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PRODUCTION OF MELT-SPUN Al-20Si-5Fe ALLOY AND BORON CARBIDE (B_4C) COMPOSITE MATERIAL

In this study, metal matrix composite materials containing melt-spun Al-20Si-5Fe alloys and boron carbide was produced by high energy ball milling and then hot pressing at 200 MPa pressure and 450°C. Mechanical and microstructural characterizations were performed by using an optical microscopy, X-Ray diffractometer, and dynamic microhardness tester. It was observed that boron carbide particles were homogenously distributed in the microstructure and values of microhardness and elastic modules were averagely 830 MPa and 42 GPa, respectively.

Keywords: Metal matrix composite, rapid solidification, Al-Si alloys

1. Introduction

The hypereutectic Al-Si-Fe alloys are a kind of the structural materials used for high temperature applications [1,2]. They are used in different kinds of industries such as automotive, military and aerospace because of some properties good castability, low density, good thermal conductivity, high strength etc. [3]. Fe-containing intermetallic compounds dispersed in the microstructure make Al-Si-Fe alloys durable at elevated temperatures. However, there are generally large brittle Fe-containing intermetallic compounds and coarse Si phases in the microstructure of conventional cast-Al-Si-Fe alloys. The phases such as Fe-bearing intermetallics and Si which display coarse and needle-like morphologies are harmful in terms of mechanical properties because of the stress concentration produced at the end of the acicular phase during the deformation process. Therefore, modification of Si phases and neutralization of detrimental effects of Fe-containing phases in hypereutectic Al-Si-Fe alloys have been investigated considerably to obtain optimum mechanical properties. In the literature, different kinds of production techniques are used to modify primary and eutectic Si and Fe-bearing intermetallics such as gas atomization and spray deposition [5,6]. It is also reported that methods of melt spinning (MS) and high energy ball milling (HEBM) can be used a refined and modified microstructure in Al-Si alloys. On the other hand, method of HEBM can also be used to prepare metal matrix composites reinforced with ceramics because it is an effective way to improve reinforcement distribution in matrix. Boron Carbide (B_4C) is commonly used as reinforcement material in aluminum matrix composites due to its properties such as low specific gravity, high hardness value, and high elastic modulus value. However, to the best of our knowledge, there is limited or no information in the literature about composite materials of boron carbide and melt spun Al-20Si-5Fe alloys produced by a combination of MS and HEBM processes. Therefore, in this study, we produced a metal matrix composite of melt spun Al-20Si-5Fe alloy and B_4C by using a method in which we produced rapidly solidified Al-20Si-5Fe ribbons by melt spinning, milled a mixture of melt spun ribbons and B_4C by HEBM technique, and then compacted the milled powder mixture by hot pressing technique. The technique of microhardness measurements was used to determine mechanical properties of the samples produced in the present study.

2. Experimental

In this study, rapidly solidified B_4C reinforced aluminum matrix composite was produced by milling of a mixture of melt spun Al-20Si-5Fe ribbons and 15 % wt. B_4C particles in a HEBM machine and then hot pressing of milled powder at 450°C and 200 MPa, respectively. During melt spinning processes, a stream of molten Al-20Si-5Fe alloy was ejected by 200 mbar argon gas pressure onto a copper wheel that was rotating at linear velocity 25 m/s. Pure Al ingot with purity of 99.999 pct, Si scrap with purity of 99.99 pct, and Fe ingot powder with purity of 99.99 pct were used as starting materials in this study. A planetary ball mill with stainless steel vessel was used for high-energy milling of the mixture. HEBM process was performed at 800 rpm. Ball-to-powder weight ratio was 40:1, with stearic acid added (10 wt pct

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of mixed powder) to moderate the cold-welding process. In this study, all percentages are wt. pct. unless otherwise stated. An Eze Nanotechnology EZ001 model melt-spinner was used to produce rapidly solidified samples. The melt spinning processes were performed using a copper wheel with 25 m/s disk velocity by pressurized argon of 200 mbar. In this study, milling time was selected as 10 minutes for powder materials because in the high-energy ball milling process, the level of contamination will increase with increasing milling time. Depth sensing indentations were performed by using Bruker UMT-2-SYS. Load – unload curves were obtained under three maximum loads (0.75, 1.5 and 2.5 N).

