A PROMISING PREPARATION METHOD FOR AL/7075-B4C/AL LAYERED COMPOSITE BY CONTINUOUS CASTING AND HOT ROLLING

Yubo Zhang*,Yingshui Yu, Tingju Li

Key Laboratory of Solidification Control and Digital Preparation Technology (Liaoning Province), School of Materials Science and Engineering, Dalian University of Technology, Dalian 116024, China

* Corresponding author E-mail: ybzhang@dlut.edu.cn

Keywords: Layered composite, B_4C reinforcement, Semi-continuous casting, Hot-rolling, Mechanical properties

ABSTRACT

Layered composite possesses the combinative properties of different materials, such as high strength, high ductility, low density, etc. In the present work, a three-layered composite material, in which the outer layer is pure Al and the interlayer is 7075-B_4C with 40 wt.% B_4C, was obtained by a two-step method consisting of semi-continuous casting and hot rolling process. During semi-continuous casting, the uniform distribution of reinforcement B_4C particles along with a good metallurgical bonding was achieved, with no defects, cavities or segregation at the interface. Then, the hot rolling was carried out at 450 ^oC, and the composite plate of 20mm thickness, including the interlayer of 14mm, was obtained. The layered composite exhibited evident soft-hard-soft structure with layers of different hardness (165HV of inner layer and 27.6HV of outer layer) and satisfactory compression performance.

1 INTRODUCTION

Al-matrix composites are widely used in the automotive and aerospace industries due to their low density, easy processing and good mechanical properties[1]. Boron carbide (B_4C) is an ideal reinforcement, as well as one of the hardest materials, which possesses great physical and mechanical properties, such as high melting point, neutron absorption ability, good impact and wear resistance[2-3]. Therefore, a lot of attention has been paid to the synthesis and characterization of B_4C reinforced Al matrix composites. However, the bad sinterability of B_4C and its low wettability with Al increases the cost and complicates the manufacturing process, leading to a serious constraint to the widespread application.

After a period of development and research, B_4C-reinforced Al-matrix composite is considered to have better application prospects as a layered structure composite material[4-5]. The B_4C-reinforced Al layered composite (BRALC), which consists of Al in outer layer and Al-B_4C mixture in inter layer, can offer better protective performance with lower weight. By the combination of properties from different layers, BRALC can realize both high strength and plasticity. It is reported that a soft-hard-soft structure layered material has significant shock resistance and protection performance, and is considered as a candidate to replace the traditional high-hardness armor[4]. Hence, the BRALC is a promising armor material to meet the demand of lightweight design and high barrier property in protection.

Many methods, such as pressureless infiltration[6], casting[7], powder metallurgy[8] and hot pressing, etc., can be used for the production of B_4C reinforced Al matrix composite. For BRALC, only powder metallurgy and casting have been reported. Higher efficiency and lower cost processes are still needed for its wide application. In addition, there are some questions remained during the fabrication. For example, it is difficult to achieve high proportion of B_4C in a large size production, i.e. in the industrial application level.

In the present study, a three-layer composite material consisting of two Al layers and one 7075-

B_4C inner layer with 40% B_4C particles was produced by a two-step method comprising the semi-continuous casting and hot rolling process. The composite obtained fulfills demands to large size, high B_4C content as well as low cost. The distribution of B_4C particles, the conformations of interface and the mechanical properties of material were studied in this paper.

2 EXPERIMENTAL PROCEDURE

The BRALC produced in this work consists of three layers, the pure Al outer layers and the inner 7075-B_4C layer. The outer layer is made of commercial purity aluminium (CPAl, 99.7 wt.%), while 7075 aluminum powder and B_4C powder with average particles size 35 μm and 72 μm, respectively, were used as the starting materials for the inner layer. In order to obtain 40 wt.% B4C content in the inner layer, the mass ratio of 7075 aluminum powder and B_4C powder used was 3:2. Prior to the semi-continuous casting, the powder was pretreated in a ball grinding mill for 3 hours.

