SLIDING WEAR CHARACTERIZATION OF CEMENTED CARBIDES FOR HIGH PERFORMANCE CUTTING TOOLS

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ABSTRACT.

Cemented carbides have been used for manufacturing of cutting tools during the last several decades; the main constituents are tungsten carbide particles, which are hard and brittle, and cobalt as binder metal, which is relatively soft and ductile. In general the material properties are determined by cobalt content and tungsten carbide grain size, for example hardness increases with decreasing grain size and binder content.

The aim of this work was to investigate and discuss the relationships among the microstructure, mechanical properties and chemical composition of cemented carbides because wear resistance is not a unique property of a cutting tool which can be determined by one simple laboratory test, or correlated with one simple property such as hardness. The tribological study showed that in addition to the grain size, the morphology, the gaps between particles and the binder content directly affect the wear rate of WC substrates, which must be considered for applications of these materials for cutting tools.

RESUMEN.

Los carburos cementados se han utilizado para la fabricación de herramientas de corte durante las últimas décadas, constituidos por partículas de carburo de tungsteno (duras y frágiles) y cobalto que actúa como aglutinante (relativamente suave y dúctil). Sus propiedades están principalmente determinadas por el contenido de cobalto y tamaño de grano del carburo, por ejemplo la dureza aumenta con la disminución del tamaño de grano y el contenido de aglutinante.

El objetivo de este trabajo es estudiar las relaciones entre microestructura, propiedades mecánicas y composición química de carburos cementados teniendo en cuenta que la resistencia al desgaste de una herramienta de corte no es una propiedad que puede ser determinada con una prueba de laboratorio o relacionarla únicamente a una propiedad como la dureza. El estudio tribológico llevado a cabo mostró que además del tamaño de grano, la morfología, los espacios entre las partículas y el contenido de aglomerante afectan directamente la rapidez de desgaste de los substratos de WC, lo cual deberá ser considerado para aplicaciones de estos materiales para herramentales de corte.

Keywords: cemented carbides, cutting tools, wear resistance, pin on disk.
Palabras Clave: carburos cementados, herramientas de corte, resistencia al desgaste, estudios tribológicos.

1. INTRODUCTION

Cemented Carbides are required to fulfill a variety of different machining applications, the key word for manufacturers of cutting tool is productivity, for example a 30% reduction of tool cost, or a 50% increase the tool lifetime results only in a 1% reduction of manufacturing cost. In contrast an increase in cutting data by 20% reduces manufacturing cost by 15% [1].

In the early 1920s Schroeter, working in the laboratories of Osram in Germany, heated tungsten powder with carbon to produce the carbide WC in powder form, with a grain size of a few micrometers [2] [3]. Cobalt was found to be the most efficient metal for bonding WC particles. The mixed powders were pressed into a compact which next were sintered in hydrogen above 1300°C. Unlike many powder-metal products, tungsten carbide cobalt mixtures can be sintered to full density-free from porosity in a single heating cycle [2,4].

Over the years, the basic WC-Co material have been modified in percentage of their chemical composition, morphology and grain size to produce a variety of cemented carbides, which are used in a wide range of applications, including metal cutting, mining, construction, rock drilling, metal forming, structural components, and wear parts [3].

Much effort has been made to investigate the effect of the addition of other carbides to the basic WC-Co structure, such as TiC, TaC and NbC, depending on the required properties and application of the tool, for example, TaC additions improve the thermal fatigue resistance [2][3] and additions of vanadium and chromium carbides are the most effective grain growth inhibitors [3].

This paper reports the results of a comparative study of cemented carbides characterization, actually used as cutting tools, particularly relative to their wear resistance behavior. Firstly, correlations between wear level and coefficient of friction and moreover, the material and test parameters were elucidated.

2. EXPERIMENTAL

2.1 Starting materials and specimens preparation details

Five WC-Co compositions with different properties and carbides grain size were used as starting samples. The shape of test specimens was cylindrical of 12.7 mm in diameter and 0.5 mm thick with the aim of obtaining a flat and smooth surface. For the specimen preparation, conventional metallographic techniques were used. The grinder/polisher operations were executed using an equipment LECO model SS1000 (LECO Corporation, Michigan, United States) by means of a diamond abrasive (Fig. 1).

