

## ASTM G132 testing for evaluating abrasion resistance of WC-Co hardmetal

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### Abstract

The current test method experimentally simulates two-body abrasive wear of WC-6wt% Co hardmetal using modified pin abrasion tester configuration (ASTM G132). Silicon carbide (SiC) and alumina (Al<sub>2</sub>O<sub>3</sub>) with different sizes ranging from 22µm to 200 µm were used as abrasives in this test. Experiments were performed for different normal force from 4 to 16 N with constant sliding speed of 150 mm/s for 30 m sliding distance. Worn surface morphology and topography were characterized through SEM and white light interferometry. The obtained results clearly highlights the potential of pin abrasion tester for characterizing two body abrasion of hardmetals.

### Keywords

Pin abrasion tester, cemented carbide, abrasion resistance, ASTM G132

### 1. Introduction

Hardmetals and cermets are composites materials composed of hard carbide ceramic particles (WC, TiC, TaC and NbC).bonded together by a metallic binder (Ni, Co, Mo, etc.) (Antonov et al., 2010; Huang et al., 2017; Jianxin et al., 2012; Pirso et al., 2011). These materials are widely used in cutting tools and wear parts applications due to its outstanding properties of hardness, toughness and wear resistance (Bonny et al., 2009; Bonny et al., 2010). Earlier research on cutting tool suggests that abrasion is the dominating tribological mechanism in the cutting tool (Astakhov, 2004; Wright et al., 1981), the phenomenon involved in the material removal process may differ significantly (Barrow, 1972). Different mechanism such as oxidation, diffusion and adhesion wear during machining process affect the lifetime of the cutting tool were explored earlier (Astakhov, 2004; Opitz et al., 1968). From materials perspective, tungsten carbide (WC) and cobalt (Co) are the suitable hard and binder phase to achieve better mechanical and abrasion properties (Geoffrey, 1995; Ortner et al., 2014). Grain size and binder ratio are two major controlling factors which affects the mechanical and tribological properties(Zuñega et al., 2012). Generally, the size

of the WC grain ranges from 0.3 to 40  $\mu\text{m}$  and the Co ratio varies from 3 to 30 wt%. The coarse WC (10-40  $\mu\text{m}$ ) are mainly used in mining applications (O'Quigley et al., 1997). For metal cutting application, the size of grain typically from 1-3  $\mu\text{m}$  and 6 wt% of cobalt are mostly preferred (Jianxin et al., 2012). From the view point of wear prevention, fine grain has greater wear reduction when compared to the coarse microstructure of WC-Co (Saito et al., 2006). There has been considerable interest over a number of years in developing a test rig to simulate and analyze the abrasive wear in laboratory scale.

Several methods has been developed to characterize the abrasion resistance of WC/Co in laboratory scale including single and multiple asperity contact (Gant et al., 2006; Gant et al., 2005; Gee, 2001; Thakare et al., 2012). A scratch tester is mainly explored to check the accumulation of plastic deformation during abrasive wear and damage wear mechanisms of cemented carbide (WC-Co) in single asperity contact (Gee et al., 2011; Zuñega et al., 2012). Multiple asperities pertains to two and three body abrasion by containing hard counterface/asperity/particles is rubbed/trapped against the testing material. This is often used to check the abrasion resistance of materials by controlling the experimental factors such as load, speed, abrasion rate, etc (Gant et al., 2006; Gee et al., 2007). Dry/wet sand rubber wheel based on ASTM G65 standard is common method to produce the three body abrasive wear by passing the abrasives such as silica ( $\text{SiO}_2$ ) and alumina ( $\text{Al}_2\text{O}_3$ ) between rubber and sample contact (ASTM, 1991). The major advantage of this test is the fresh abrasive passes through each time during this operation. However, this system suffers with different problems, mainly in controlling the abrasive feed rate (Gant et al., 2006) and it produces only low stress abrasion (ASTM, 2013a). Another abrasion test that has been specifically standardized to check the high stress abrasion resistance of cemented carbide is the ASTM B611 steel wheel slurry abrasion test (ASTM, 2013a). Most of the literatures and ASTM B611 standard suggested that the average particle size of the abrasives/slurry which is used in the test is larger than 500  $\mu\text{m}$  (Gant et al., 2006; Gee et al., 2007). Thus, the standard is only applicable for abrasive size larger than 500  $\mu\text{m}$ . Research has been attested that decrease in the abrasive size remarkably influences the wear mechanism of WC/Co (Krakhmalev, 2008). Moreover, both the standards (G65 and B611) does not clearly represents the contact condition of the cutting tool (Budinski et al., 2017; Krakhmalev et al., 2007). Considering the different contact kinematics, the hardmetals used in the cutting tool application, also needs to be characterised by experiments pertaining to two body abrasion (Larsen-Basse, 1997). A standard test system for two body abrasion is the ASTM G132 (ASTM, 2013b), however this standard is seldom used due to the fact that material removal rate is insufficient to determine the abrasion resistance of hardmetal. Although, a few literatures has been attested that the flat/edge abrasive wear of cemented carbide using pin on abrasive paper under two body dry abrasion conditions (Krakhmalev, 2008; Krakhmalev, 2007; Larsen-Basse, 1997).