The schematic diagram of semi-continuous casting installation is shown as Fig.1a, and it mainly consists of powder feeder unit, CPAl pouring unit, mould unit, cooling unit, the pressure and drawing unit. During the semi-continuous casting process, the CPAl was melt in the resistance furnace at 780 ºC, and poured into the gap between the inner and outer mould at 740 ºC. It would be soon solidified under the influence of 1st cooling water. Then, the ingot was pulled down continuously under the effect of the drawing drive. Meanwhile, the mixed powder (included 7075 alloy and B_4C powder) was poured into the inner mould through the feeder with Ar gas protection, and continuously pulled down with the outer shell by pressure head, until the work was completed.

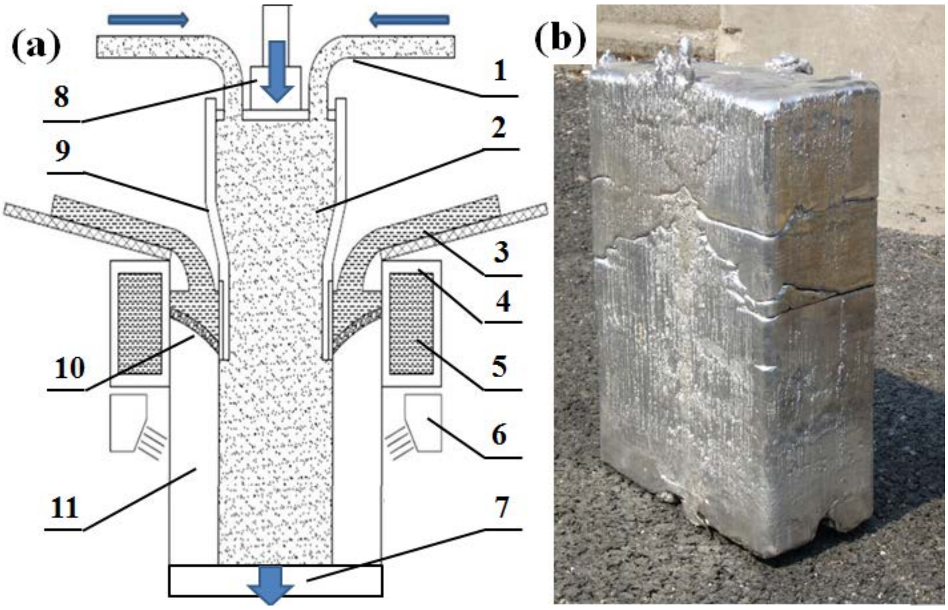

Fig.1 (a) The schematic diagram of semi-continuous casting equipment, 1-feeder of powder, 2-powder, 3-CPAl melt, 4-mould, 5- 1st cooling water, 6-2ed cooling water, 7-drawing drive,8-pressure head, 9- inner mould, 10-solidification interface, 11-layered structure composite ingot, (b) real product of BRALC

The casting ingot with the size 520 mm×230 mm×120 mm (length×width×height) was obtained, as shown in Fig.1b. After simple surface treatment of the ingot, a hot-rolling process at 450 ºC was carried out by a twin-roller rolling machine, as displayed in Fig.2a. Thin composite plate was fabricated with reduction ratio ≤15% in each rolling pass. This procedure was repeated several times to obtain the BRALC with different thickness. The BRALC plates with 20mm and 3mm thickness are shown in Figs. 2b and c, respectively. In this study, the sample plate of 20 mm thickness was cut into pieces of appropriate size for further analysis.