Three sequential polishing processes were performed by using 6μm, 3μm and 1μm grade diamond paste to minimize any residual stress in the surface layer.

2.2 Chemical composition and hardness

The chemical nature of WC-Co was estimated through semi quantitative analysis in SEM because it was complicated to dissolve carbides and determine its chemical composition for example through Inductively Coupled Plasma Mass Spectrometry (ICP-MS), also the optical emission technique was tested, however the detection limits for W were out of specification. Through SEM specific analysis was performed on ten particles and an average for each sample was determined.

Fig 1. LECO polishing equipment

On the other hand, the HV10 and HV30 Vickers hardness was measured with Clemex micro hardness equipment model CMT-HD with indentation loads of 1 Kg for 10 seconds according to the standard ISO 3878.

2.3 Sliding wear test

One of the main problems in the evaluation of friction and wear properties is coping with variability. This factor is inherent in every tribological process because of the great number of influencing parameters, their potential fluctuations, and time dependencies [5].

In this research, wear test were carried out on CSM Instruments Tribometer (model TRB-S-DU) by pin-on-disk test in dry. The values of a coefficient of friction (μ) were obtained directly in automatic form when each test finished from the Tribox 4.1 software attached into the equipment. For this purpose sapphire ball with a diameter of 6 mm was slid on the WC substrates in separated tests. For each test, the sapphire ball was fixed on the load arm, and the sample was set on a rotating disk (Fig. 2), the contact normal load used was 10 N and the sliding speed was 0.20 m/s with a distance of 1500 m for the complete test. The temperature during the test was maintained at 26±1°C with a relative humidity of 20-30%. The volume loss and the worn track section values were determined by a standard test method as indicated in the

ASTM/G99-05 assuming that there was no significant pin wear [6].

The radius of the worn track section was 3.82 mm in all samples. During each wear experiment, the equipment made a continuous record of the imposed normal force (F_N) and the tangential friction force (F_T) in the sliding pair pin–disk and the coefficient of friction (μ) were calculated according to Eq (1):

$$\mu = F_T / F_N \qquad (1)$$

The friction coefficient was determined during the test by measuring the deflection of the elastic arm (as it can be seen in Fig. 2). Wear coefficients for the disk materials were calculated from the volume of material lost during the test, making sure that the pin was not worn.

The control of the test parameters such as speed, frequency, contact pressure and environmental parameters (temperature, humidity and lubricant) allow simulation of the real life conditions of a practical tool wear situation.

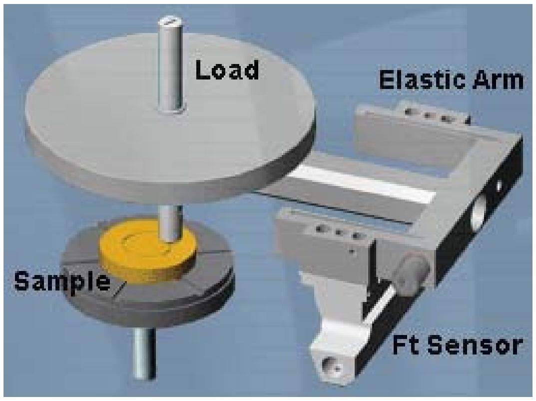

Fig 2. Schematic illustration of CSM Tribometer

A photographic illustration of the pin-on-disk configuration during sliding contact is depicted in Fig. 3.

2.4 Grain Size Evaluation

With the aim of measuring the grain size of WC-Co with precision, it was necessary to prepare each sample by conventional metallographic techniques, scanning electron microscopy was essential to obtain photomicrographs with very good resolution. Next in these images previously obtained by SEM the distribution was acquired using the computer image analyzer software delimiting each grain manually as it can be seen in Fig. 4, and in agreement with the linear intercept method, at least 1000 grains were measured for each grade.

