Study on Thermal Behaviour of Tungsten Cemented Carbide Tip Scraps

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Abstract. WC-Co is widely used as a hard metal tool tip for metal machining purposes. This study investigates the oxidation behavior of WC-Co tips from industrial waste products. The results of this study are also used as a consideration in the utilization of WC-Co tips waste as a reinforcing material for applications in the mining industry. The study was carried out by oxidizing WC-Co tips at 900 °C for 1, 3 and 5 h. In type A WC-Co tips, oxidation starts from parts that have been damaged and worn out due to the previous use process. Meanwhile, the type B WC-Co tips has better oxidation resistance compared to type A as indicated by the absence of volume expansion. This is due to the different coating material for each WC-Co tips, TiAlC for type A and TiC-TiN for type B. The oxide from type A carbide forms microcracks due to volume expansion and has a porous microstructure.

Keywords: Tool tip · WC-Co · Oxydation

1 Introduction

In the modern manufacturing industry, the use of cemented carbides has increased significantly, especially in the application of cutting tools, rock drills and molds due to their high hardness, wear resistance, and good corrosion resistance [1–3]. The use of cemented carbide as a cutting tool produces several advantages, including the high precision dimension and good product quality. However, cemented carbide has disadvantages when used at relatively high temperatures due to oxidation which will certainly affect the properties of the cemented carbide [4].

Several studies have reported on the effect of oxides on the properties of cemented carbides. Cemented carbides in this case are tungsten carbide and cobalt (WC-Co) which are exposed to a temperature of 900 °C, the volume expansion is more than 200% [5]. Shi et al. reported that the effect of oxidation on WC-10Co will significantly reduce the hardness of cemented carbide [6]. Based on a study conducted by Xian Wu et. al., at high temperatures, the element Co is oxidized earlier than the WC and there is an weight

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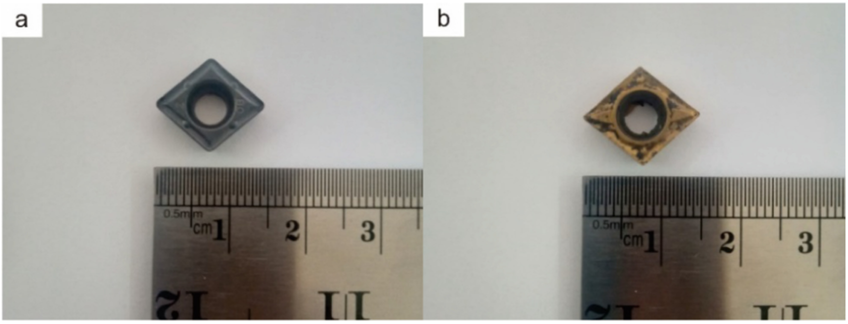

Fig. 1. Industrial waste WC-Co Carbide tip (a) type A and (b) type B

gain of the WC when heated at a temperature of 700 °C [3, 7]. In addition, the oxidation reaction in WC-Co is very slow at low temperatures and will increase drastically at high temperatures [8]. Several other studies stated that the oxides formed in WC-Co were dominated by compounds of WO_3 and $CoWO_4$, as well as a small amount of Co_3O_4 and Co_2O_3 compounds [5, 6, 8–10].

Very few studies have been conducted on WC-Co insert tip that is disposed from the manufacturing industry. Nowadays, several research has been conducted on recycling of the WC-Co or use as reinforcement for other materials. Therefore, in this study, an investigation was carried out on the oxidation behavior of WC-Co carbides from industrial waste products. The results of this study are also used as a consideration in the utilization of carbide tip waste as a reinforcing material for applications in the mining industry.

2 Experimental Procedures

WC-Co tips were obtained from industrial cutting tool after several time used and being waste, as shown in Fig. 1. The WC-Co tips which obtained is distinguished by color and categorize into two type, type A for gray color carbide tips and type B for yellow color carbide tips. The isothermal oxidation experiments were carried out to investigate the oxidation effect on the WC-Co insert tips. The WC-Co insert tips were dried firstly inside the vacuum furnace to remove any moisture content. Each carbide tip was heated to temperature 900 °C inside the muffle furnace. After achieving the temperature set condition, the sample was held for 1, 3, and 5 h. After that, the samples were cooled in the normal air condition outside the muffle furnace. The schematic curve of the heat treatment process was shown in Fig. 2.

