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EFFECT OF FREE CARBON ON THE MECHANICAL AND TRIBOLOGICAL PROPERTIES OF CEMENTED CARBIDES

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Abstract: *In this paper the friction and sliding wear of WC-Co cemented carbide with free graphite content are studied. The influence of the mixing parameters of the initial powders to the graphite distribution and wear rate is presented. The aim of the study was to develop a new bearing material based on the conventional WC-Co. Friction and wear tests were carried out using four different types of WC-Co alloys under unlubricated conditions against steel (0.45 wt.% C) disk. Sliding wear tests were carried out using moderated block-on-ring equipment. The effect of free carbon in the cemented carbide structure on the wear rate is discussed. It is shown that wear resistance of cemented carbides depends on the carbon content and graphite distribution in the alloy. Free carbon phase was successful in decreasing the wear of the WC-Co. It was shown that there is correlation between standard deviation value of graphite distribution and wear test results.*

Key words: Cemented carbide; Friction; Sliding wear; Wear mechanisms

1. INTRODUCTION

WC based cemented carbides are widely used in engineering applications for their excellent mechanical properties and outstanding wear resistance in combination with high toughness. The mechanical properties of WC-Co depend on the WC grain size and the ductile binder phase. The sliding and abrasive wear resistance of WC-Co is often proportional to its hardness, but inversely proportional to the fracture toughness [1]. Improving the resistance in sliding wear is very important for the manufacturing of seal rings, bearings, sockets etc. The bearings and the seals often work in dry sliding conditions.

Of three major types of wear (abrasive, erosive and sliding), sliding wear is the most complex type of wear, not in concept but in the way different materials respond to sliding conditions [2]. Sliding wear of WC-Co cermets has been studied under various circumstances [3-12]. The published data indicate that the wear resistance of this material under dry conditions is high, depending on carbide/binder ratio, and carbide grain size, being also greatly dependent on the bulk hardness of the material [10-12].

There have been many attempts to predict sliding wear rate. Majority of the associated scientific works recently published state that the Archard´s wear formula is the most acknowledged formula in the field of sliding wear [13]:

$$W = k \cdot s \cdot F_n / H \qquad (1)$$

where W – volumetric wear [mm^3], k – dimensionless wear coefficient, s – length of distance covered [m], F_n – normal? pressure applied [N], and H is the Vickers hardness number of the softer material. Lancaster [14] proposed the modified empirical wear formula:

$$k = W / \ F_n \cdot s \qquad (2)$$

This wear coefficient k, with units of mm^3 N^{-1} m^{-1}, has proved more useful for the comparison of the wear behaviour of different materials than Archard´s equation.

In this study, it was tried to design a microstructure involving the free graphite being imbedded in the matrix of conventional WC-13 wt% Co cemented carbide. The unique composite microstructure was expected to increase the wear resistance of the cemented carbide. The graphite was expected to react as a solid lubricant during the sliding wear test.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The WC-Co hard metal samples were fabricated using a conventional Boart Longyear TCD S13 powder as a matrix material. The structure of l WC-13% wt.% Co cemented carbide with graphite granulates is illustrated in Fig. 1B.

The free graphite bath in the WC-Co matrix was got by adding graphite powder to the WC-Co powder. The mass fraction of free graphite to matrix were 1.5 wt%. The graphite was mixed with the powder of WC-13 wt.% Co by dry-milling (Fig. 1A).

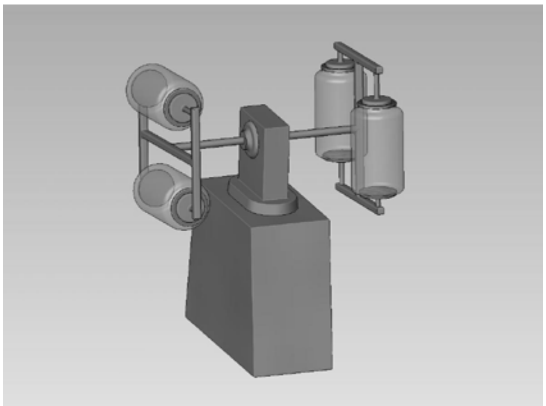
All the materials were fabricated using a conventional powder metallurgy route [15]. Compaction pressure was 80 MPa and sintering temperature 1400 ºC.