Fig 3. Pin-on-disk sliding contact equipment

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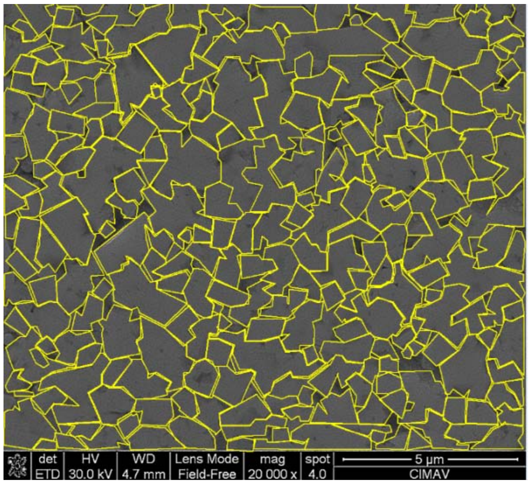

Fig. 4. SEM image revealing grain size distribution in WC-Co sample.

RESULTS

The chemical composition determined by SEM-EDXS in WC-Co matrix is listed in Table 1.

The WC grain size was quite dependent on the size of initial powders and the addition of grain growth inhibitors. The grain size and distribution of WC in cemented carbides are illustrated in Fig 5. The K40XF grade (Fig 5d) exhibits the coarsest WC grain structure, with 56% of the grains being smaller than 0.8μm and 81% being smaller than 1.4μm. The 2608 grade was the finest microstructure (Fig 5b), with 95% of the grains smaller than 0.8μm and 100% of the grains smaller than 1μm. Alternatively the 2210 grade (Fig 5a) with 74% of the grains smaller than 0.8μm and 100% of the grains smaller than

Sample	**Average chemical composition (Wt %)**			
	W	**C**	**Co**	**Cr**
2210	80.5	10.2	9.06	0.24
2608	85.1	7.4	7.5	NE
DK460	89.5	6.4	4.2	NE
K40XF	76.7	10	10.5	2.8
DK460UF	90.3	6	3.7	NE

Table 1. Chemical composition (SEM-EDXS)

1.4µm. The figure 6 summarize the profile of hardness regard to distance for the five samples studied. As it can be seen, the 2608 grade presents the highest hardness values; additionally the K44UF and K40XF grades show more variability in this property. There is a big difference between the hardness of 2608 sample and the rest of specimens, which is notorious also in the grain size of the microstructure.

On the other hand, the coefficients of friction were recorded continuously during the test; the average values determined in each sample are illustrated in Fig. 7.

The graphs shows that the coefficient of friction of 2608 grade is lower than 2210, DK460, K40XF and K44XF. In the initial stage of wear testing, a burnishing wear process established a smooth wear track surface by ploughing away the surface asperities or roughness.

As the wear proceeded further, the wear track became smothering and the coefficient of friction fixed on a steady level.

The binder phase is partially removed between tungsten carbide grains by a combination of plastic deformation and micro abrasion leaving spaces amongst them and this action is believed to constitute the initial stage of wear [7,8].

Finally the Fig. 8 shows the wear rate for WC-Co specimens determined from tribological test. It is clear that 2608 sample present the minimal wear rate in contrast with K44UF sample which showed the highest wear rate. In the figure can be seen that the both 2210 and 2608 samples presented the minimum wear rates, these samples had particle sizes finer as could be seen above in Fig. 5. However for the K40XF sample, which presented size particle larger wears less rapidly than the samples DK460UF and K44UF. This behavior may not be related directly with size particles in itself, but rather with the morphology and accommodation between particles as a consequence of sintering process. As can be seen in Fig. 5 these last two samples show large gaps between WC particles. Additionally this Fig. 8 also shows the values of volume loss due to the friction and the worn track wide determined from wear surface in each sample. These data are directly related with wear rate in all specimens.

