FUNCTIONALLY GRADED AL MATRIX MATERIALS CONTAINING 10, 20 AND 30 % B_4C_p STACKS

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Abstract: *As a relatively new class of materials that exhibits a gradual compositional or microstructural change along one axis, functionally graded materials (FGM) emerged. As a result of this change, properties of the material also vary. This property change can be controlled by tailoring the composition or microstructure of the individual stacks in the FGM.*

In the present study, aluminum matrix functionally graded composite materials with increasing amounts of B_4C particles in an aluminum matrix were formed. The functionally graded materials were composed of 4 composite stacks with different compositions; namely, 0, 10, 20 and 30 volume % B_4C particles. The matrix material was aluminum - 4 wt.% copper alloy. Preparation of the functionally graded materials was conducted through powder metallurgical methods including mixing, cold pressing and sintering without pressure. Samples were produced in dimensions according to 3-point bending standards.

Microstructure of the functionally graded materials contained some porosity, amount of which was seen to increase with increasing B_4C reinforcement amount. All the stacks were subjected to Vickers microhardness measurements and it was seen that the hardness of the layers increased significantly with increasing reinforcement amount. The unreinforced layer had a hardness of 55 $HV_{0.1}$ and that of the layer containing 30 % B_4C was 143 $HV_{0.1}$. On the other hand, the bending strength of the functionally graded material was seen to be lower than that of the unreinforced sample.

Keywords: FUNCTIONALLY GRADED MATERIALS, Al-4Cu

1. Introduction

As a relatively new class of materials that exhibits a gradual compositional or microstructural change along one axis, functionally graded materials (FGM) emerged. As a result of this change, properties of the material also vary. This property change can be controlled by tailoring the composition or microstructure of the individual stacks in the FGM [1].

Chemical composition, porosity or an additional property of the FGM can change gradually in its arrangement. This structure of FGMs prevents formation of any mismatch between the top and bottom surfaces of the material [1].

In order to produce aluminum matrix functionally graded materials, centrifugal casting has been frequently employed in the literature [2,3]. This technique relies on the difference between the density of the matrix phase and the reinforcement particles. Higher density of the reinforcement particles leads to their accumulation on the outer region of the samples, by the action of centrifugal force. In the study of Rajan, SiC reinforced A356 Al alloy FGM parts were obtained by centrifugal casting. It was reported that the volume % of the SiC particles in the outer rim of the samples were in 40-45 % range. The SiC amount gradually decreased in a region of 8 mm in the outer rim of the sample. Hardness of the outer region was about 110 HB whereas the unreinforced region was 90 HB [3].

Another useful method of obtaining the FGM structure is powder metallurgy. In the study of Erdemir et al. [4], SiC reinforced A2024 matrix FGMs were prepared by powder metallurgy. Microhardness of the layers was assessed and an increase up to a certain amount of reinforcement was reported [4].

In the present study, in order to produce functionally graded composite materials with increasing amounts of B_4C particles in an aluminum matrix, cold pressing and sintering was utilized. Obtained FGMs were composed of 4 composite stacks with different compositions: 0, 10, 20 and 30 volume % B_4C particles. Microstructure and mechanical properties of the obtained FGMs were investigated.

2. Experimental Procedure

Preparation of the functionally graded materials was conducted through mixing, cold pressing and sintering without pressure. Samples were produced in dimensions according to 3-point bending standards [5], which indicated that the span length is 25 mm and thickness is 6 mm and width of the sample is 12 mm.

The FGMs were produced by stacking technique, in which each layer having a definite composition was prepared and laid in a steel mold. After a gentle pressing, the successive stack was laid and thereby a FGM containing 4 layers of the desired thickness was obtained.

The matrix alloy was Al-%4Cu and reinforcement was B_4C particles. Size of aluminum and B_4C particles were smaller than 10 microns. Powders of aluminum, copper and boron carbide were weighed and mixed. The thickness of each stack was calculated as 1.6 mm.

Samples were pressed at 600 MPa pressure. The green samples were sintered in an atmosphere controlled furnace. Sintering was conducted at 610 ^oC for 30 min in flowing nitrogen.

Sintered samples were subjected to microstructural examinations by optical microscope (Nicon Eclipse, LV150) after metallographic preparation. For the preparation of the samples, 600, 1200 and 3000 grit sand papers were used. Final polishing was done with 1 micron polycrystalline diamond paste. Microhardness measurements were conducted according to Vickers method and 0.1 kg load was applied for 15 seconds. 3-point bending tests were performed by a Shimadzu AG-IC 50 kN unit.

3. Results and Discussion

The weight of the samples before sintering was about 7.50 g. After sintering, there was an increase in the weight of about 30 mg, which was attributed to nitrogen intake during sintering.

Density of the FGM sample was 92 % of the theoretical density.

Bending Strength and Strain

After 3-point bending tests, stress-strain curves of the samples were obtained. The highest tensile stress on the sample during bending test occurs on the bottom side of the sample. In addition, the unreinforced side of the FGM generally presents higher strength and ductility. On the other hand, the side of the FGM having high amount of reinforcement particles is known to possess lower ductility and strength. The properties of the FGM sample are anisotropic. Therefore, the orientation of the FGM sample during the 3-point bending operation is important and affects the results of the stress-strain test.