The properties of tested specimen materials are listed in Table 1

Material notation	Free graphite wt.%	Density (g/cm3)	HRA	TRS MPa
S13	0	14,2	80	3200
S13-C1	1,0	12,9	60	800
S13-C1.5	1,5	12,7	71	400
S13-C2	2,0	12,0	62	320
S13-C3	3,0	10,6	20	260

Table 1. Chemical composition (wt. %) and properties (density, HRA, transverse rupture strength TRS) of tested materials.

The materials in table are based on Boart Longyear S13, which is fine grained cemented carbide with 13 wt.% of cobalt. Other mixtures consist of S13 cemented carbide plus free graphite, given in Table 1 by weight percentage.



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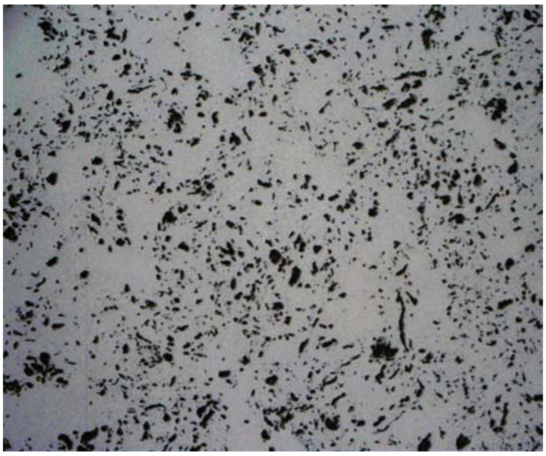

B

Fig. 1. (A) mixing equipment (B) structure of hardmetal with free graphite in WC-Co matrix.

The hardness of the samples was measured using Rockwell hardness test HRA and a Vickers pyramid indenter. Vickers hardness tests were made under a load of 10 kgf using a load time of 10 s. Using both methods an average hardness value was determined (base of five indentions).

Transverse rupture strength was determined in accordance with the ASTM Standard B406-95 by three point method using device "Instron 8516".

Tribological tests were performed in a specially designed block-on-ring tribometer (Figure 2.). The block was pressed against steel disk (d=178mm) with normal load (F_n=40 N) and at constant sliding speed (2.2 ms^{-1}). Carbon steel with hardness of 200HB was chosen for counterbody as a typical material for shafts and other machinery parts, working in sliding pairs with hardmetals. Wear tests were conducted under dry conditions in air. Room temperature and humidity were kept within 21±2° C and 40±5% RH, respectively.

Sliding distance was set at 8 km run. The test specimens were employed as the blocks with dimensions 22mm×12mm×5mm. The surface roughness of both WC-Co specimens and steel ring were prepared under R_z≈1.0μm.

Wear loss of the hardmetal blocks was obtained by weighting the block before and after the sliding using a digital balance with a scale 0.1 mg. Since the wear of materials generally fluctuates, the sliding test was repeated at least ten times under the same conditions. The standard deviation of test result was calculated.

The free graphite in the WC-Co microstructure was investigated by optical microscope and the graphite deviation were analysed by program Omnimet. With the Omnimet software it was possible to separate black graphite flakes from the cemented carbide matrix and analyze the distribution, size and shape of the graphite flakes. The test specimen was divided into 36 areas (fields) each ca 414000 μm². On every field the amount of free graphite were measured. The amount of graphite was given in volumetric percentage. Using those 36 results the standard deviation of free graphite in test specimen was automatically calculated. Mostly the amount of free graphite was between 10 and 25% and the mean value ca 15%.

The comparison of deviation of free graphite content makes it able to estimate weather the graphite is divided equally or not.

