A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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FABRICATION AND CHARACTERIZATION OF Cu/B_4C SURFACE DISPERSION STRENGTHENED COMPOSITE USING FRICTION STIR PROCESSING

WYTWARZANIE METODĄ ZGRZEWANIA TARCIOWEGO I CHARAKTERYSTYKA POWIERZCHNIOWODYSPERSYJNIE WZMACNIANEGO KOMPOZYTU Cu/B_4C

Friction stir processing has evolved as a novel method to fabricate surface metal matrix composites. The feasibility to make B_4C particulate reinforced copper surface matrix composite is detailed in this paper. The B_4C powders were compacted into a groove of width 0.5 mm and depth 5 mm on a 9.5 mm thick copper plate. A tool made of high carbon high chromium steel; oil hardened to 63 HRC, having cylindrical profile was used in this study. A single pass friction stir processing was carried out using a tool rotational speed of 1500 rpm, processing speed of 40 mm/min and axial force of 10 kN. A defect free interface between the matrix and the composite layer was achieved. The optical and scanning electron micrographs revealed a homogeneous distribution of B_4C particles which were well bonded with the matrix. The hardness of the friction stir processed zone increased by 26% higher to that of the matrix material.
Keywords: Surface dispersion strengthened composite, Friction stir processing, Copper, Boron carbide

Zgrzewanie tarciowe ewoluowało jako nowa metoda wytwarzania kompozytów powierzchniowych z osnową metaliczną. W pracy szczegółowo opisano możliwość wytworzenia kompozytu na powierzchni miedzi zbrojonego cząstkami B_4C. Proszki B_4C sprasowano w rowku o szerokości 0,5 mm i głębokści 5 mm wykonanym na blasze miedzianej o grubości 9,5 mm. Do wytworzenia kompozytu użyto narzędzia o profilu cylindrycznym, z wysokowęglowej stali o wysokiej zawartości chromu, hartowanego w oleju do 63 HRC. W jednym przebiegu obróbki zgrzewanie przeprowadzono przy prędkości obrotowej narzędzia 1500 obr/min, szybkości przesuwu 40 mm/min i osiowej siły 10 kN. Osiągnięto cel w postaci pozbawionego wad połączenia pomiędzy matrycą i warstwą kompozytu. Mikrofotografie optyczne i ze skaningowej mikroskopii elektronowej wykazały jednorodną dystrybucję cząstek B_4C, które były dobrze połączone z matrycą. Twardość strefy zgrzewnej tarciowo wzrosła o 26% w stosunku do materiału matrycy.

1. Introduction

Copper based ceramic particulate reinforced metal matrix composites (CMMCs) have been gaining much attention owing to their good mechanical, thermal and tribological properties. CMMCs are applied where good wear resistance without loss of thermal and electrical conductivity of the matrix is needed [1]. The introduction of hard, non deformable ceramic particles into matrix alloy causes a loss in ductility and toughness of CMMC. The life of components depends on surface properties in many applications. Therefore, it is appropriate to modify the surface of the component by reinforcing with ceramic particles while the inner matrix retains the ductility and toughness. The modified surface dispersion strengthened composite layer is called as surface metal matrix composite (SMMC) [2].

Friction stir processing (FSP) is a novel technique used to fabricate SMMC [3]. Mishra et al [4] developed FSP, based on the principles of friction stir welding (FSW). One method to produce SMMC using FSP is to make a groove of required depth, compact with ceramic particles, plunge the tool and traverse along the groove [5]. The frictional heat softens the matrix alloy and the ceramic particles are distributed within the plasticized matrix alloy by the stirring action of the tool. This technique has been effectively used by several investigators to fabricate SMMC on aluminum, magnesium, steel and titanium alloys [6-11].