3. Results and discussions

Optical micrograph in the Figure 1 shows the microstructure of the rapidly solidified Al-20Si-5Fe-15B_4C metal matrix composite after the hot pressing. According to Figure 1a, microstructure consist of a dark matrix and embedded bright colour pulverized ribbons with different sizes ranging from 5 to 100 µm. On the other hand, a more detailed representation of microstructure is given Figure 1b. From the Figure 1b it can also be seen that homogeneously distributed fine B_4C particles with sizes 4-6 µm are embedded in the matrix. Figure 2 shows the X-ray diffraction pattern of the compacted B_4C reinforcement melt – spun Al-20Si-5Fe-B_4C alloy metal matrix composite. According to the XRD measurements, the microstructure of the metal matrix composite sample contained an Al, Si and B_4C phase, which it is in agreement with the Fig. 1.

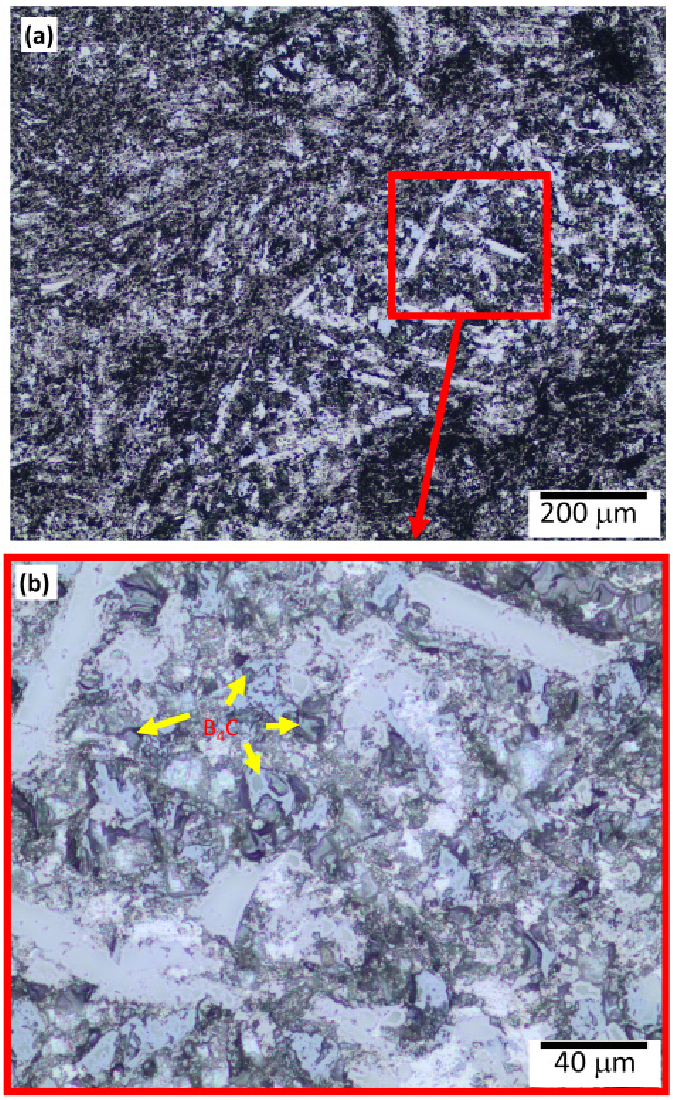

Fig. 1. Optical micrograph of the microstructure of the rapidly solidified Al-20Si-5Fe-15B_4C metal matrix compounds after hot pressing

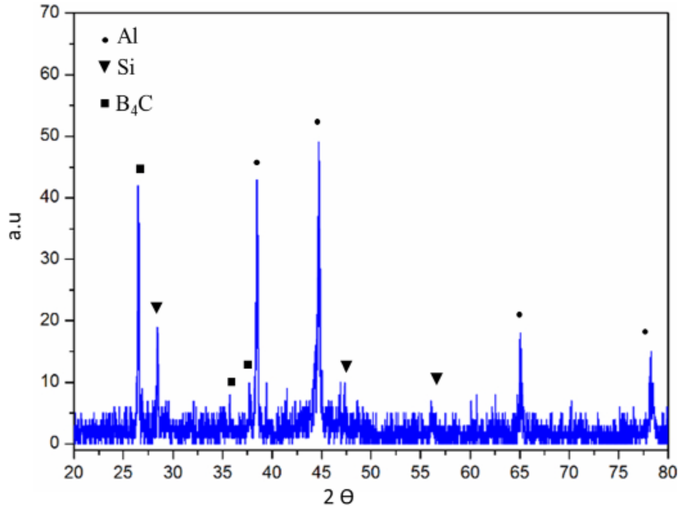

Fig. 2. The X-ray diffraction pattern of compacted B_4C reinforcement melt –spun Al-20Si-5Fe alloy metal matrix composite

