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Fabrication of Mo-Ti functionally graded material①

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Abstract: Molybdenum alloys and titanium alloys were sintered at 1 473 K for 1 h under a pressure of 30 MPa. It was found that the addition of Al can increase evidently the relative density of sintered Mo-Fe alloys. The Fe-Al additives are also suitable for the sintering of titanium alloys, and the Mo alloy and Ti alloy can be densified concurrently with the same additives 3 %Fe-1.5 %Al. The experimental results also showed that during the sintering of Mo-Ti alloys the Fe-Al sintering aids promoted the formation of Mo-Ti solid solution, but the solid solution reaction occurred at the low sintering temperature of 1 473 K is inadequate. Finally, Mo-Ti system functionally graded material has been successfully fabricated. Its density changed gradually from 9.52 g/cm^3 to 4.48 g/cm^3 in thickness direction. Such a material can be used in dynamic high-pressure technology.

Key words: molybdenum-titanium; functional gradient alloys; sintering **Document code: A**

1 INTRODUCTION

A new kind of functionally graded materials (FGM) with density gradient will be used in dynamic high-pressure technology[1]. Such FGM can produce quasi-isentropic compression on target materials, providing extreme experimental conditions of pressure or velocity for dynamic physics study[2]. Recently, the research on such FGM of Al-Cu system has been reported[3], but Al and Cu tend to form different kinds of compounds, resulting in brittleness of the materials. It is also difficult to obtain wholly dense Al-Cu system FGM because of great difference in melting temperature between Al and Cu.

Ti is a kind of metals with good plasticity. According to the phase diagram of binary alloy, Ti and Mo have no trend to form compound. Moreover, the density difference between Ti and Mo is approaching to that between Al and Cu. Taking all of above factors into account, the authors study on fabrication of Mo-Ti system FGM with the density gradient in this paper.

To achieve high relative density of sintered compacts, the sintering temperatures of 1 523 ~ 1 573 K are needed for both Mo and Ti alloys[4~6], but the varieties of used sintering additives are different from each other. It is important to choose a new kind of sintering additives suitable for both alloys to fabricate wholly dense FGM of such a system. The sintering activator Fe is effective to some extent on densification of Mo alloys[7]. The literature[8] also illustrates that not only the relative density of the sintered Ti alloys but also their flexural strength can be improved by increasing the amount of alloy additive Fe within 4 %. In addition, Al is a fundamental alloying element in Ti alloys[9]. Based upon the above analysis, the selection of the Fe-Al sintering additives are put forward in this paper for studying on densification of Mo alloys and Ti alloys.

The W-Mo system FGM in higher density range has been successfully fabricated at the same sintering temperature[10]. Therefore, this paper will provide a basis for further fabricating

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wholly dense W-Mo-Ti system FGM with density gradient through one-step sintering on the same conditions.

2 EXPERIMENTAL MATERIALS AND METHOD

The fresh powders of Mo, Ti, Fe and Al with average particle sizes of 2.4, 30, 30 and 20 μm respectively were used. The powders were given in the design ratio, mixed mechanically and blended for enough time to make them homogeneous. The mixture was put into a graphite mould, and sintered under a pressure of 30 MPa at 1 473 K for 1 h in a furnace with a flowing argon. The size of all sintered samples is 20 mm in diameter and 3 ~ 4 mm in height. Their densities were measured by the water-immersion technique.

In preparing the Mo-Ti system FGM, four transient layers were inserted between the Mo side and the Ti side, in which the volume ratios of Mo to Ti took the values of 4∶1, 3∶2, 2∶3 and 1∶4 in turn. The same sintering additives 3% Fe-1.5%Al were used for all sintered layers. To satisfy the condition that such FGM should not be very heavy, the thickness of each transient layer was fixed at 0.15 mm. The microstructures of Mo, Ti and Mo-Ti alloy were observed by scanning electron microscopy (SEM). The area distributions of elements Al, Mo, Ti and Fe in the Mo-Ti alloy, and the line distributions of elements Mo and Ti for the cross-section of Mo-Ti system FGM were examined by X-ray wave-dispersion spectrometry (XRWDS).