The current method improvises the test protocol beyond the standard and compares the abrasive wear of cemented carbide (WC-6%Co) from pin abrasion tester with most widely available literatures data from ASTM G65 and ASTM

B611. The prepared composition of WC-6%Co has similar microstructure and mechanical properties comparable to commercial cemented carbide. The present wear study and the corresponding microstructure correlations also helpful to understand the importance of contact conditions by the influence of different abrasives of cemented carbide under two body abrasion.

## 2. Material and experimental procedure

### *Pin abrasion tester (G132)*

In this present study, a pin abrasion tester (ASTM G132 standard, see Fig. 1) was selected to experimentally simulate the two body abrasion occurring in a dry-sliding. In the abrasion test, the disc containing abrasive paper rotates whereas the pin mounted on the loading arm moves in the horizontal direction. This simultaneously combined motion results in a spiral sliding path and ensures that the specimen is continuously in contact with fresh abrasives. The required normal load on the pin is applied by means of calibrated weights. The vertical displacement of the sample and the tangential load are monitored to measure the wear and friction coefficient, respectively.

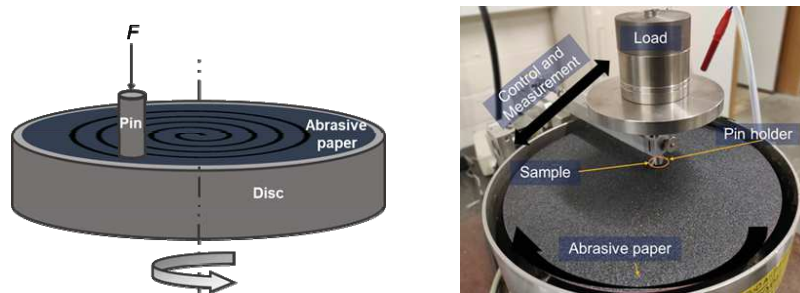


Figure 1. Schematics and photograph of pin abrasion tribotester

### *Materials and properties*

The as sintered WC-6Co (94 vol% WC-6 vol% CO) supplied from MTM KU-Leuven were used as a test material. The hardness of WC-Co is  $1383 \pm 18$  Kg/mm<sup>2</sup> measured by Vickers hardness tester with a scale standard of HV<sub>30</sub>. The calculated density and fracture toughness ( $K_{IC}$ ) of the WC-Co is 14.765 g/cm<sup>3</sup> and  $10.94 \pm 0.58$  Mpa. m<sup>1/2</sup>. The as-received material was in cylindrical form of 5 mm length and 4 mm diameter and the contact surfaces were machined by EDM. The microstructure of WC-6Co sample were characterized using SEM (FEG JEOL JSM-7600F) (see Fig. 2).

In the microstructure, the dark interconnected structures are the binder content and bright contrast and form of skeleton grains belongs to the carbide phase. The contact surfaces were characterized through 3D roughness investigation and the measurement of roughness data were carried out with a Taylor Hobson type Talysurf CCI white light interferometer. The average surface roughness of the

samples was  $0.1 \pm 0.05 \mu\text{m Ra}$ . The specimens were thoroughly cleaned using ultrasonic cleaning in acetone for 15 min. The samples were weighed using an electronic balance with an accuracy of  $\pm 0.0001 \text{ gm}$ .

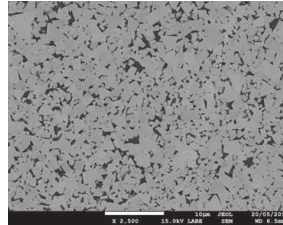


Figure 2. SEM morphology of the WC-6%Co sample

### *Experimental testing*

The testing specimen was linearly loaded starting from 4 to 16 N by means of calibrated weights. Additionally, a load of 2N from the specimen holder is corrected has been used in all the calculations. Two types of abrasive papers namely SiC and  $\text{Al}_2\text{O}_3$  of different grit sizes such as P800, P180, P120 and P80 were used in the current test matrix. A sliding distance of 30 m (with 3 m intermediate pause for paper change) at a sliding speed of 150 mm/s was used for abrasion testing. To accomplish the 30 m sliding distance the sample holder arm was reinitialized to its starting position at the end of paper change over. The tests were carried out at room temperature, that was measured to be between  $24 \pm 5^\circ\text{C}$  and relative humidity  $40 \pm 5 \%$  during all the experiments. The testing conditions were operated based on the test matrix from DOE and each test was repeated three times for repeatability check.