Barmouz et al successfully applied FSP technique to fabricate Cu/SiC SMMC in recent times [12-15]. He studied various aspects of FSP process on the formation Cu/SiC SMMC. It was reported that the processing speed significantly influenced the distribution of SiC particles. Higher processing speed led to poor distribution of SiC particles and vice versa [12]. The size of the SiC particles considerably influenced the grain size and wear rate of Cu/SiC SMMC. Nano size SiC particles yielded finer grains and lower wear rate compared to macro

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size SiC particles. Increased volume fraction of both micro and nano sized SiC particles enhanced the wear resistance of the composite layer [13]. Increasing the number of passes resulted in the reduction of SiC particles size and grain size of copper and improved the dispersion and separation of SiC particles due to longer processing time and severe stirring action in the stir zone [14]. The tool pin profile also contributed to the formation of Cu/SiC SMMC. A straight cylindrical pin profile produced uniform distribution of SiC particles and finer grain size in the stir zone, increased hardness and wear resistance compared to square pin profile [15]. B_4C coating on copper and steel fabricated by various methods other than FSP is extensively applied in nuclear industries [16,17].

In the present work, an attempt is made to fabricate Cu/B_4C SMMC using FSP and study the microstructure and microhardness of the same.

2. Experimental procedure

Commercially available pure copper plate of 50 mm length, 100 mm width and 9.5 mm thickness was used in this study. A groove of 0.5 mm in width, 5 mm in depth and 50 mm in length was made in the middle of the plate using wire EDM and compacted with B_4C powder. The average size of B_4C powder is 3 μm. The SEM photomicrograph of B_4C powder is shown in Fig. 1. A pinless tool was initially employed to cover the top of the groove after filling with B_4C particles to prevent the particles from scattering during FSP. A tool made of high carbon high chromium steel (HCHCr) oil hardened to 63 HRC, having cylindrical profile was used in this study. The tool had a shoulder diameter of 18 mm, pin diameter of 6 mm and pin length of 5.8 mm. FSP was carried out automatically in an indigenously built FSW machine at tool rotational speed of 1500 rpm, processing speed of 40 mm/min and axial force of 10 kN.

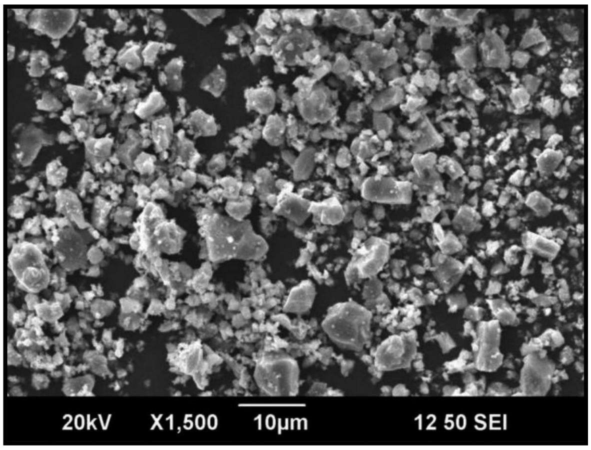

Fig. 1. SEM photomicrograph of as received B_4C powder

Two specimens were obtained from the centre of the friction stir processed plate and were polished as per standard metallographic procedure. The polished specimens were etched with a color etchant containing 20 g chromic acid, 2 g sodium sulfate, 1.7 ml HCl (35%) in 100 ml distilled water. The digital image of the macrostructure of the etched specimen was captured using a digital optical scanner. The microstructure was observed using a metallurgical microscope and a scanning electron microscope. The X-ray diffraction pattern (XRD) of the composite layer was recorded using Panalytical x-ray diffractometer. The microhardness was measured using a microhardness tester at 500 g load applied for 15 seconds along the cross section of the specimen.

3. Results and discussions

3.1. Macrostructure

Fabrication of Cu/8vol.% B_4C surface dispersion strengthened compositeis successfully accomplished using FSP. The macrophotograph of the cross section of the Cu/B_4C composite layer is presented in Fig. 2. It is evident from the figure that the composite layer is well bonded to the copper substrate. There are no macroscopic defects such as tunnel, worm hole, pin-hole etc., for the combination of chosen process parameters. During FSP the frictional heat plasticizes the copper and the B_4C particles are distributed and embedded in Cu matrix due to the stirring action of the rotating tool. FSP distributes the ceramic particles compacted in the groove to a width and depth of 15 mm and 3 mm respectively. Kumar and Kailas [18] identified two different modes of material flow in the formation of FSP zone namely "pin driven flow" and "shoulder driven flow". The magnitude of resultant material flow determines the size of the FSP zone.