Scanning electron microscope (SEM, Rigaku, SU 3500; Japan) with secondary electron image (SEI) method was used to determine the morphology of the WC-Co insert tips sample. The chemical composition of the samples was tested using energy dispersive spectroscopy (EDS; Rigaku, SU 3500; Japan).

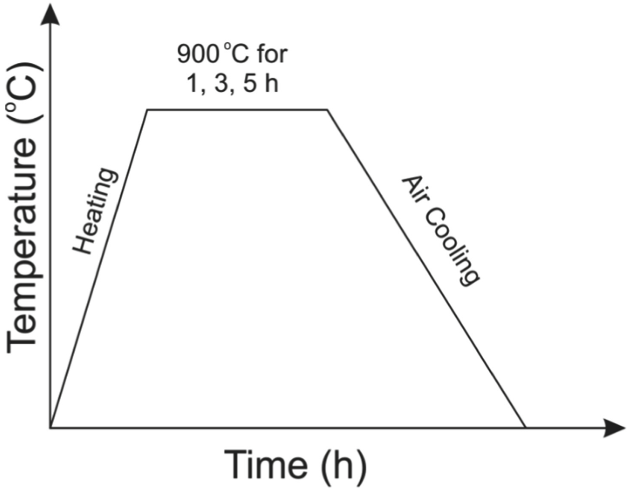

Fig. 2. The schematic curve of the heat treatment process.

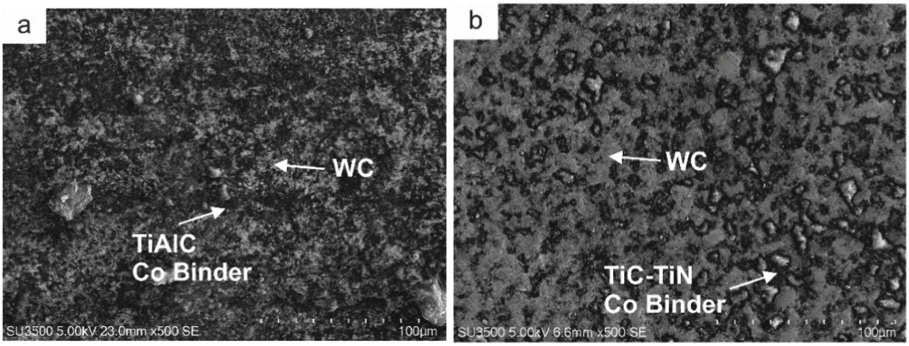

Fig. 3. Secondary image of carbide tips (a) type A and (b) type B

3 Results and Discussions

3.1 Microstructure of WC-Co Tips

Figure 3 shows the observed SEM images of the surface of WC-Co insert tip type A and type B. In type A insert tip, WC particles are bond by Co element. From the EDS results, it was found that on type A carbide tips has a layer that consist of 23.88 at.% Ti, 25.13 at.% Al, and 38.01 at.% C. Type B carbide tips also has similar situation as type A, but the coating material which has given into the carbide tips is different from type A. Based on the EDS results, type B carbide tips has a composition of 32.22 at.% Ti, 21.79 at.% C, and 29.76 at.% N. The addition of nitride and carbide compounds such as TiC, VC, Mo2C, TiN, NbC, etc. can increase the resistance to oxidation and improve the mechanical properties of the WC-Co insert tip [5, 11].