## **3. Results and discussion**

### *Wear test results*

Fig. 3a represents the relationship between volume loss and load for WC-Co with the presence of different size of SiC abrasives (ranging from 22 to 200  $\mu\text{m}$ ). The results show that the wear in terms of volume loss increases with increasing load. This probably due to the increment of load should increases the asperity contact between specimen and abrasive paper which further leads to the major material removal from the surface, resulting higher amount of volume loss. On the other hand, the effect of abrasive size on the wear of WC-Co shows that at a certain particle size (critical particle size) the rate of change in wear decreases (Fig. 3b). The volume loss increases significantly with the increase of particle size until the critical particle size of 82  $\mu\text{m}$  is reached, after which the volume loss follows a lower increment rate. The test was repeated three times and the calculated variation shows the test is moderately significant in case SiC particle ( $p=0.01-0.34$ , 5% significance level)

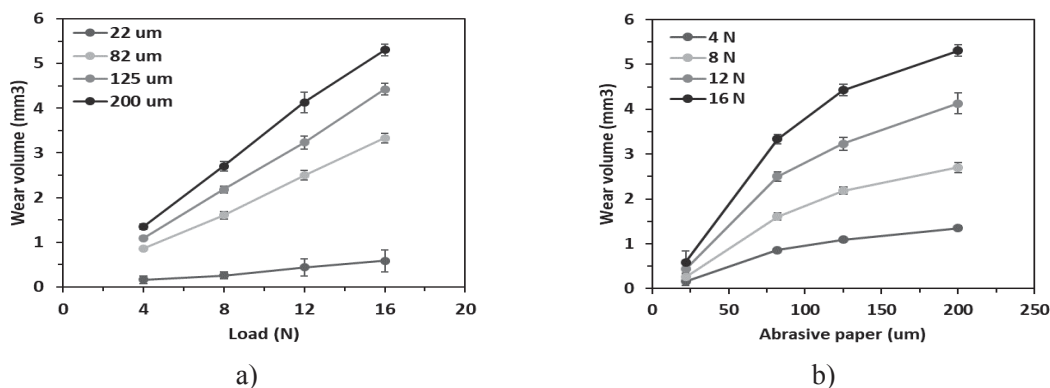


Figure 3. Rate of wear volume loss as a function of a) load b) abrasive particle size (SiC)

The relationship between volume loss and load for WC-Co with presence of different size of alumina ( $Al_2O_3$ ) abrasives (between 22 to 200 μm) is shown in Fig. 4. Similar wear trend were found for WC-Co when tested against alumina and SiC abrasives. The results show that the volume loss of WC-Co using alumina abrasives is lower than SiC abrasives. This is probably due to the hardness of abrasives which plays a major role in material removal.

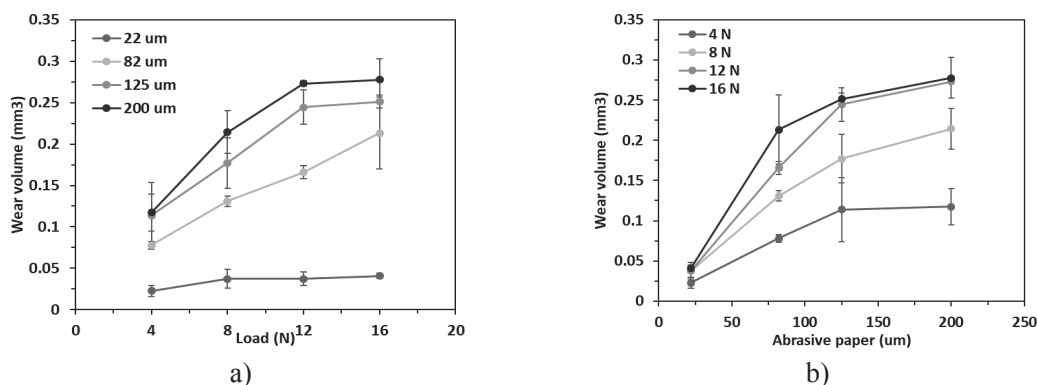


Figure 4. Rate of wear volume loss as a function of a) load b) abrasive particle size ( $Al_2O_3$ )

Existing literature studies, the severity of contact between the abrasive particle and specimen surface in case of alumina particle is significantly lower compared to SiC particle (Gant et al., 2006; Jia et al., 1996; Thakare et al., 2012). Hence, the removal of material from surface in case of alumina abrasives is low. The calculated statistical variation shows that the is not relatively significant in case of  $Al_2O_3$  abrasives ( $p=0.17$  to  $0.38$ , 5% significance).