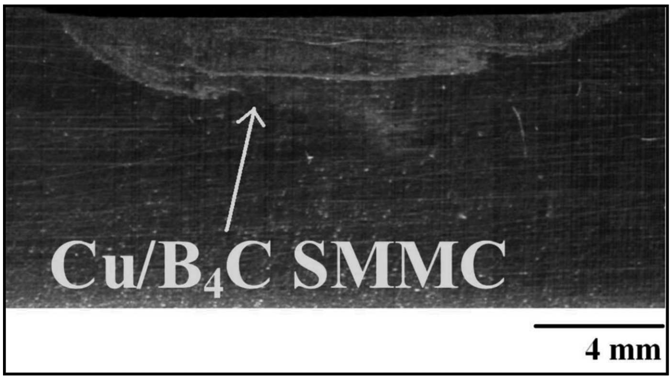

Fig. 2. Photomacrograph of Cu/B_4C SMMC

3.2. Microstructure and XRD

The optical photomicrograph of copper is shown in Fig. 3. The color etchant precisely reveals the microstructure of copper. The average grain size is about 30-35 μm measured using linear intercept method. Fig. 4 and 5 respectively show the optical and scanning electron micrographs of the interface between Cu/B_4C composite layer and Cu. It is clear from the figures that absence of any defect along the interface depicts good bonding between SMMC layer and substrate. The banded structure present adjacent to the interface indicates the thermomechanically affected zone (TMAZ) which is a unique feature of FSW. The width of TMAZ is observed to be 50 μm. TMAZ exhibits the distribution of B_4C particles along parallel bands in the Cu matrix. The frictional heat generated by the rotating tool and application of high stresses during FSP lead to stretching of B_4C particles along the shear stress directions.

