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Preparation of Ti-Mo system functionally graded materials by co-sedimentation①

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[Abstract] A new kind of method, co-sedimentation method, was used to fabricate functional gradient material(FGM) in order to eliminate the interfaces in gradient materials. The deposit bodies obtained from the sedimentation of Ti and Mo particles were densified at 1 673 K under a pressure of 20 MPa in flowing argon for 1 h. Finally, Ti-Mo system FGM with continuous change of composition was successfully prepared. The results reveal that the sedimentation method is an effective way to manufacture FGM with continuous change of composition. Moreover, the results also show that the compositional gradient of FGM can be adjusted in a wide range through both particle size distribution and the ratio of powders.

[Key words] co-sedimentation; functional gradient material; titanium-molybdenum
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1 INTRODUCTION

Functionally graded materials (FGM) is a new kind of non-homogeneous composites[1]. Widespread attention has been paid to such kind of materials for its superior characteristics and novel design ideas and important application background. It is well known that formation process is one of the key points for the application and development of FGM[2]. To satisfy the needs of different application conditions, many methods such as gas-phase deposition (PVD and CVD)[3], self-propagating high-temperature synthesis (SHS)[4], plasma spraying, powder metallurgy (PM)[5] etc have been recently developed. Particularly, PM is considered to be not only one of more convenient and promising ways to fabricate large tiles but also one of the most popular ways in the research of FGM.

Nowadays, PM method often uses powder-stacking way involving consolidation of layered green compacts, i.e. according to the design request, two kinds of powders are uniformly blended into different ratio mixtures and then the mixtures are stacked layer by layer in a die in turn and finally sintered. Such a stacking way results in component steps in the sintered samples, which limits the exhibition of the superior characteristics of FGM in practical application. Other methods mentioned above are good for microscopic gradient layers under the given conditions, but their own defects such as expensive device and products with high porosity and low strength restrict their practical applications. In order to solve the problem, this article reports a new kind of way, co-sedimentation[6], through which particles are consecutively stacked in homogeneous suspension liquid. Such way can easily eliminate the inner interfaces of FGM and realize a smooth variation of composition. In the present research, we successfully prepared Ti-Mo system FGM[7] with continuous change of composition by co-sedimentation. Such FGM can be applied in dynamics high-pressure technology.

Co-sedimentation method is developed based on the phenomenon that small particles in dilute suspension liquid can continuously settle. In the laminar flow ($Re \ll 1$) the movement of a particle can be described by Stokes law[8]

$$V = D^2 g(\rho_p - \rho)/18\eta \quad (1)$$

where V is the settling velocity of particle; D is the particle diameter (If it is not spherical, D is the Stokes diameter of the particle); g is the gravity acceleration; η is the viscosity of suspension liquid.

From Eqn.(1), it can be concluded that the settling velocity of particle varies directly with the square of D and inversely with η. So the settling velocity can be controlled through D and η.

2 SEDIMENTATION AND SINTERING

2.1 Sedimentation experiment

2.1.1 Effect of particle size distribution on gradient structure of Ti-Mo

In order to investigate the effect of particle size distribution on Ti-Mo gradient layer, Ti powders with different particle size distributions were selected to carry out the experiment when the other factors were unchanged. In Table 1, the description of sam-

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Table 1 Sample characteristics

Sample	Ti powder			Mo powder			φ(Ti)/φ(Mo)
	w/g	Particle size distribution	$D_{50\%}$/μm	w/g	Particle size distribution	$D_{50\%}$/μm	
1#	14.34	Fig.1(a)	11.70	16.25	Fig.2(a)	4.20	2∶1
2#	14.34	Fig.1(a)	8.13	16.25	Fig.2(a)	4.20	2∶1
3#	10.75	Fig.1(b)	8.63	24.33	Fig.2(b)	3.10	1∶1
4#	14.34	Fig.1(b)	8.63	16.25	Fig.2(b)	3.10	2∶1