The stress-strain graph of the FGM is presented in Fig.1. This bending test was conducted when the unreinforced side of the FGM was facing up, and the 30 % B_4C containing side was facing down. The FGM sample presented a bending strength of 139 MPa. Bending strain value of this sample was about 4.3 %. These values can be considered to be low for aluminum alloys and composites. In our previous studies, it was found that the bending strength of the unreinforced Al-%4Cu alloy is around 370 MPa and its bending strain is around 25 %. The low strength of the FGM may be attributed to the orientation of the sample. The brittle layer, containing 30 % B_4C has very low ductility and thus, formation of a crack during the bending test is very easy on that side. Once the crack forms, it propagates vertically, along the thickness of the sample, on to the upper layers. The strength of the FGM is expected to be higher when the unreinforced side is facing down, since the unreinforced layer is more ductile and formation of a crack is more difficult.

When the stress-strain plot of the FGM is examined, it can be seen that there are 3 drop points in the strength (as pointed with arrows). The first drop is believed to belong to the formation of the crack at the bottom stack. The second and large drop most probably forms when the level containing 20% B_4C cracks. After that there is a slight increase in stress, which may be related to strain hardening of the remaining 2 layers that are low in B_4C composition.

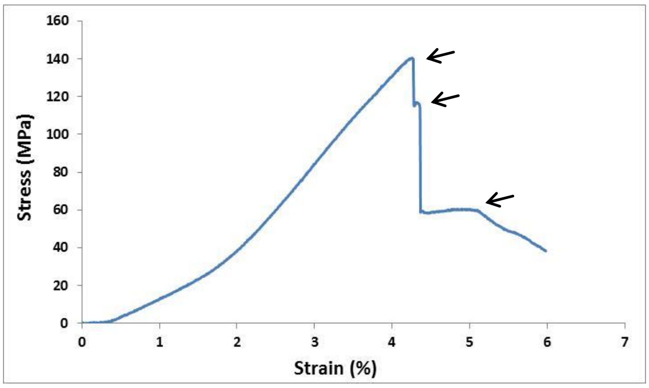

Fig. 1 *Stress-strain plot of the FGM sample obtained by three point bending test.*

Macrostructure

Macrostructure of the FGM can be visualized in Fig. 2 and Fig. 3. Fig.2 is a macro image of the fracture surface of the FGM after bending test. Fig.3 is a stereo microscope image. In both figures, the levels in the macrostructure of the functionally graded material can be visualized.

Fig. 2 *Image of the FGM after bending test, exposing the 4 levels in its structure.*

Formation of a delamination defect is seen in Fig.3 (pointed with arrow). This delamination may probably form during bending test, after the formation of vertical cracks. The delamination of levels is undesired in FGMs. Increasing the sintering time or temperature may be useful in order to provide better bonding between the levels.

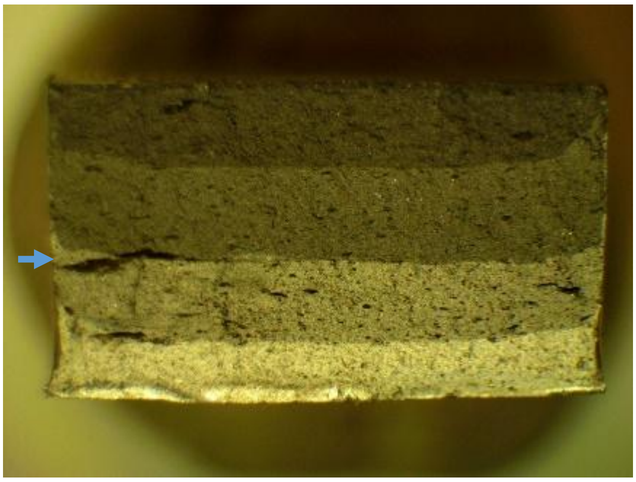

Fig. 3 *Stereo microscope image of the FGM having 0, 10, 20, 30 % B_4C. (Total thickness is about 6.5 mm)*

Microstructure

After polishing the fracture surfaces of the FGM, they were examined by optical microscope. Microstructure of the FGM is given in Figs. 4-6. Fig.4 presents the transition region of the stacks having 0 and 10 % B_4C. In Fig.5, transition from stack having 10 % B_4C to 20 % B_4C can be seen. Transition zone of the stacks having 20 and 30 % B_4C is given in Fig. 6. In Figs 5 and 6, transition line between different stacks is not easy to distinguish; therefore it was marked with a dash-line. B_4C particles are evenly dispersed in the each level of the FGM.

The black irregular shapes in these micrographs are voids in the structure of the FGM. It can be seen that the amount of the voids increases with the increase in the amount of B_4C particles in the stacks.

