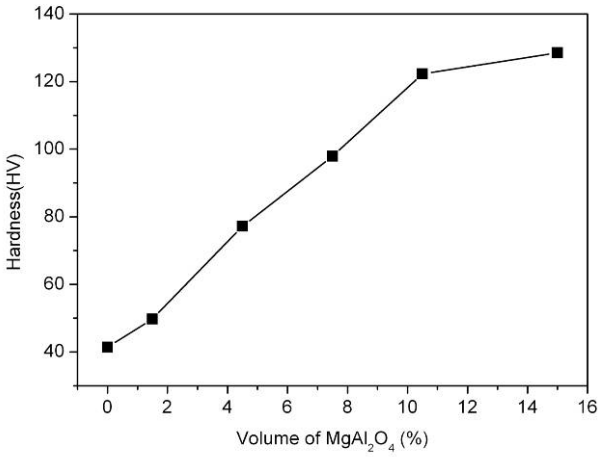

Fig.4 The hardness of the composites with different volume percentage of whiskers.

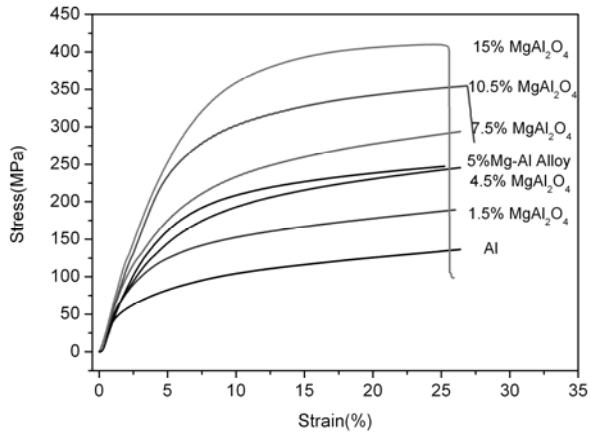

Fig.5 The Stress-Strain curve of the compressive test.

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