DISCUSSION

In general, friction and wear is believed to result from three components: adhesion, ploughing and asperity deformations [7], several mechanisms have been proposed to explain how material is removed from the surface of WC-Co during sliding test because friction contacting bodies is a complicated phenomenon. The applied load is initially carried by only a few surface asperities, as sliding proceeds, the load is distributed over a large contact area since the surface roughness decreases. As indicated by [5,7,8] and based on the recorded responses from the sliding test, the wear resistance of WC based cemented carbides generally increases with reduced carbide grain size and decrease binder content, and thus, with increases hardness. Fig. 7 shows the values of friction coefficient, the 2608 grade have the lowest friction coefficient and the highest hardness (Fig 6), it is well know that coarse-grained cermets usually have lower abrasive wear resistance than that of fine or medium grain size and it is clear that the heterogeneity in the particles morphology and the gaps between them is obviously related to the sizes and all this is critical to the wear behavior and coefficient of friction observed in WC-Co structure. Based on the experiments completed during this test program and the interpretation of the sliding tribological testing, the following is a summary obtained in this investigation:

1. The sliding wear of cemented carbides depends in complex manner on hardness, grain size and cobalt content of the composite. Heterogeneity in the particles morphology and the gaps between them is obviously related to the sizes and all this is critical to the wear behavior and coefficient of friction observed in WC-Co structure
2. Smaller grain size tends to higher wear resistance and hardness.
3. The most effective technique to improve sliding wear resistance is to reduce the cobalt and/or reduce the grain size.
4. For example the K40XF exhibits the coarsest WC grain structure, with 81% smaller than

1.4µm, 1640HV and friction coefficient of 0.36µ. Contrariwise the 2608 grade was the finest microstructure with 95% of the grains smaller than 0.8µm, 1980HV and friction coefficient of 0.25µm. From the point of view of machining, the fine grain carbide grade features high cutting-edge stability while maintaining high wear resistance and considerable toughness, this grade is applied in highly wear-resistant materials, such as hardened steels, graphite, high-strength aluminum alloys, as well as abrasively acting composite materials.