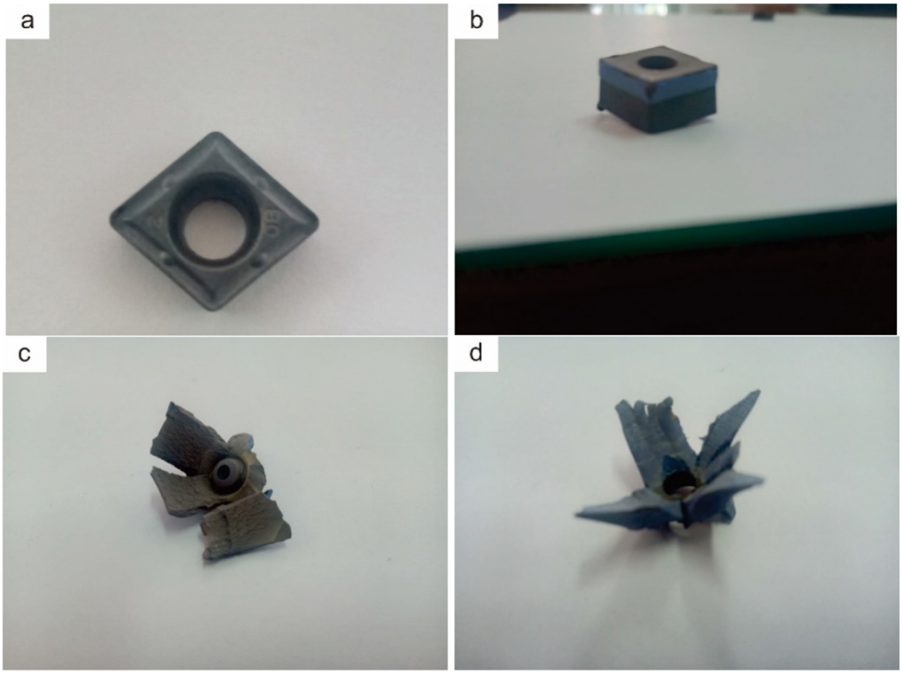

Fig. 4. Macroscopic images of carbide tips type A which isothermally oxidized at 900 °C with various times: (a) 0 h, (b) 1 h, (c) 3 h, and (d) 5 h.

3.2 Oxidation of WC-Co Tips

Figure 4 shows the comparison of WC-Co tips after heat treating at 900 °C for 1, 3, and 5 h. As can be seen in Fig. 4(b), after heat treating at 900 °C for 1 h, oxidation starts at the surface of the sample and expands uniformly upwards. Then two layers with different colors are formed as can be seen in Fig. 4(b). In Figs. 4(c) and 4(d), the WC-Co insert tips undergo oxidation over 3 and 5 h. The oxide was developed further from the worn and damaged tips during the operation before. The thinning effect of the TiAlC protective layer due to the previous cutting process made the carbide tips easily oxidized at high temperatures. WC-Co insert tip that are heated for more than 3 h completely transform into tungsten oxide or cobalt oxide. In addition, the volume expansion causes the WC-Co insert tip unable to maintain their original shape.

On the other hand, type B WC-Co insert tips which was oxidized at a temperature of 900 °C for 1, 3, and 5 h gave different results compare to type A. Figures 5(b), 5(c), and 5(d) show the results of the macrostructure of oxidized type B carbide tips. Compare to before heat treated, the entire type B carbide tip did not experience volume expansion due to oxidation as type A carbide. It can be the result of difference coating material on WC-Co insert tip type B which uses TiC-TiN. TiC-TiN are not easily oxidized at a temperature of 900 °C. Meanwhile, TiC phase only starts to oxidize if it is heated to a

