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Influence of Sn and Bi additions on the structures and wear properties of Cu–Sn–P–Ce cBN tools

In this work Sn and Bi were added to Cu–Sn–P–Ce for improving its microstructures and properties. Structures of the three matrices were investigated by XRD, SEM and EDS. The $Cu_{41}Sn_{11}$ *became the main microstructure with some pores, the grinding ratio increased, and the grinding efficiency improved slightly with the addition of Sn to Cu–Sn–P–Ce. Bi was distributed in the form of simple substance, the grinding ratio increased, and the grinding efficiency greatly reduced with the addition of Bi to Cu–Sn–P–Ce.*

***Keywords**: cBN, metal matrix, structure, wear properties.*

INTRODUCTION

Stainless steels are difficult to machine because of their high toughness, high work hardening rate and low thermal conductivity. Due to the poor machining ability, the surface and sub-surface are easily affected by the machining process. Jiang et al. compared grindability of different stainless steel grades and reported poor wheel life and high adhesion between the workpiece and the wheel [1]. A high volume fraction of martensite has been found to be introduced on 304 L stainless steel surface by grinding process [2].

The cubic boron nitride (cBN) tool is demonstrated to be beneficial for stainless steels grinding due to lower grinding forces and deflection [3]. The cBN tool is composed of cBN and matrix. Further, the microstructure of the matrix influences the wear properties of tools. However, few investigations have been attempted to the microstructures of matrix and its effect on the wear properties of tools. A brittle metal matrix should be designed to improve the efficiency of metal matrices. For metal matrices, Cu–Sn alloy system is widely used, with 80Cu–20Sn[1] alloy being a relatively brittle matrix [4]. Cu–P alloy in the preparation of the matrix material can improve the efficiency and prolong the service life [5]. Cu–Ce alloy can increase diamond retention capacity [6], Sn and Bi can decrease the sintering temperature [7].

In this work Sn and Bi were added to Cu–Sn–P–Ce for improving its microstructures and properties, respectively. The effects of microstructures on grinding performances were studied in terms of the friction coefficient, grinding ratio and quantity of metal removal. The investigated results will optimize the suitable matrix for grinding stainless steels.

EXPERIMENTAL PROCEDURE

The starting metal materials were the water atomized 80Cu–20Sn powder and tin powder with the particle size of less than 75 μm, and the water atomized 92Cu–8P,

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[1] Hereafter the composition is given in wt %.

the water atomized 80Cu–20Ce and Bi powder with the particle size of less than 43 μm. Mixtures of these starting powders were prepared by mechanical mixing for 2 h. The three matrices were hot-pressed in graphite molds for 5 min at 450 °C under 25 MPa.

The friction coefficient were measured using a pin-on-disk wear testing rig at a sliding speed of 0.81 ms^{-1} for 3 min, according to the method of Venkateswarlu et al. [8]. This test was conducted against a 304 L stainless steel, and the applied load was 200 N.

A solution of 2 g of $FeCl_3$, 2 g of $K_2Cr_2O_7$, 20 mL of HCl and 100 mL of water was used to reveal the structures of the polished specimens under an optical microscope. Structural aspects were performed through X-ray diffraction (XRD), and chemical analysis via X-ray dispersive energy spectroscopy (EDS) coupled to a scanning electron microscope (SEM).

Grinding experiments were also carried out on the pin-on-disk wear testing rig in the same experimental conditions. The cBN tools contained 50 % (0.44 $g{\cdot}cm^{-3}$) of diamond grains with a grain size of 250–300 μm (50/60 US mesh) embedded in three matrices.