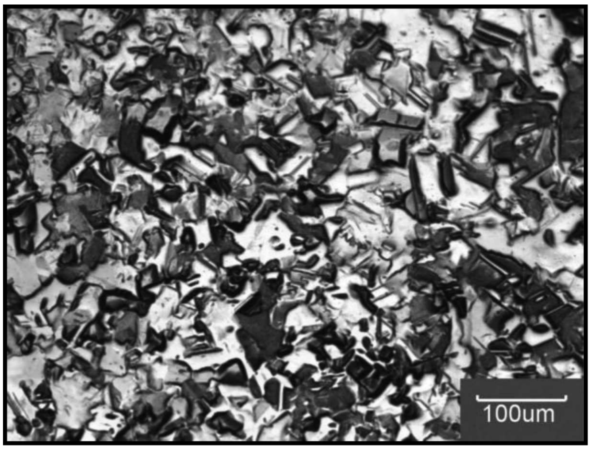

Fig. 3. Optical photomicrograph of copper

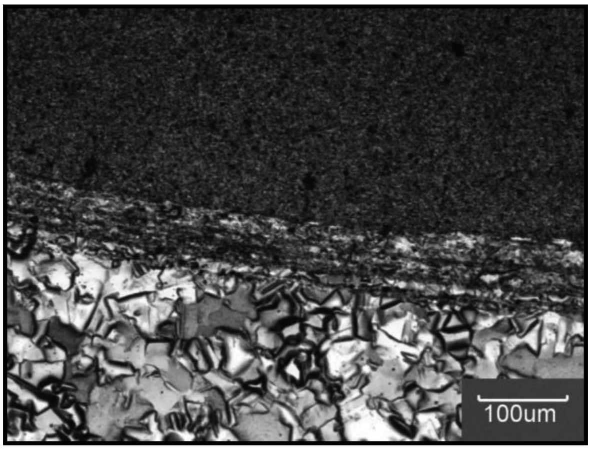

Fig. 4. Optical photomicrograph of interface zone

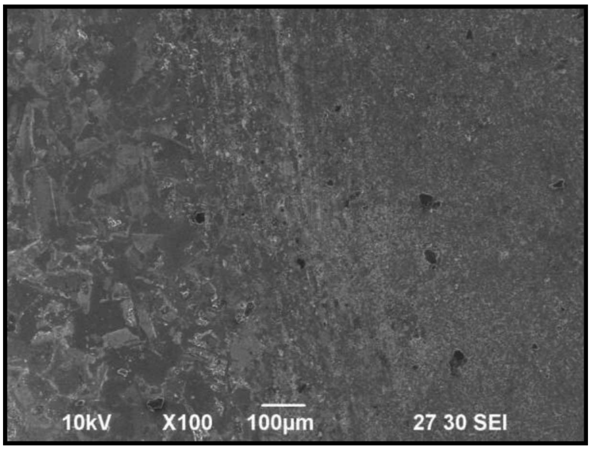

Fig. 5. SEM photomicrograph of interface zone

The optical and scanning electron micrographs of the stir zone (SZ) of Cu/B_4C composite layer are respectively shown in Fig. 6 and 7. B_4C particles are distributed homogeneously and bonded well with the copper matrix. The stirring of the tool causes high plastic strain which rearranges B_4C particles compacted in the groove into homogeneous distribution in the stir zone. FSP is considered as a hot working process in which the work piece is subjected to severe plastic deformation through the rotating pin and shoulder. The maximum temperature can reach 0.8 times the melting temperature (unit in K) of work piece material. The high temperature and severe plastic deformation results in fragmentation of B_4C particles. The average B_4C particle size in the stir zone is about 1-3 μm which is 12-14 μm lower than that of the as received B_4C particle. The large variation in B_4C particles size as depicted in Fig. 1f gives an evidence of fragmentation. Unbroken, partially broken and thoroughly broken B_4C particles are clearly visible.

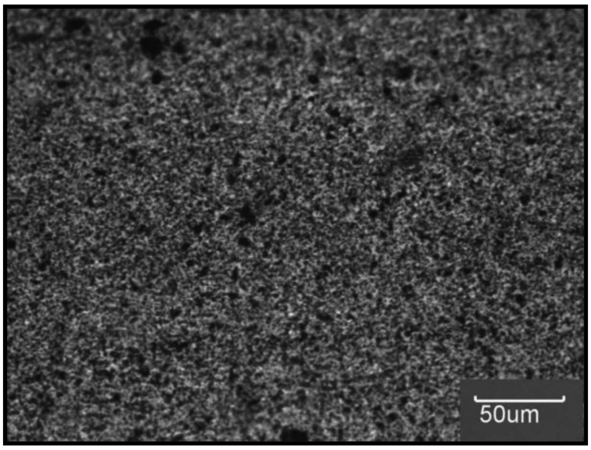

Fig. 6. Optical photomicrograph of stir zone

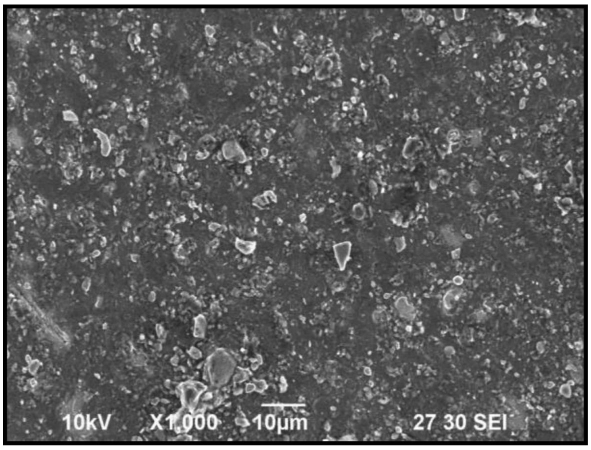

Fig. 7. SEM photomicrograph of stir zone

B_4C coating on Cu is difficult to achieve using conventional coating methods such as plasma spraying, laser melt injection etc due to the instability of B_4C particles in contact with liquid Cu which triggers interaction between B_4C and Cu [19]. Such interactions are avoided using the novel solid state technique FSP. The applied frictional heat does not promote any reaction between Cu and B_4C. The XRD plot presented in Fig. 8 shows no evidence for the formation of third phase within the composite layer apart from the peaks of Cu and B_4C. Therefore FSP is an appropriate technique to fabricate Cu/B_4C SMMC.