Figure 3 shows loading – unloading curves of the rapidly solidified Al-20Si-5Fe-15B_4C metal matrix compounds obtained as a result of indentation tests. It is obviously seen from the Figure 3 that the sample exhibited an elasto-plastic behavior at ambient temperature [7]. Also loading curves under different maximum loads could be fitted by one curve due to their overlapping characters.

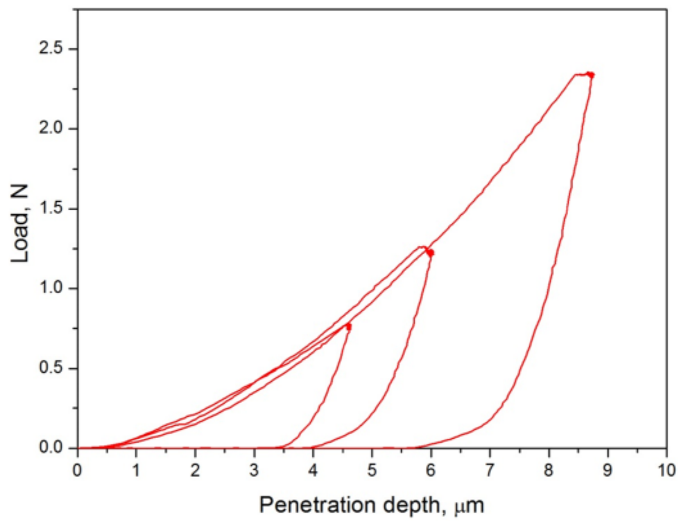

Fig. 3. Loading – unloading curves of rapidly solidified Al-20Si-5Fe-15B_4C metal matrix composite obtained from indentation tests

The unloading part of the loading-unloading curves showed also the similar behavior when they were shifted according to their final penetration depths. In the literature, such overlapping characters of loading-unloading curves is interpreted as the fact that the sample has a similar elastic and plastic deformation mechanism for given experimental load range [7,8].

Figure 4 shows microhardness values calculated by using Oliver-Pharr approach [9] from the loading-unloading data under different peak loads. Microhardness values were 773, 863, and 860 MPa for the maximum loads of 0.75, 1.5, and 2.5 N, respectively. Average microhardness value of the compacted sample was 830 MPa which was dramatically higher compared to results of Kilicaslan at al.'s [7] study in which dynamic microhardness of HEBMed melt – spun Al-20Si-5Fe alloy was measured as 245 MPa. It is well known that in the microhardness tests, generally higher microhardness values are measured under lower loads and vice versa and this phenomenon is called as ISE [7,8].

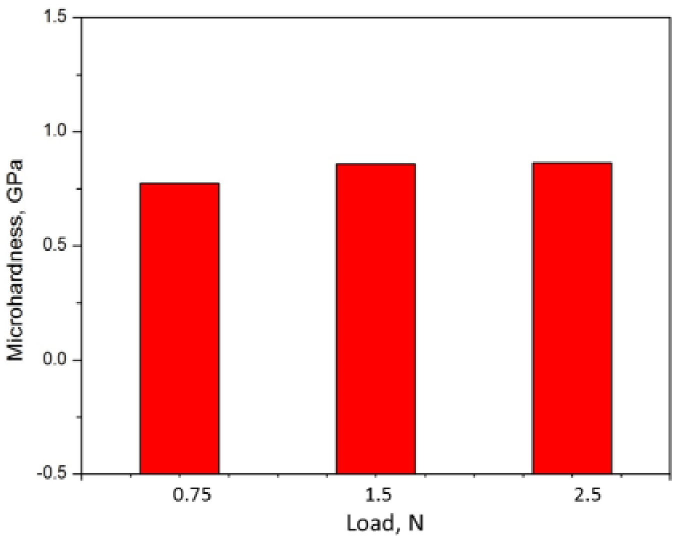

Fig. 4. Microhardness values calculated using Oliver-Pharr approach from the loading-unloading data under different peak loads