RESULTS AND DISCUSSION

Influence of Sn and Bi additions on the structures

Figure 1 shows the optical microstructure of the Cu–Sn–P–Ce specimen after hot pressing at 450 °C. Four colors structural constituents were observed under the optical micrograph, i.e., a ‘yellow’ structural constituent, a ‘light gray’ structural constituent, a ‘gray’ structural constituent, and a ‘dark gray’ structural constituent. Four points in the matrix were investigated by EDS to semiquantitatively define the compositions of different color structural constituents in Fig. 2. The EDS quantitative results indicate that the point 1 is composed of 81.1 at % Cu and 18.9 at % Sn; point 2, 73.8 at % Cu and 26.2 at % P; point 3, 74.4 at % Cu and 25.6 at % P; point 4, 87.2 at % Cu and 12.8 at % Sn. Meanwhile, the diffraction peaks of αCu, Cu_3Sn, Cu_3P, and $Cu_{41}Sn_{11}$ were found in Fig. 3. Combined with the results of the XRD and EDS, the four different color structures can be ascertained based upon our previous research [9]. The yellow structural constituent is αCu, the Sn being dissolved in solid solution with the Cu. The light gray, gray, and dark gray structural constituents are $Cu_{41}Sn_{11}$, Cu_3Sn, and Cu_3P.

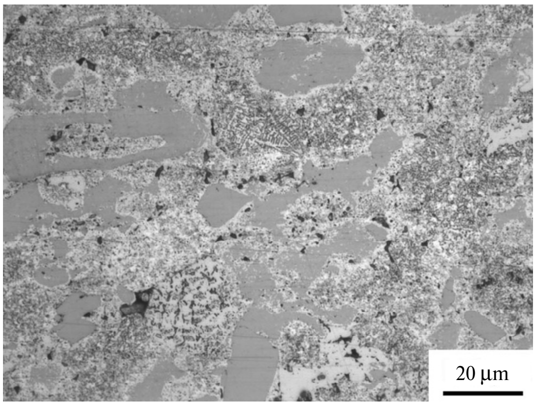

Fig. 1. Optical microstructure of the Cu–Sn–P–Ce specimen.

Figure 4 shows the optical microstructures of the Cu–Sn–P–Ce–Sn specimen after being hot-pressed at 450 °C. By the addition of the element Sn, the amount of the αCu decreased, the $Cu_{41}Sn_{11}$ became the main microstructure and a little Cu_3Sn was found at the centre of $Cu_{41}Sn_{11}$. The amount of pores increased due to Sn melting and reacting with αCu.

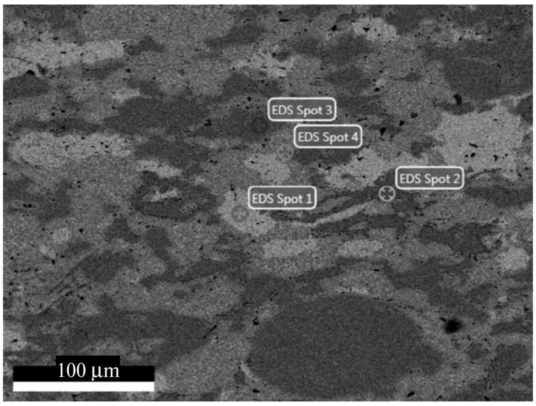

Fig. 2. SEM micrograph of the Cu–Sn–P–Ce specimens.

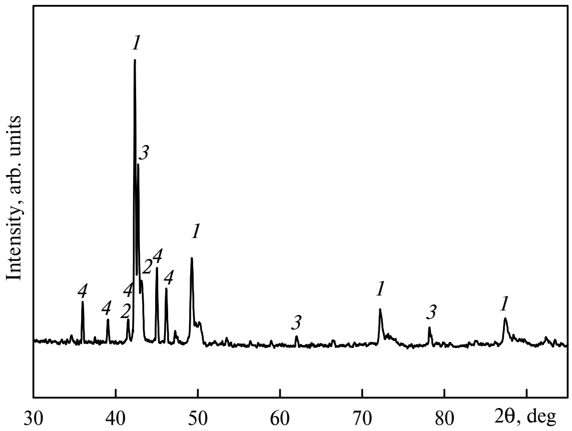

Fig. 3. X-ray diffractograms of the Cu–Sn–P–Ce specimens: Cu (*1*), Cu_3Sn (*2*), $Cu_{41}Sn_{11}$ (*3*), Cu_3P (*4*).