3 RESULTS AND DISCUSSION

The relative density of Mo alloy only with 3% Fe sintered at 1 473 K exhibits the low value 89.7% (shown in Table 1). When the Fe content is held at constant, the relative densities of Mo alloys are increased rapidly with addition of Al. It is thought that during sintering the Al particles melted at first, then solved the Fe powders adjacent to them. Consequently, part sintering activator Fe can exist in liquid form, thus improving its sintering activation capability, and this is favorable to advance the relative densities of the Mo alloys. Al and Fe are also of aid to the sintering of the Ti. With 3%Fe-1.5%Al additives the relative density of the Ti alloy even comes up to 99.2%. The microstructure of Mo95.5Fe3Al1.5 alloy is shown in Fig.1(a) and that of Ti95.5Fe3Al is shown in Fig.1(b). The Mo alloy and Ti alloy are concurrently densified with the same sintering aids.

Table 1 Relative density of Mo and Ti alloys sintered at 1 473 K for 1 h under a pressure of 30 MPa

Composition of alloys	Theoretical density /($g·cm^{-3}$)	Measured density /($g·cm^{-3}$)	Relative density /%
Mo97Fe3	10.13	9.09	89.7
Mo96Fe3Al1.0	9.86	9.25	93.8
Mo95.5Fe3Al1.5	9.73	9.52	97.8
Mo95Fe3Al2.0	9.60	9.33	97.2
Ti	4.51	4.29	95.2
Ti98.5Al1.5	4.47	4.38	98.0
Ti95.5Fe3Al1.5	4.52	4.48	99.2

Fig.2 shows the back-scattered electron image of Mo-Ti alloy (in which the volume ratio of Mo to Ti is 2∶3) and area distribution images of elements Al, Mo, Ti and Fe. Since the Fe-Al sintering aids are suitable for both Mo and Ti particles, during sintering Mo and Ti will interact concurrently with the sintering aids, and this will undoubtedly activate the diffusion of Mo and Ti to each other, thus promoting the formation of Mo-Ti solid solution. The fact that the sintering additives Fe and Al just exist more in the matrix of Mo-Ti solid solution than in Mo or Ti verifies the above analysis.

It can also be seen from Fig.2 that part Mo and Ti isolated from one another are scattered in the matrix of Mo-Ti solid solution, which means that at the low sintering temperature (1 473 K) the solid solution reaction occurs between Mo and Ti is inadequate.

The wholly dense Mo-Ti system FGM fabricated is shown in Fig.3. With the decrease of Mo content and the increase of Ti content, the density of the FGM changes gradually from 9.52 $g·cm^{-3}$ to 4.48 $g·cm^{-3}$ within the middle 0.8

mm thickness range (shown in Fig.4).

4 CONCLUSIONS

(1) The addition of Al can increase evidently the relative density of sintered Mo-Fe alloy. With the same sintering additives 3%Fe-1.5%Al, the Mo alloy and Ti alloy can be concurrently densified.

(2) Inadequate solid solution reaction occurred between Mo and Ti in Mo-Ti alloys sintered at 1 473 K. During sintering Fe and Al