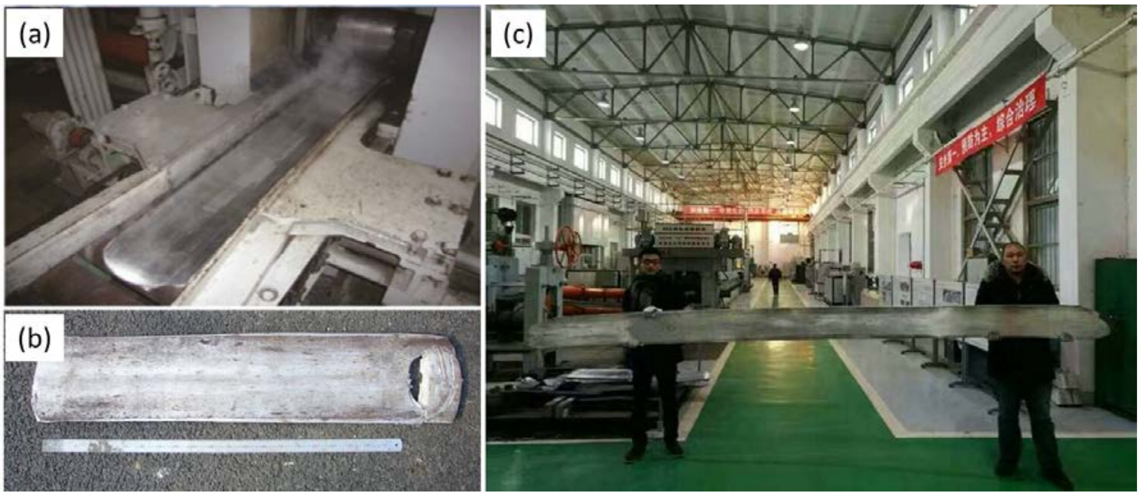

Fig.2 (a) The hot rolling process and BRALC plates with thickness of 20mm (b) and 3mm (c)

The phase composition, microstructure, element distribution, hardness and compression performance were investigated by using scanning electron microscopy (SEM, SUPRA55; ZEISS), electron probe micro analysis (EPMA, EPMA-1600; SHIMADZU), compression testing (DNS100; Changchun Research institute for Mechanical Science Co, Ltd) and Vickers hardness testing (THVS-3000, Timetester Co, Ltd, Beijing, China), respectively.

3 RESULTS AND DISCUSSION

Figure 3 shows the cross-sectional macrostructure and microstructures at different regions of the BRALC plate. It is clear from Fig. 3a that the composite has three-layered structure, which consists of two outer CPAl layers and the inner 7075-B_4C layer with a straight interface between them.

The marked region in Fig. 3a is magnified in Fig. 3b to observe the inner layer microstructure. It indicates that the B_4C particles (in dark contrast) are uniformly distributed within the matrix without considerable segregations. 7075 powder transformed into matrix during hot rolling process, and wrapped B_4C particles tightly. The interfacial microstructure between outer CPAl layer and inner 7075-B_4C layer is shown in Fig.3c, a straight interface as well as a good bonding between different layers was obtained after hot rolling. That is probably due to similarity of Al-based matrix in all layers. In addition, there are no cavities or cracks near the interfacial region, suggesting that the experimental parameters of both semi-continuous casting and hot rolling process were suitable.

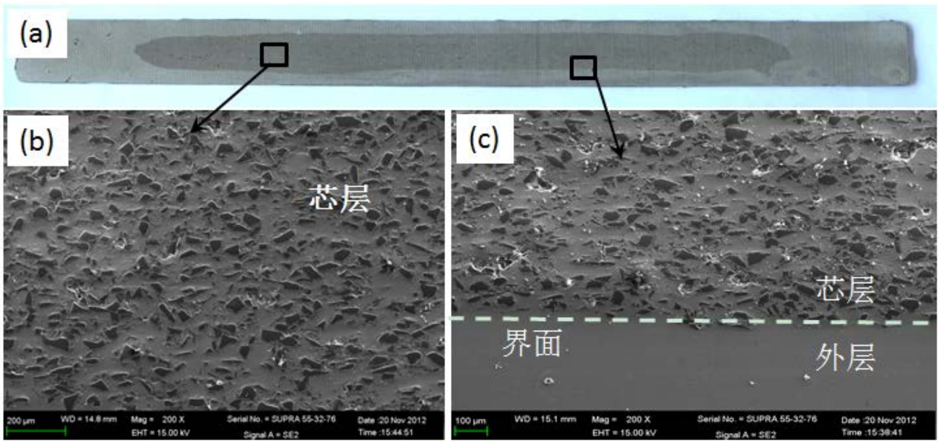

Fig.3 (a) The cross section macrostructure of BRALC plate (thickness 20mm) and the microstructures of inner layer (b) and interface(c)

Figure 4 shows EPMA micrographs and elemental mapping results of 7075-B_4C layer. It is clear from Figs. 4a and b that B_4C particles remain in good shape with smooth edges, suggesting that no remarkable reaction or decomposition occurred during continuous casting or rolling process. Figs. 4c-f represent the elemental distribution of Al, Mg, Zn and Cu, respectively. In Fig. 4c, aluminum oxide can be found surrounding the B_4C particles as a layer, that probably generated during the ball milling process. Mg element mainly distributes in the boundary of α-Al grain and exhibits reticular structure (Fig. 4d). Zn and Cu disperse uniformly in the whole matrix, no element segregation is observed in Figs. 4e-f.