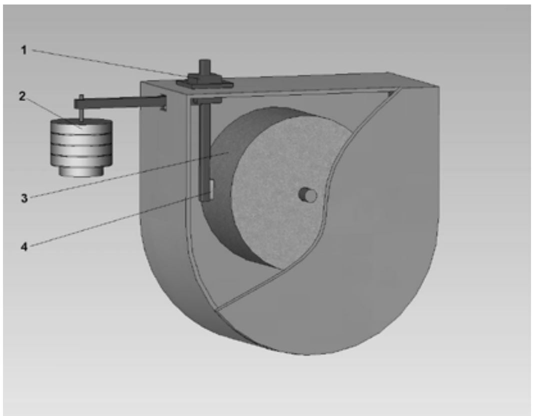

Fig. 2. Schematic image of the moderated block-on-ring-tester used in this study: 4 – specimen, 3 –steel ring, 1 – bar, 2-load

The aim of the analyze was to calculate the volumetric amount of free graphite on the surface of test specimen. From every tested specimen 36 fragments were analyzed and the standard deviation of graphite content distribution on the surface of test specimen was calculated.

The standard deviations value of wear test results were compared with the standard deviation value of free graphite distribution and an analysis was made to find correlations (a) between material properties and wear resistance, and (b) between powder preparation parameters and properties of obtained material.

3. RESULTS AND DISCUSSION

3.1 The influence of mixing time period to the graphite distribution

The aim of the study was to investigate the influence of production parameter (mixing time) to the microstructure of cemented carbide and also to the wear resistant rate.

Figure 3 illustrates the changes in standard deviation of free graphite volumetric (volumetric amount is given as a percentage of area) distribution values, unit is %. It was seen that the lowest standard deviation value has the material obtained by the mixing time 15 min.

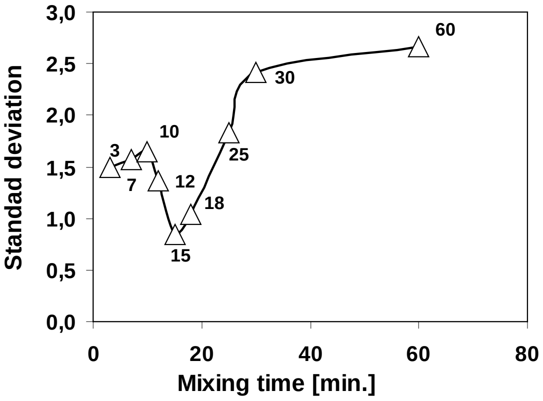

Fig. 3. The standard deviation of free graphite distribution values in hardmetal obtained by different mixing times.

Shorter and longer mixing period caused wider deviation of free graphite distribution values, it means that 15 minutes is the optimum mixing period to obtain the equal graphite distribution all over the test specimen surface.

As seen in Fig. 4 there is correlation between standard deviations of wear test results and free graphite deviation in the cemented carbide microstructure. It was seen that 15 min. is the optimum mixing period because the standard deviation of free graphite was lowest compared to the materials obtained by shorter or longer mixing period.

The analysis of both, wear tests and microstructure, gave the same result – the optimum time for the cemented carbide and graphite powder is 15 minutes. It was proved that there is tight correlation between processing parameters and properties of obtained material.

The results of experiments (mass loss) at loads of 40N are presented in Fig. 4 and it was seen that the WC-Co-C material with most equal graphite deviation (smallest standard deviation value of graphite distribution) did not have the best wear resistance.

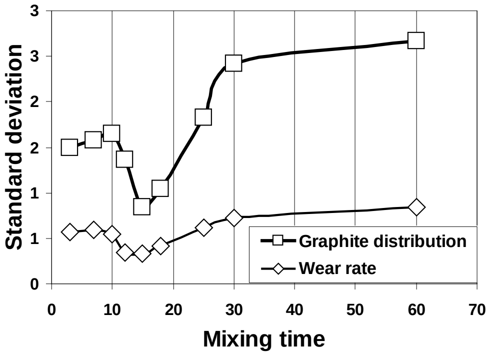

Fig. 4. The standard deviation of graphite distribution compared to the standard deviation of test results by sliding wear

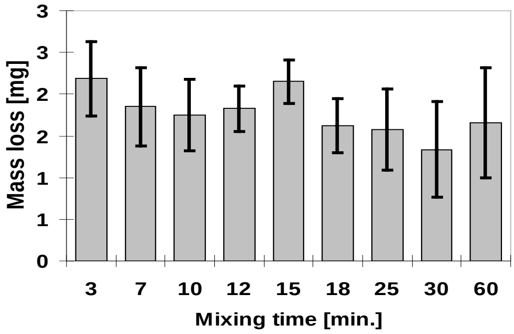

Fig. 5. The mass loss of tested materials vs. mixing time.