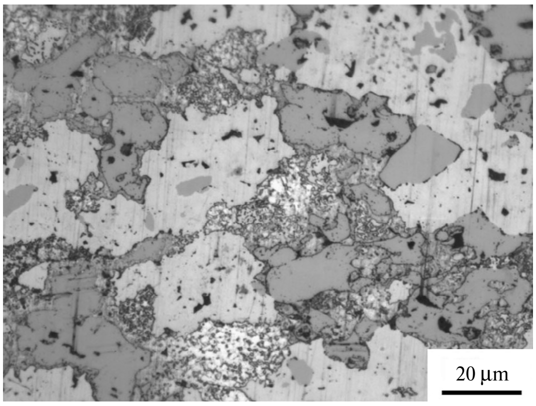

Fig. 4. Optical microstructure of the Cu–Sn–P–Ce–Sn specimen.

Figure 5 shows the SEM micrograph of the Cu–Sn–P–Ce–Bi specimen after hot pressing at 450 °C. By the addition of the element Bi, a bright structural constituent appeared, which was Bi investigated by EDS. The result shows that Bi was distributed in the form of simple substance in some pores of the samples due to the immiscibility between Bi and the other alloys.

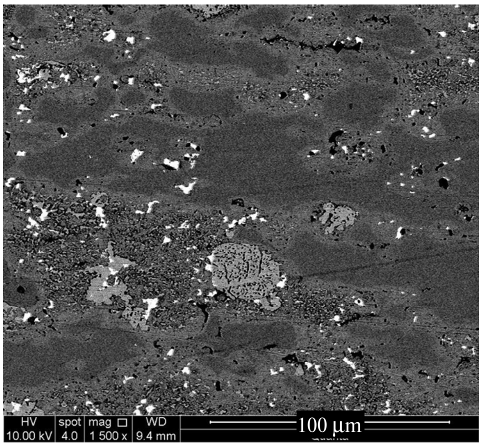

Fig. 5. SEM micrograph of the Cu–Sn–P–Ce–Bi specimen.

Influence of Sn and Bi additions on the wear properties

The friction coefficients varying with time are illustrated in Fig. 6, the friction coefficient decreased after adding Sn and Bi in Cu–Sn–P–Ce. Moreover, the friction coefficient decreased and the curve became smooth especially with the addition of Bi (see Fig. 6, *c*).

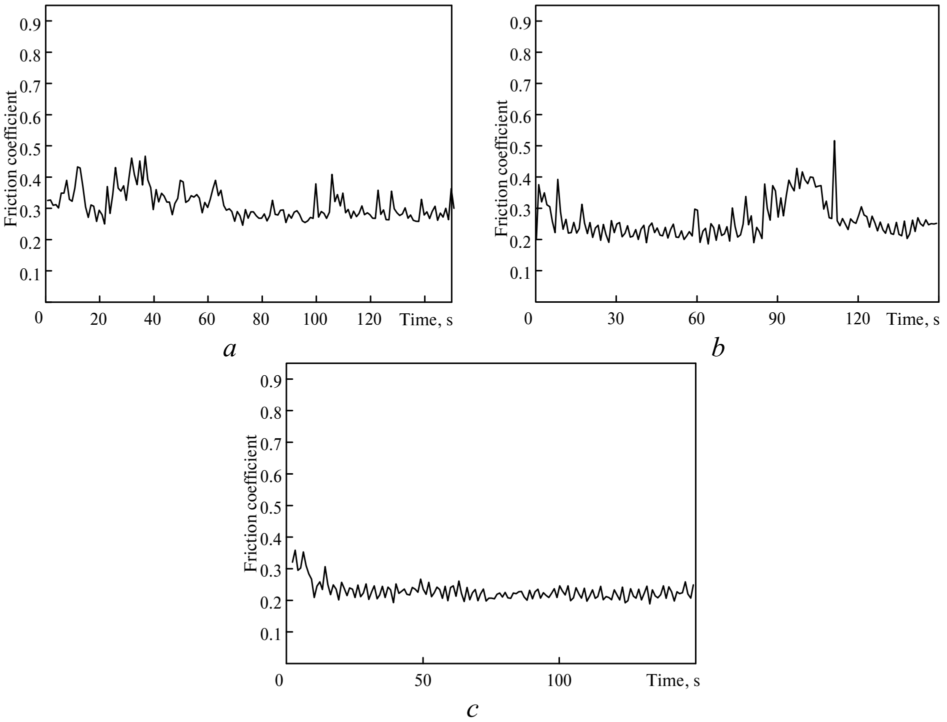

Fig. 6. Friction coefficients vs. time: the Cu–Sn–P–Ce specimen (*a*), the Cu–Sn–P–Ce–Sn specimen (*b*) and the Cu–Sn–P–Ce–Bi specimen (*c*); average friction coefficient – 0.313 (*a*), 0.262 (*b*), 0.229 (*c*).