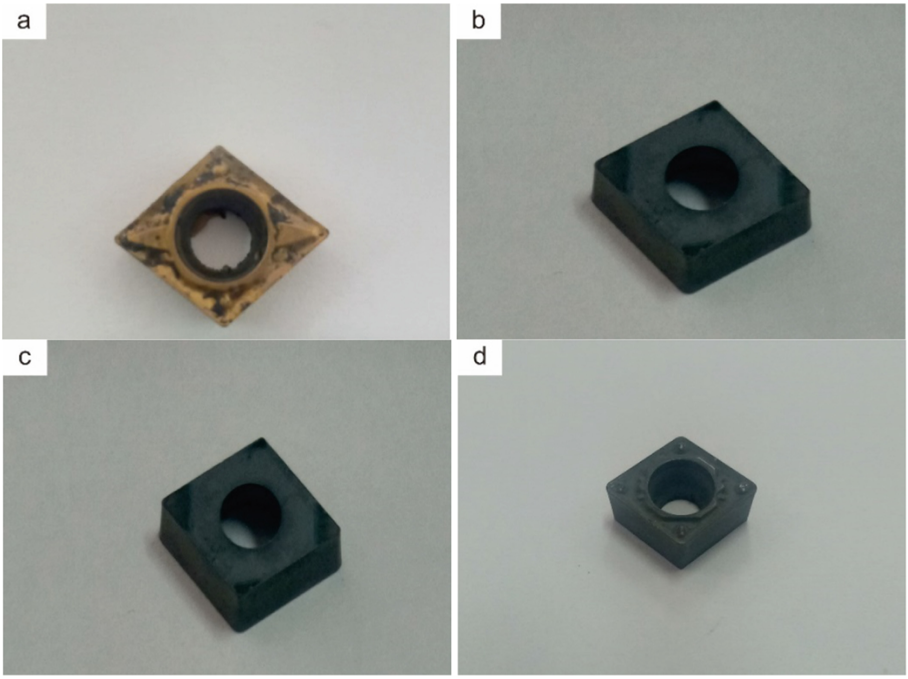

Fig. 5. Macroscopic images of carbide tips type B which isothermally oxidized at 900 °C with various times: (a) 0 h, (b) 1 h, (c) 3 h, and (d) 5 h.

temperature of 1000–1200 °C [12]. However, the EDS results showed that there was an oxide element on the WC-Co insert tips surface and it's indicated as TiO_2 compounds. The formation of thin layer TiO_2 on the carbide surface is in agreement with previous studies. Chen et al. and Yin et al. were mentioned that oxides layer still can be form on the TiN coating at temperature range of 450–600 °C [13, 14].

Figure 6(a) shows the micrograph of type A WC-Co tips. The figure shows an indication of oxidation mechanism on type A carbide tips. In Fig. 6(a) three areas are formed in the type A WC-Co tips which indicate different oxidation behavior at 900 °C. Area 1 is an area that does not occur oxidation, Area 2 is the first oxidation that occurs on the surface of the WC-Co tip before peeling off, and Area 3 is the oxidation that occurs inside the coating layer. Compared to the unoxidized area, the oxidized region forms microcracks that propagate in the direction of oxide growth due to the large volume expansion of the oxidized region. Oxygen can easily transport through the WC-Co tip due to the presence of microcracks so the oxide can grow rapidly [5]. As can be seen in Fig. 6(b), some porous structure was form in the oxidized region.

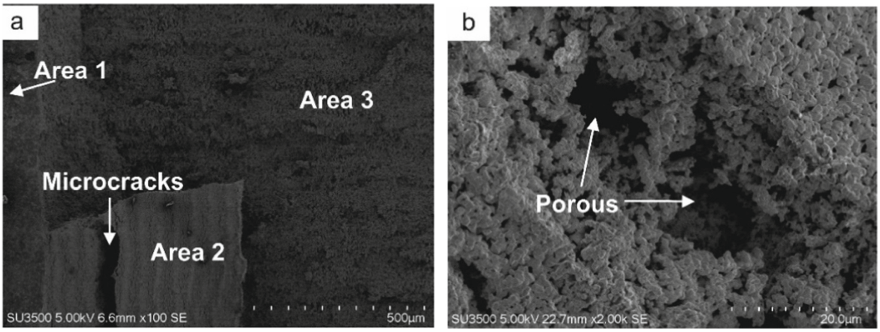

Fig. 6. Secondary electron images of carbide tips type B showing (a) interface between an unoxidized region and an oxidized region and (b) microstructure of oxidized carbide tip.

4 Conclusions

Investigation of WC-Co tips was carried out to determine the effect of temperature on the formation of oxides on tips. WC-Co tips in this study are divided into two types based on the color of tip, type A and type B. Apart from color, the two carbide tips are also distinguished by their coating material, TiAlC for type A and TiC-TiN for type B. In type A, oxidation starts from parts that have been damaged and worn out due to the previous cutting process. The oxidation causes volume expansion and the WC-Co tip unable to maintain its shape. Type B WC-Co tips have better oxidation resistance compared to type A as indicated by the absence of volume expansion on the type B but thin layer oxide is still formed on the carbide surface. This is because the type of TiC coating material is more resistant to oxidization until temperature range of 1000–1200 °C than TiN which begins to form TiO_2 at 450–600 °C. The oxide formed in type A carbide forms microcracks due to volume expansion and has a porous structure.

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