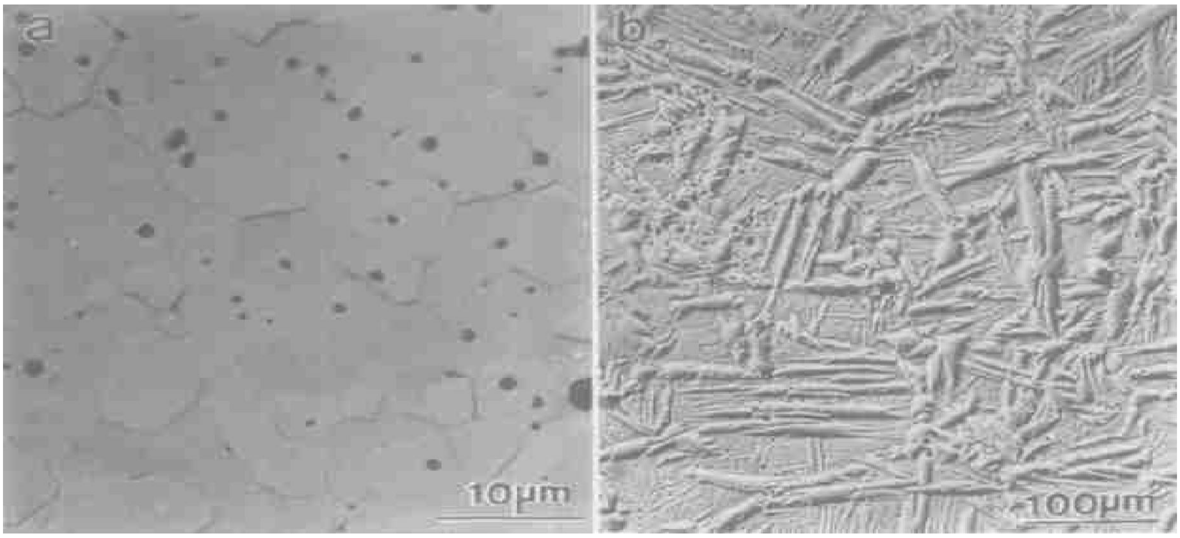

Fig.1 Microstructures of Mo95.5Fe3Al1.5 alloy (a) and Ti95.5Fe3Al1.5 alloy (b) (etched)