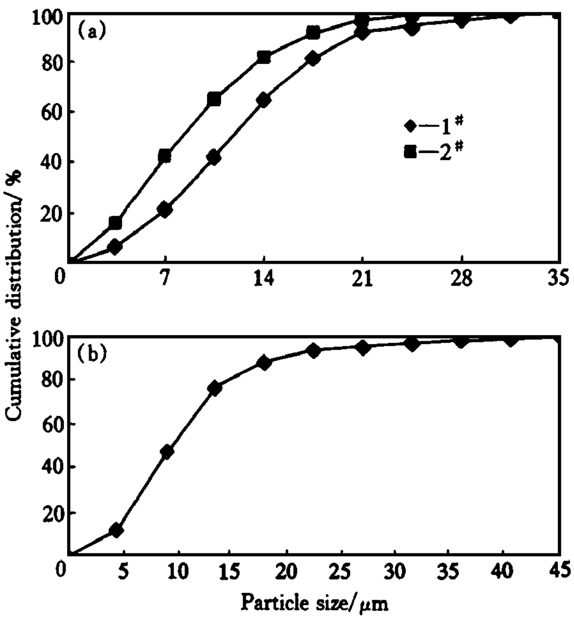

Fig.1 Cumulative distribution of Ti powder
(a) —1# and 2#; (b) —3# and 4#

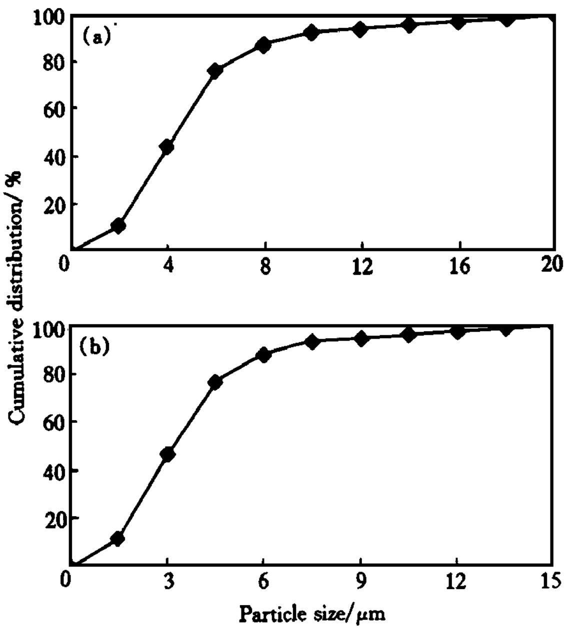

Fig.2 Cumulative distribution of Mo powder
(a) —1# and 2#; (b) —3# and 4#

ple 1# and 2# with different particle size distributions is given, and Fig.1 shows the cumulative distribution of Ti powder.

2.1.2 Effect of ratio of powder Ti to Mo on gradient layer

The powders with different ratios of Ti to Mo were chosen to conduct the sedimentation experiments. The relative data about the 3# and 4# samples are listed in Table 1 and shown in Fig.2.

The masses of Ti and Mo powders listed in Table 1 were put into alcohol to make homogeneous suspension liquid with the volume ratio of 0.6% between solid and liquid, and then the suspension liquid was transferred into the sedimentation device to start experiment.

2.2 Sintering

The steps involved in the sintering of the gradient Ti-Mo specimen included drying deposit bodies, taking them out of the sedimentation device, compacting, transferring them into the graphite die and finally consolidating at 1 673 K under a pressure of 20 MPa in flowing argon for 1 h.

3 RESULTS AND DISCUSSION

The distributions of elements Ti and Mo along the cross section of Ti-Mo system FGM were measured by electron probe and the results are shown in Fig.3.

It can be seen from Fig.3 that the continuously gradient structures have been formed in Ti-Mo samples just as expected. Fig.3(a) and (b) suggest that when the particle size distribution of Mo powder is unchanged, the compositional gradient of Ti-Mo sample can be adjusted through varying Ti powder. It is known that the particle size distribution is described by two parameters, particle size and content of each particle size, and that one or two parameters change can lead to the change of particle size distribution. Based on the previous analysis, it is known that the change of particle size can affect setting time. However, the setting time directly determines the position of particle in the deposit body. In addition, it is obvious that the content of each particle size directly influences the Ti-Mo volume ratio of corresponding gradient layers. Therefore, the compositional distribution of FGM can be controlled by choosing the particle size distribution of Ti or Mo powder.

Fig.3(c) and (d) reveal that when the particle size distributions of Ti and Mo are unchanged, the compositional distribution of Ti-Mo sample can also