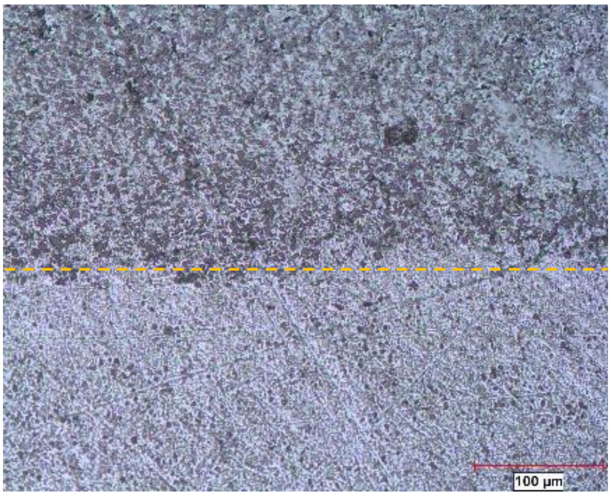

Fig. 4 *Optical microscope image of the transition region between the levels containing 0 % and 10 % B_4C.*

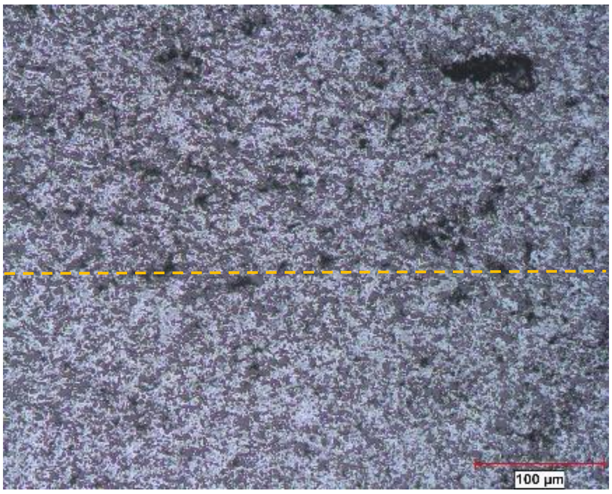

Fig. 5 *Optical microscope image of the transition region between the levels containing 10 % and 20 % B_4C.*

The voids in the structure become larger in the stacks that have higher amount of B_4C. This may be due to 2 reasons. The first one is that when the amount of hard B_4C particles is high, the transfer of stress to lower regions of the sample during cold compaction is low, which leads to lower green density of these layers. The second reason may be during sintering, due to high amount of B_4C, the aluminum particles that form the matrix need to cover a larger path for merging with each other.

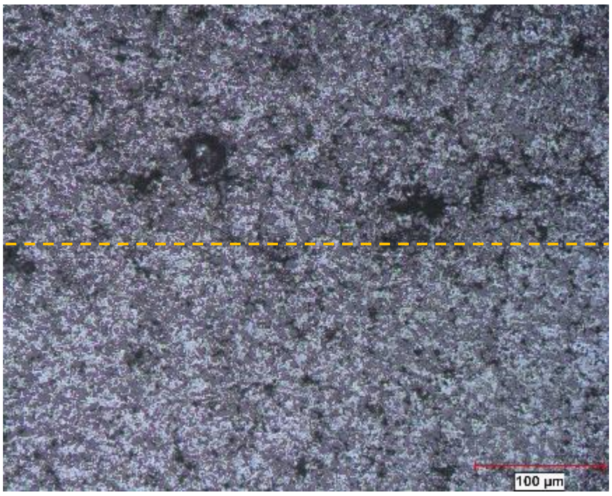

Fig. 6 *Optical microscope image of the transition region between the levels containing 20 % and 30 % B_4C.*

Hardness

In Fig. 7, microhardness values of the levels are given. The level that did not contain B_4C had an average hardness of about 55 $HV_{0.1}$ and that of the layer containing 30 % B_4C was 143 $HV_{0.1}$. The B_4C reinforcement had a significant effect on the hardness. The wear resistance of the layer containing 30 % B_4C is expected to be the highest.

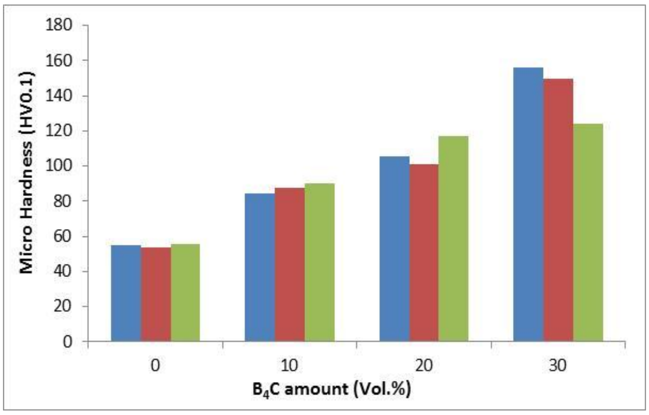

Fig. 7 *Vickers microhardness values of the levels of FGM (each group represents 3 measurements)*

4. Conclusion

Aluminum matrix functionally graded composite materials with increasing amounts of B_4C particles in an aluminum matrix were formed. The low strength of the FGM was attributed to the position of the high reinforced layer being in the high stress region of the sample during the bending test. On the other hand, the presence of the reinforcement particles was seen to have an important effect on increasing the hardness of the stacks.

Acknowledgements

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