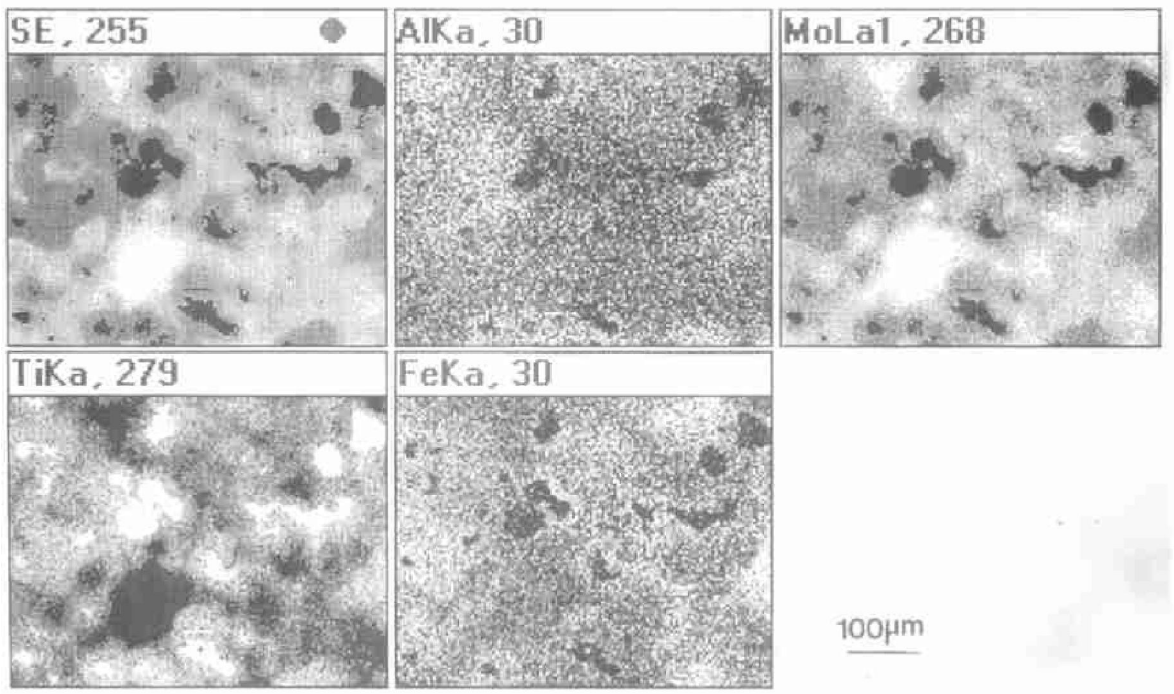

Fig.2 Back-scattered electron image of Mo-Ti alloy and area distribution images of elements Al, Mo, Ti and Fe

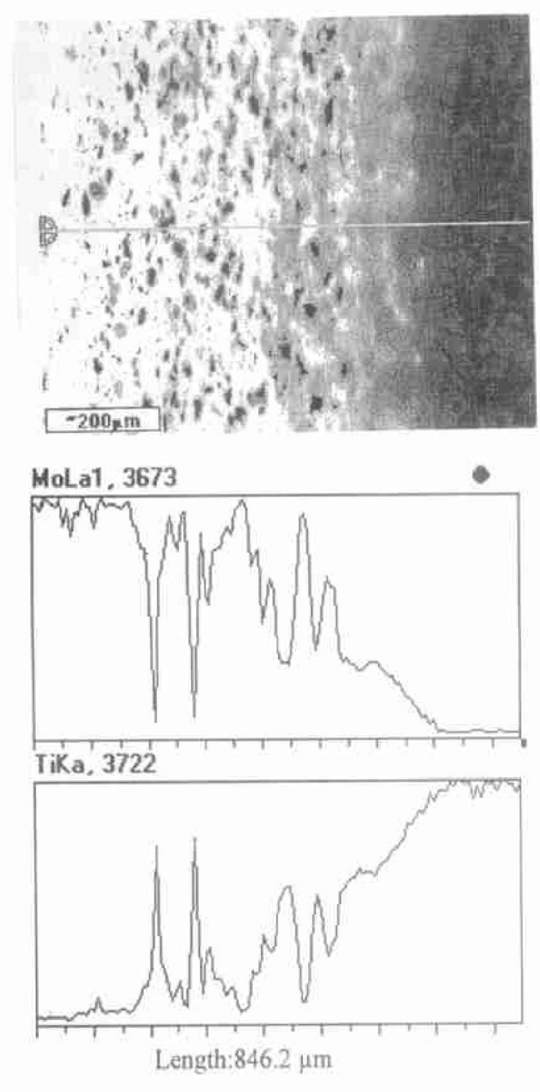

Fig.3 Back-scattered electron image for cross-section of Mo-Ti system FGM and line distribution images of elements Mo and Ti in direction of thickness

promotes the formation of Mo-Ti solid solution.

(3) The wholly dense Mo-Ti system FGM is successfully fabricated. Its density changes gradually from 9.52 g/cm^3 to 4.48 g/cm^3 within the middle 0.8 mm thickness.

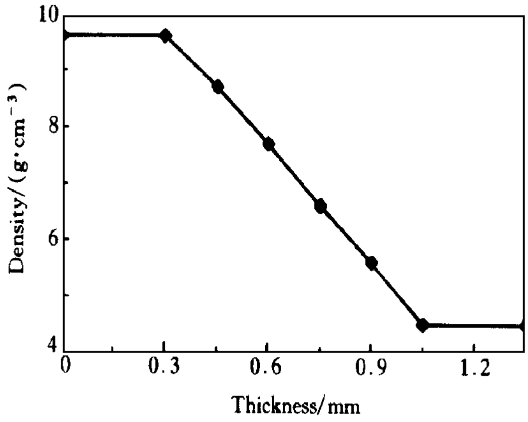

Fig.4 Change of density of Mo-Ti system FGM with its thickness.

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