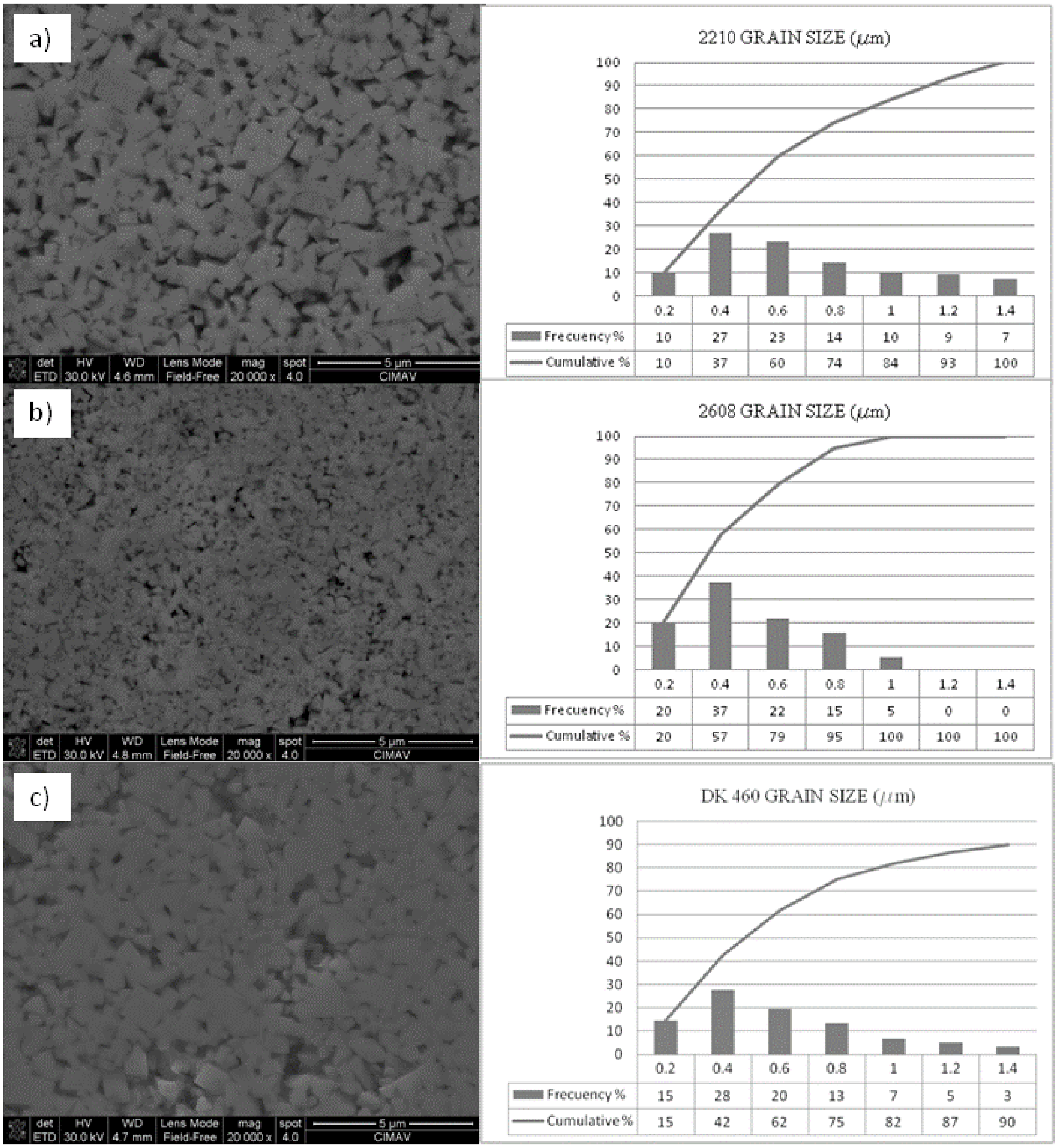

Fig 5a.SEM images 20,000X and grain size: a) 2210, b) 2608, c) DK 460

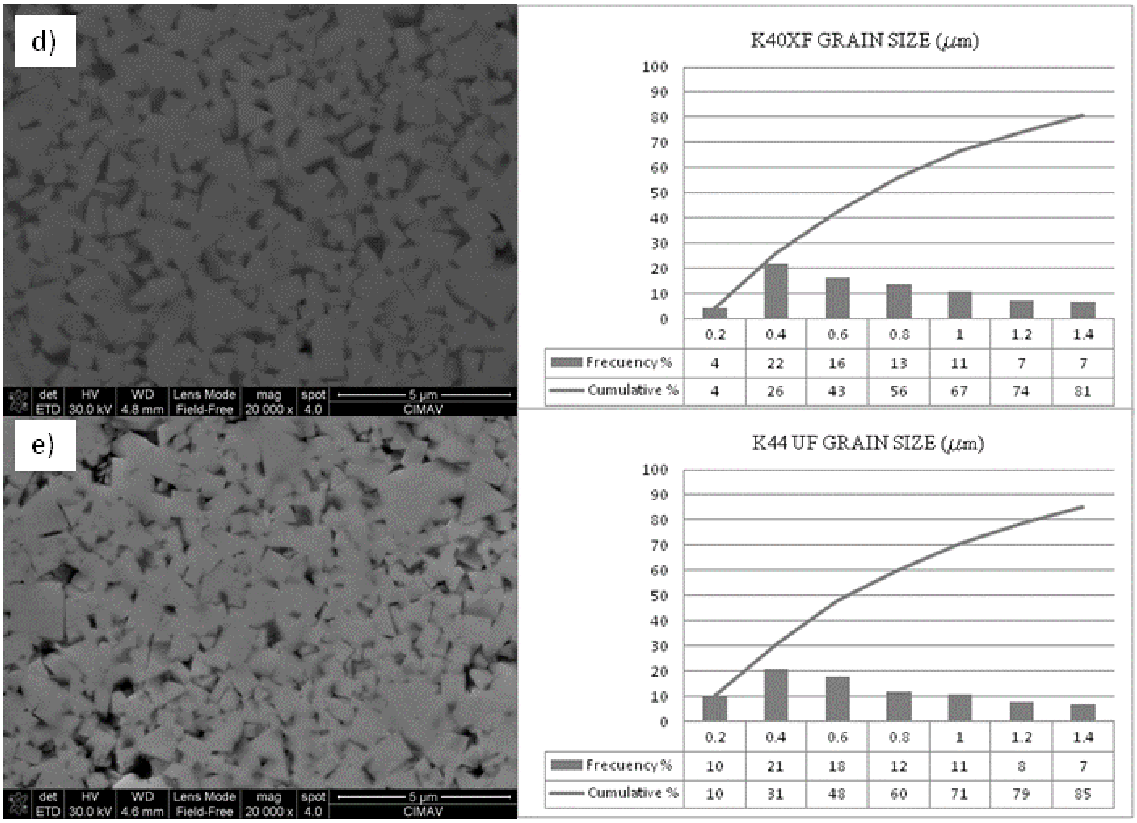

Fig 5b.SEM images 20,000X and grain size: d) K40XF y e) K44UF

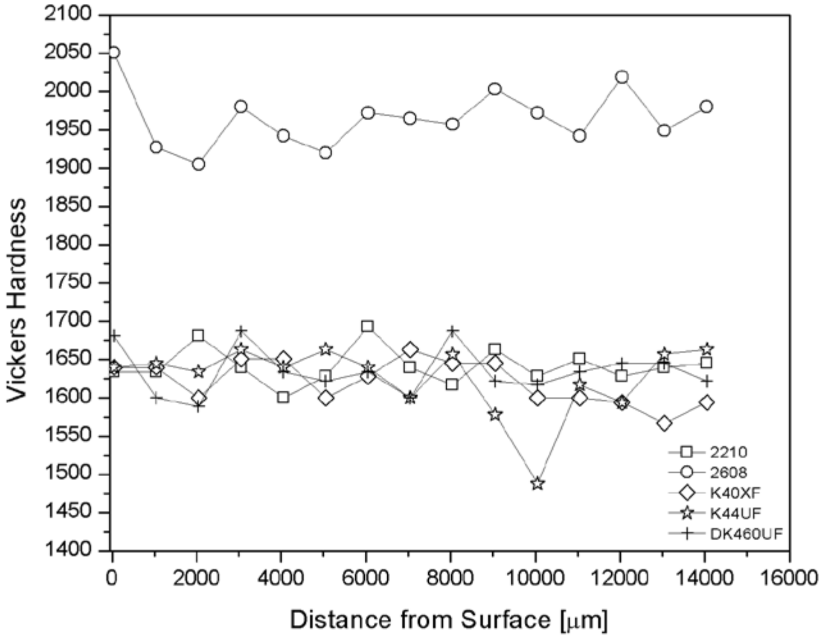

Fig 6.Vickers hardness of five samples of cemented carbides studied

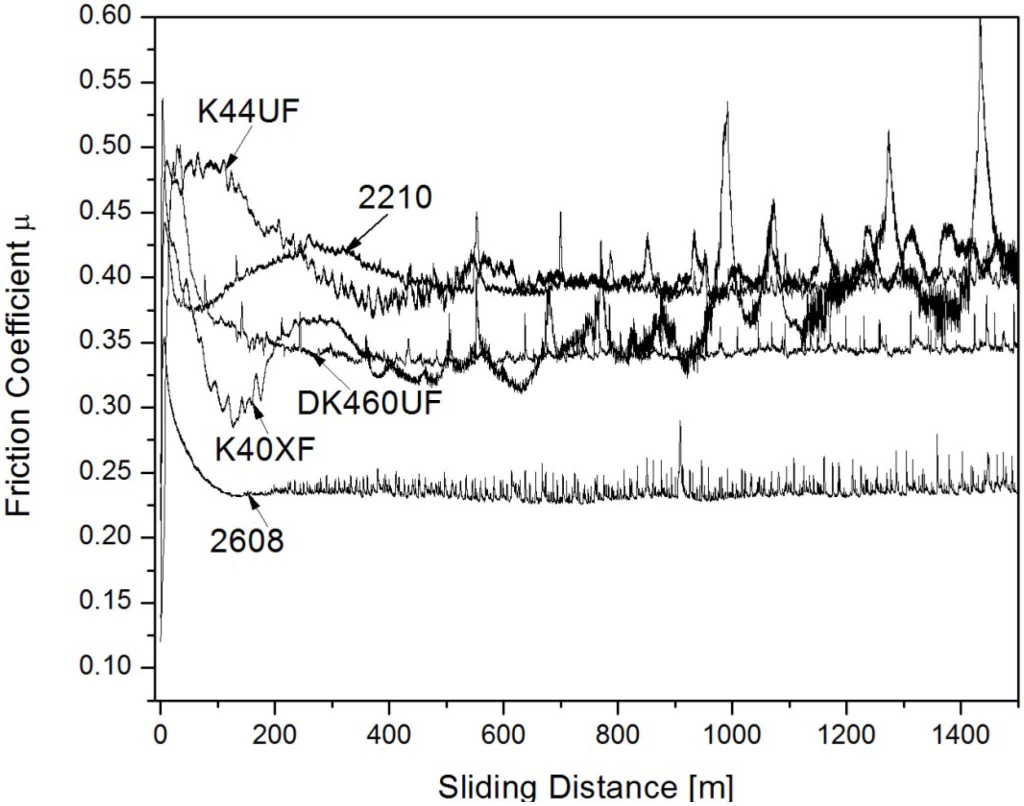

Fig 7. Friction coefficient regard to sliding distance of the five different cemented carbides considered in the present study

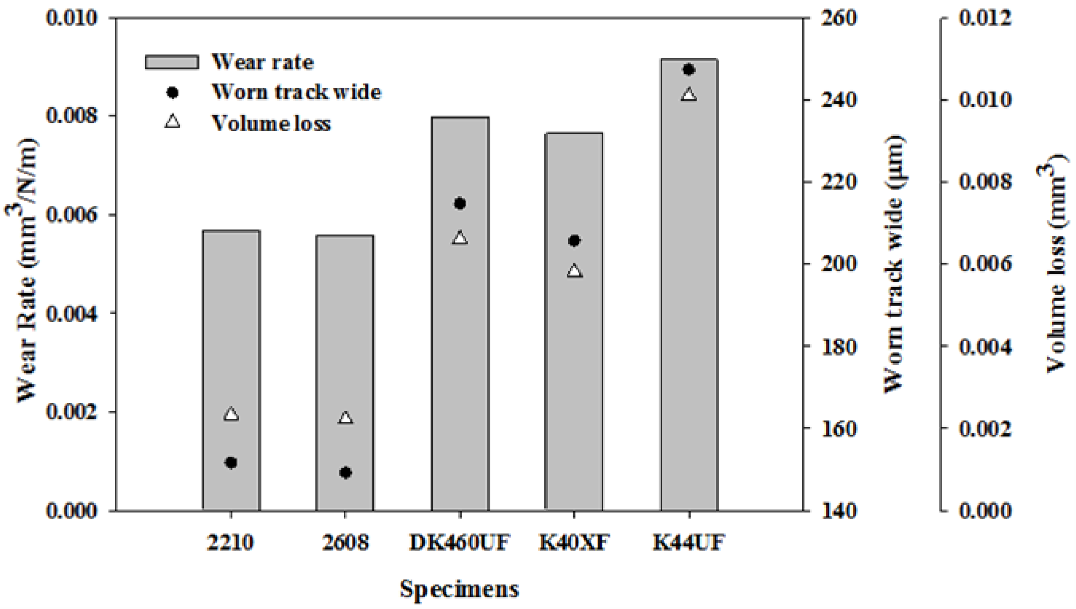

Fig. 8. Wear rate, worn track wide and volume loss determined from tribological test for WC-Co substrates

Daily technical life situation is much more complex, since additional doping components prevent grain growth during sintering process and also act on material properties like hardness and toughness. Thus cemented carbide grade development is always based on a tailor-made carbide composition, i. e. cobalt content, grain size and additive composition, for reaching an optimum application performance in machining.

CONCLUSIONS

The tribological study showed that in addition to the grain size and the morphology, the gaps between particles and the binder content directly affect the wear rate of WC substrates. This combination of factors must be considered when developing cutting tools for high performance applications.
A future work it is needed to evaluate the effect that have some other types of binders in the manufacturing of cemented carbides and carry on a study of the wear behaviors in machining operations such as cutting tools.

ACKNOWLEDGEMENTS

This research was supported by 3G Herramientas Especiales SA de CV. Monterrey N.L, México and CONACyT. Additional support was provided by the research group in Mechatronics and Intelligent Machines of Tecnológico de Monterrey. Also we would like express our gratitude to B.Sc. Miguel Esneider from CIMAV Monterrey for his help with the experimental procedures.

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