Kilicaslan et al. [10] applied very similar conditions for production of melt-spun Al-20Si-5Fe powders and used only 50 mN maximum load during indentation experiments. On the other hand, in the present study, 0.75, 1.5 and 2.5 N max loads which are obviously much higher than 50 mN, were used. Therefore, it should have expected that for a same composition material, the microhardness values measured by them should have been higher than values obtained in the present study, but the situation is quite opposite. Hence, it was thought that microhardness values obtained in the present study were higher compared to values obtained by Kilicaslan et al since the sample used in the present study contained 15 wt. % B_4C.

Figure 5 shows elastic modulus values calculated by using Oliver-Pharr approach from the loading-unloading data under different peak loads. Elastic modulus values were 32, 48 and 45 GPa for the maximum loads of 0.75, 1.5 and 2.5 N, respectively. Normally, the elastic modulus values should have stayed constant under different loads. Because, the elastic modulus is one of the intrinsic properties of materials and it is related bonding forces among atoms [11]. However, there are works in the literature investigating load dependence of elastic modulus based on different models such as proportional specimen resistance (PSR) and modified proportional specimen resistance (MPRS) models [12-13]. In these kind of works, elastic modulus values are investigated within in a wide loading regime. Hence, in our study, to make any discussion about why elastic modulus values are changed with the applied load, we don't have sufficient data.

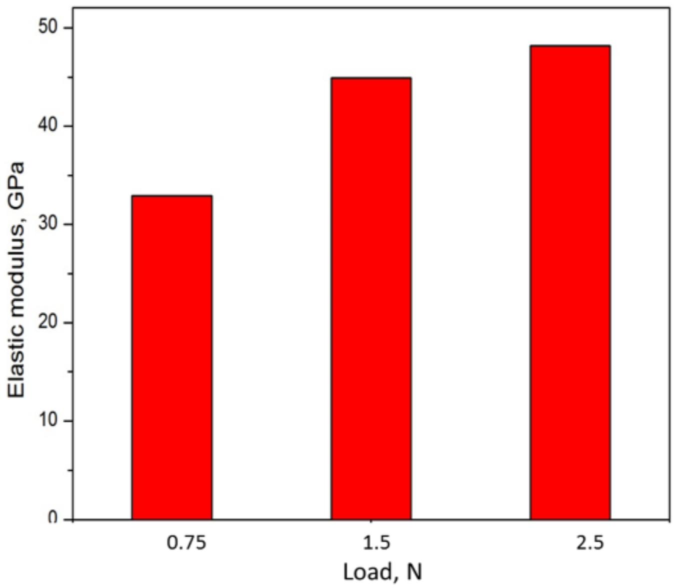

Fig. 5. Elastic modulus values calculated using Oliver-Pharr approach from the loading-unloading data under different peak loads

Average elastic modulus value for the compacted sample were 42 GPa which was dramatically higher compared to results of Kilicaslan at al.'s study [10] in which dynamic microhardness of HEBMed melt – spun Al-20Si-5Fe alloy which was produced by using a very similar method except for B_4C addition was measured as 14 GPa. Therefore, it was also thought that elastic modulus values obtained in the present study was higher than those obtained by Kilicaslan et al. because 15 wt. % B_4C was added to melt-spun Al-20Si-5Fe powder milled for ten minutes.

4. Conclusions

In summary, this study reported production of rapidly solidified metal matrix composite of Al-20Si-5Fe-15B_4C and characterization of its mechanical properties by depth sensing indentation analyses. The conclusions are as follows:

– Rapidly solidified metal matrix composite of Al-20Si-5Fe-15B_4C was successfully synthesized.
– Rapidly solidified metal matrix composite of Al-20Si-5Fe-15B_4C exhibited an elasto-plastic behavior at ambient temperature.

– Average microhardness and elastic modulus values of the rapidly solidified metal matrix composite of Al-20Si-5Fe-15B_4C were 830 MPa and 42 GPa, respectively which were dramatically higher compared to a similar material without B_4C additions.

Acknowledgements

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