Table shows the grinding ratio and quantity of metal removal in the same experimental conditions. Before adding Sn and Bi the grinding ratio of Cu–Sn–P–Ce was 26, and after that the grinding ratios were 42 and 70. Meanwhile, the quantity of metal removal increased from 156 to 168 mg, and decreased from 156 to 61 mg, respectively. These results indicate that the grinding ratio increases in almost 1.6 times and the grinding efficiency improves slightly after adding Sn in Cu–Sn–P–Ce. Furthermore, the grinding ratio increases almost 2.7 times and the grinding efficiency greatly reduces after adding Bi to Cu–Sn–P–Ce.

Results of the grinding ratio and quantity of metal removal of the specimens

Matrix	Grinding ratio	Quantity of metal removal, mg
Cu–Sn–P–Ce	26	156
Cu–Sn–P–Ce–Sn	42	168
Cu–Sn–P–Ce–Bi	70	61

The changes of wear properties can be explained by the transformations of the structures. In our previous research [9], the increase of the amount of $Cu_{41}Sn_{11}$ can improve the wear resistance distinctly. Therefore, adding Sn in Cu–Sn–P–Ce should improve wear resistance and increase the grinding ratio of the tool. In addition a few pores in the matrix are available to absorb the metal chip from work pieces which corresponds with the decrease of the friction coefficient, so better chip accommodation can improve the grinding efficiency. The wear of the tool can also be reduced because Bi can enhance the lubrication effect and reduce the friction coefficient. Thus, the grinding ratio increases greatly after adding Bi in Cu–Sn–P–Ce. Nevertheless, the less wear of matrix causes the less protrusion of abrasive, and the grinding efficiency greatly reduces.

CONCLUSIONS

In this study structures of the three matrices were investigated by XRD, SEM, and EDS, and the results showed that the Cu–Sn–P–Ce matrices were composed of αCu, $Cu_{41}Sn_{11}$, Cu_3Sn and Cu_3P. By the addition of the element Sn, the amount of the αCu and Cu_3Sn decreased, the $Cu_{41}Sn_{11}$ became the main microstructure with some pores. And the grinding ratio increased almost 1.6 times and the grinding efficiency improved slightly. By the addition of the element Bi, Bi was distributed in the form of simple substance in some pores, the grinding ratio increased almost 2.7 times and the grinding efficiency greatly reduced.

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Методами XRD, SEM та EDS досліджено структуру матриць Cu–Sn–P–Ce з добавками Sn і Bi, які додавали для поліпшення мікроструктури і властивостей матеріалу. При додаванні Sn у Cu–Sn–P–Ce основою мікроструктури став $Cu_{41}Sn_{11}$ *з невеликою кількістю пор, коефіцієнт шліфування збільшився, а ефективність шліфування дещо покращилася. При додаванні Bi у Cu–Sn–P–Ce він був розподілений у вигляді простої* *субстанції, коефіцієнт шліфування збільшився, а ефективність шліфування значно зменшилася.*

***Ключові слова**: cBN, металеві матриці, структура, зносостійкість.*

Методами XRD, SEM и EDS исследована структура матриц Cu–Sn–P–Ce с добавками Sn и Bi, которые вводили для улучшения микроструктуры и свойств материала. При добавлении Sn в Cu–Sn–P–Ce основой микроструктуры стал $Cu_{41}Sn_{11}$ с небольшим количеством пор, коэффициент шлифования увеличился, а эффективность шлифования немного улучшилась. При добавлении Bi в Cu–Sn–P–Ce он распределялся в виде простой субстанции, коэффициент шлифования увеличился, а эффективность шлифования значительно уменьшилась.

***Ключевые слова**: cBN, металлическая матрица, структура, свойства износа.*

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