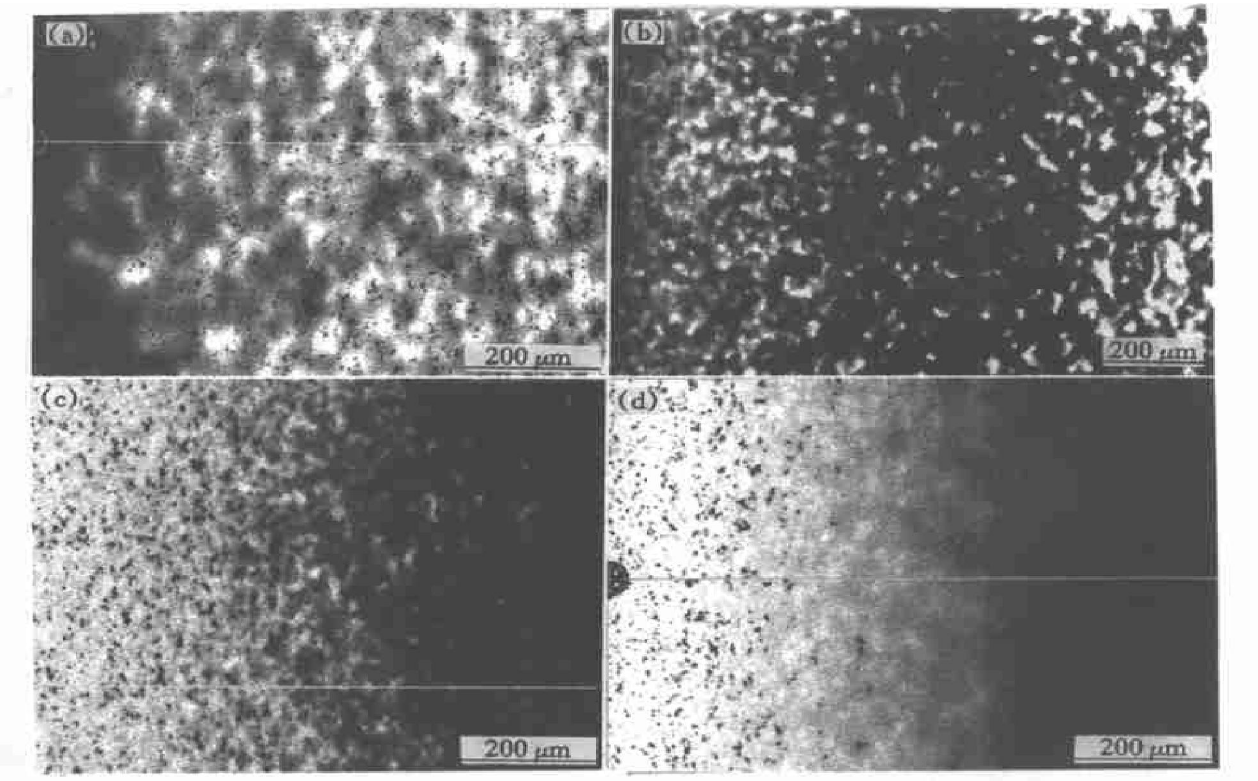

Fig.3 Back-scattered electron images for cross section of Ti-Mo system FGM and line distribution images of elements Ti and Mo in direction of thickness

(a) —1#; (b) —Area distribution images of elements Ti and Mo for sample 2#; (c) —3#; (d) —4#

be altered through adjusting the ratio of powder Ti to Mo. It is thought that the change of powder ratio directly changes the volume content of Ti or Mo powder in the mixture.

Fig.3(b) provides a special type of gradient structure different from the others shown in Fig.3. It is like a sandwich, if a desired structure is that the volume fraction of Ti decreases gradually from one side with pure Ti to the other side with pure Mo. Fig.3(b) indicates that a defect of compositional distribution exists in the sample. Such is not unavoidable in the process of experiment. Based on the above discussion, we know that such defect can be eliminated through selecting the particle size distribution of powder Ti or Mo and the ratio of powder Ti to Mo. Therefore it is a key problem to be solved immediately, i.e. how to choose the particle size distribution and the ratio meeting the design needs. However, if a mathematical model of sedimentation is set up and simulated through computer, the compositional distribution and properties of gradient material would be predicted and an optimal result would be rapidly determined. So the goal of freely designing and fabricating FGM is to be achieved.

[REFERENCES]

[1] HUANG Xu-tao and YAN Mi. Functionally graded materials: review and prospect [J]. Materials Science and Engineering, (in Chinese), 1998, 15(4): 35 - 38.

[2] ZHANG Lian-meng, TU Rong and YUAN Run-zhang. Current research level and new trends of functionally graded materials [J]. Advanced Ceramics, (in Chinese), 1995, 2(1): 23 - 26.

[3] Salito A and Barbezat G. Plasma spraying techniques for functionally gradient coating [A]. 3rd International Symposium on Structural and Functional Gradient Materials [C]. Germany, 1994. 123 - 128.

[4] YUAN Run-zhang. Composite materials and compositing process by SHS technology [J]. International Journal of Self-Propagating High-Temperature Synthesis, 1997, 6(3): 265 - 275.

[5] Watanable R, Takahashi J and Kawasaki A. Characterization of metal/ceramic functionally gradient materials [A]. 3rd International Symposium on Structural and Functional Gradient Materials [C]. Germany, 1994. 3 - 8.

[6] Jüngling T, Bronback J and Kieback B. Ceramic-metal functionally gradient materials by sedimentation [A]. 3rd International Symposium on Structural and Functional Gradient Materials [C]. Germany, 1994. 161 - 166.

[7] XIONG Hua-ping, ZHANG Lian-meng, SHEN Qiang, et al. Fabrication of Mo-Ti functionally graded material [J]. Trans of Nonferrous Materials Society of China, 1999, 9(3): 582 - 585.

[8] Ladislav Svarovsky. WANG Meng-jian and GAO Li (Tr). Solid-Liquid separation [M], (in Chinese). 1982. 32.

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