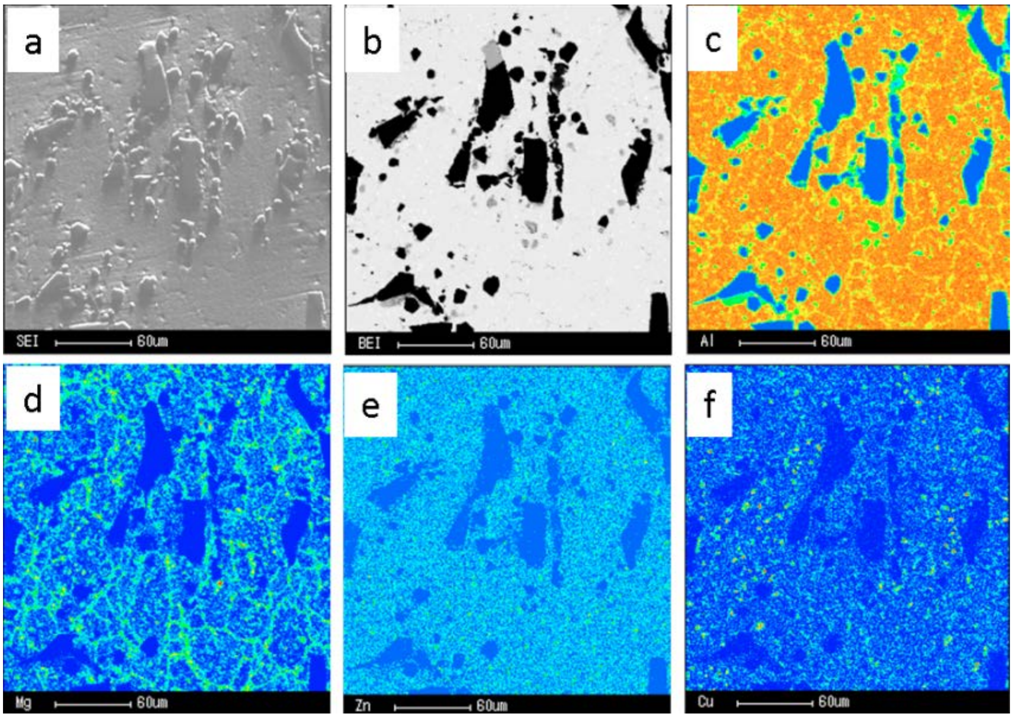

Fig. 4 EPMA analysis of inner layer, (a) secondary electron image, (b) backscatter electron image, elemental mapping of (c) Al, (d) Mg, (e) Zn, and (f) Cu

In order to verify the differences in hardness of different layers, the Vickers hardness test was carried out along the central line, perpendicularly to the interface. The result (Fig. 5a) indicates that the highest Vickers hardness 165HV corresponds to the 7075-B_4C layer, while the CPAl layer shows much lower hardness, 27.6HV. Hence, the BRALC shows an obvious variation of hardness in different layers, i.e. a good soft-hard-soft structure. The compression specimen and the compression curve are shown in Figure 5b. As it is marked on the curve, the yield of outer CPAl layer happened at the very beginning of compression test. Due to the plasticity and lower strength of Al, the deformation firstly occurred in the CPAl layer. Then no remarkable yield occurred further during the test. The plasticity of 7075-B_4C composite layer is not as good as CPAl, therefore no remarkable compression yield was observed.

In this case, CPAl layer was designed as the absorbed energy layer and support layer. Such layered structure could improve the ballistic resistance of material as compared to the materials with homogenous structure. When the armor piercing projectile impacts the composite, the projectile is first decelerated by the soft CPAl layer. When projectile impacts the inner layer, the hardness of 7075-B_4C composite could cause its fragmentation, and thus, spread the load over a larger area. The aluminum backing layer could absorb the kinetic energy of the projectile, preventing the inner 7075-B_4C layer from tensile failure and promoting more severe projectile erosion. Hence, the Al/7075-B_4C/Al three-layered composite could offer possibilities in improving damage resistance of light armor materials [9].