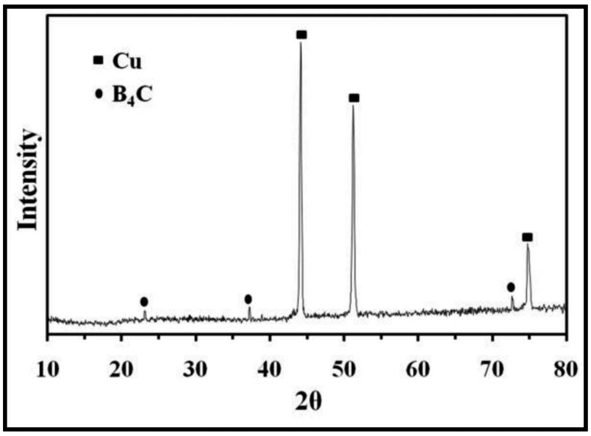

Fig. 8. XRD plot of Cu/B_4C SMMC

3.3. Microhardness

The microhardness distribution across Cu/B_4C composite layer and Cu matrix is depicted in Fig. 9. The average hardness of Cu matrix and Cu/B_4C composite layer is respectively 78.8 HV and 99.2 HV. The microhardness of the surface dispersion strengthened compositeis improved by 26%. FSW of Cu leads to softening of stir zone due to annealing effect [20]. The marginal drop in hardness adjacent to the stir zone can be attributed to annealing effect. But due to the addition of B_4C particles, the SMMC overcomes this annealing effect in the stir zone resulting in higher hardness. The factors contribute to hardening of stir zone are; (i) B_4C particles offer resistance to the movement of dislocation during plastic deformation and increase its density; (ii) B_4C particles can restrain the growth of crystal grains and refine the crystal grains of Cu (Orawan mechanism); (iii) Uniform dispersion of B_4C particles in the Cu matrix; (iv) Good bonding between B_4C particles and Cu matrix. The hardness fluctuation is observed across the surface dispersion strengthened compositewhich can be attributed to the following cause. The plasticized Cu has to flow into the groove to fill it to yield a defect free continuous stir zone. Therefore, friction stir welding and processing take place at the centre while friction stir processing alone takes place away from the centre. The centre may experience less deformation compared to the sides.

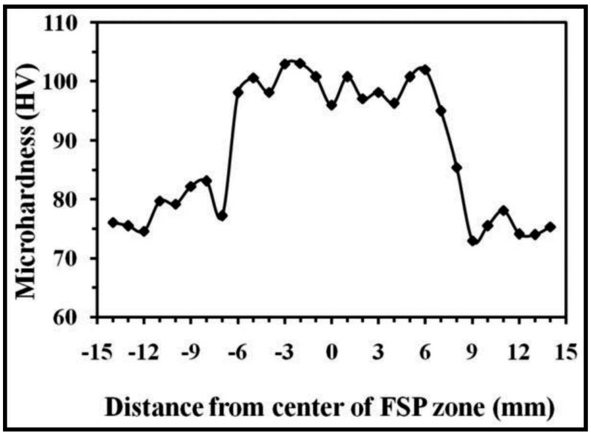

Fig. 9. Microhardness profile of Cu/B_4C SMMC

4. Conclusions

Copper reinforced boron carbide particulate surface dispersion strengthened compositeis successfully fabricated using friction stir processing. The fabricated Cu/B_4C composite layer is well bonded to the copper substrate.B_4C particles are distributed homogeneously and well bonded with the copper matrix. The hardness of the surface dispersion strengthened compositeis 26% higher to that of the copper matrix.

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