It can be explained by the phenomena that equal distribution of small graphite particles in the WC-Co microstructure is not the optimum solution for the sliding wear resistance.

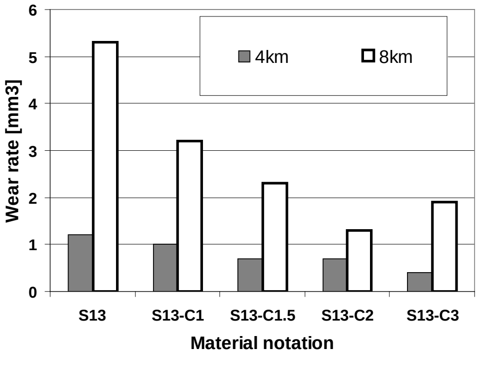

Fig. 6. Volume loss of WC-Co cemented carbides after 4 and 8 km run vs. amount of free graphite in the microstructure

3.2. The influence of free graphite content to the wear rate.

It was seen that both the unequal and equal distribution of graphite flakes helps to reduce the wear rate. There is no explanation in the moment why the material with the best graphite distribution had the worst wear resistance.

The volume wear data of S13 and S13 + free graphite specimens have been statistically analysed repeating 10 tests under the same nominal experimental conditions. Average volume loss for these and other alloys is presented in Fig6.

The volume loss of tested blocks at loads 40 N decreased dramatically with increased content of free graphite from 0 wt.% to 2 wt.%. The volume loss of the S13-C2 after 8 km run was more than three times lower than that of WC-13 wt.% Co conventional alloy (Boart S13). Fig. 6 shows that the volume loss of WC-Co alloys appears to increase with increasing sliding distance. The wear rate of tested materials was low in the initial stage of test and then increased rapidly. Only the volume of wear of WC-13 wt.% Co with 2 wt.% of free graphite increased linearly with the sliding distance. It can be explained with the phenomena that there is minimum amount of graphite needed between wear couples, to react as a solid lubricant.

Figure 6. shows that the in the present test conditions, the wear resistance of the cemented carbide with 2 wt.% free graphite was the highest.

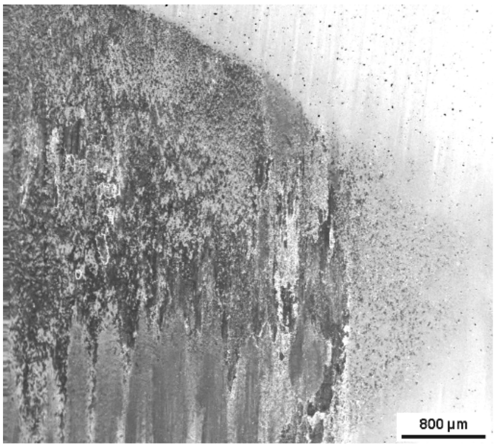

Figure 7. A-thin free graphite film on the worn surface of the tested block.

The morphological analysis of the worn surfaces was made by SEM. The wear mechanism has a complicated character and depends on material composition. The wear of WC-Co cemented carbides under dry conditions is caused mainly by removal of the cobalt binder followed by fracture of intergranular boundaries and fragmentation of carbide grains.

The free graphite worked as a solid lubricant between hardmetal block and steel ring counterbody (Fig. 7). It can be seen on Fig. 7 that there is thin graphite film on the worn surface of test specimen. As the worn area of tested WC-Co blocks was small and the contact area of carbon steel ring was much larger, then the effect of free graphite as lubricant did not apply an aggregate limit.

4. CONCLUSIONS

The following conclusions can be drawn from the experimental study:

1. Free graphite as a solid lubricant reduces the wear rate of hardmetal in the sliding conditions.
2. The optimum mixing period for the hardmetal and graphite mixtures is 15 minutes.
3. The equal graphite distribution does not guarantee the best performance in sliding conditions. The sliding wear is a complex phenomenon? and for the further investigations the optimum graphite amount and grain size have to be determined.

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