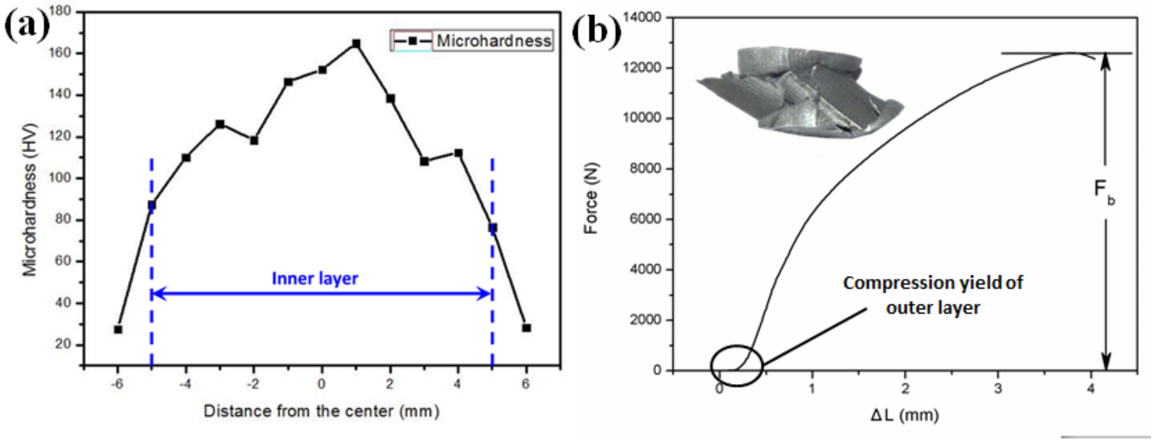

Fig.5 Mechanical properties result of (a) hardness test and (b)compression text

4 CONCLUSIONS

Based on the preparation process and the properties of the Al/7075-B_4C/Al three-layer composite, the outcome of this study can be summarized as follows:

(1) Large size and high B_4C-content three-layered (CPAl/7075-B_4C/CPAl) composite material was successfully prepared using the cost-effective method, which consist of semi-continuous casting and hot-rolling process.

(2) Uniform distribution of reinforcement B_4C particles along with a good metallurgical bonding was achieved. No defects, cavities or segregation were observed near the interface.

(3) The BRALC exhibits evident soft-hard-soft structure with layers of different hardness (165HV for inner layer and 27.6HV for outer layer) and the compression strength of 152 MPa.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (Nos. 51270142 and 51501027), the China Postdoctoral Science Foundation (No. 2015M570246).

REFERENCES

[1] Zhang J, Liu S, Lu Y, etc. Liquid rolling of woven carbon fibers reinforced Al5083-matrix composites. *Mater. Des.* 95,2016, pp.85-96

[2] Yazdani A, Salahinejad E. Evolution of reinforcement distribution in Al–B4C composites during accumulative roll bonding. *Mater. Des.* 2011, 32, pp.3137-42.

[3] Hayun S, Rittel D, Frage N, Dariel MP. Static and dynamic mechanical properties of infiltrated B4C–Si composites. *Mater. Sci. Eng. A* 2008, 487(1– 2): pp.405-9.

[4] Fernández-Fdz D, Zaera R, Fernández-Sáezv J. A constitutive equation for ceramic materials used in lightweight armors. *Comput. Struct.*, 2011, 89: pp.2316-24.

[5] Shokrieh MM, Javadpour GH. Penetration analysis of a projectile in ceramic composite. *Armor Comput. Struct.* 2008, 82(2): pp.269–76

[6] Yao. Y. T. & Chen L. Q. *Materials & Manufacturing Processes*,2009, 31(10). pp.256-264

[7] Yu, Y., Jie, J., Zhang, S., & Tu, J. (2015). Three-layer al/al–b4c composite material prepared by casting and hot rolling. *Powder Metallurgy and Metal Ceramics*, 2014, 54(7), pp.390-396.

[8] Abdullah Y, Yusof M R, Muhammad A, et al. Al/B4C Composites with 5 And 10 wt% Reinforcement Content Prepared By Powder Metallurgy. *JOURNAL Of NUCLEAR And Related TECHNOLOGIES*,2011,8, pp.42-49

[9] Thévenot F. Sintering of boron carbide–silicon carbide two-phase materials and their properties. *J. Nucl. Mate.r* 1988, 152,pp.154–62.