#### Worn surface analysis

The worn surface characteristic was examined in SEM to elucidate the factors influencing the wear and to determine the predominant wear mechanisms (see Fig. 5). The worn surface of different loads with different abrasive sizes illustrates that both plastic deformation of binder, binder removal, grain pull out

and fracture can occur simultaneously (Gant et al., 2006; Krakhmalev, 2008). In case of smaller abrasives (22  $\mu\text{m}$ ), the severity of abrasion increased when load increases from 4 to 16 N (groove depth of WC-Co increased from  $2\pm 0.5$  to  $8\pm 1$   $\mu\text{m}$ ). During initial sliding at lower load, a compressive stresses exerted by the hard SiC abrasive particles results in binder extrusion and removal of binder phase on the WC-Co surface, which leads to loss in mechanical strength and subsequent decrease in the support to carbide hard phase. The removal of binder phase around the carbide grains appears to be caused by plastic grooving which would also result in subsequent ejection of carbide grains (Vashishtha et al., 2017). However, the cracking of carbides due to abrasion using lower abrasives (22 and 82  $\mu\text{m}$ ) is relatively low, resulting mild wear. Further, a noticeable increment in the groove width on the WC-Co surface were observed when the size of abrasive increases (Vashishtha et al., 2019). The wear mechanism of WC-Co against larger abrasives (125 and 200  $\mu\text{m}$ ) displays combination of extensive cracking of the carbide grains and binder phase extrusion. These extensive carbide cracking further leads to the undermining and ejection of unsupported carbide fragments, resulting in severe wear. The present results are good agreement with the earlier literature based on ASTM G65 standard (Thakare et al., 2012). Additional literatures from ASTM G65 and B611 shows, the overall wear appears to be due to the loss of binder a carbide grains has pulled out from surface as well as the extensively deformed/fragmented carbide grains (Gant et al., 2006; Gant et al., 2005). On the other hand, an alumina abrasive shows higher binder removal in case lower abrasive size (22 and 82  $\mu\text{m}$ ) and the trend varies to plastic deformation/plastic grooving when the size of abrasives increased (125 and 200  $\mu\text{m}$ ). At 16 N load, an alumina abrasives shows material binder removal and increased plastic deformation along with smaller pullout of grains. The hardness difference between the abrasives plays major role to describe the wear mechanism of WC-Co (Axén et al., 1994; Gant et al., 2006; Jia et al., 1996).

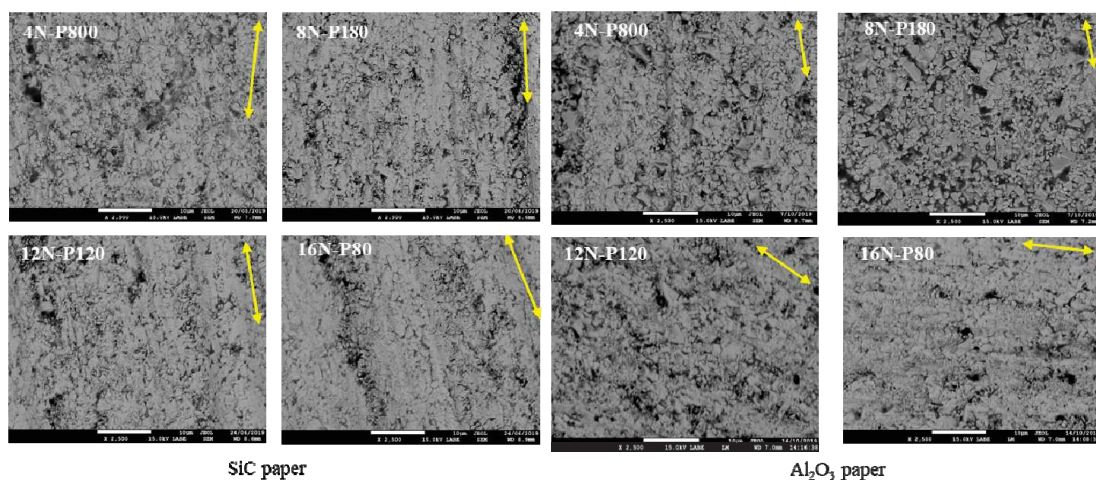


Figure 5. Worn surface morphology of WC-Co after different abrading conditions

### Topography analysis

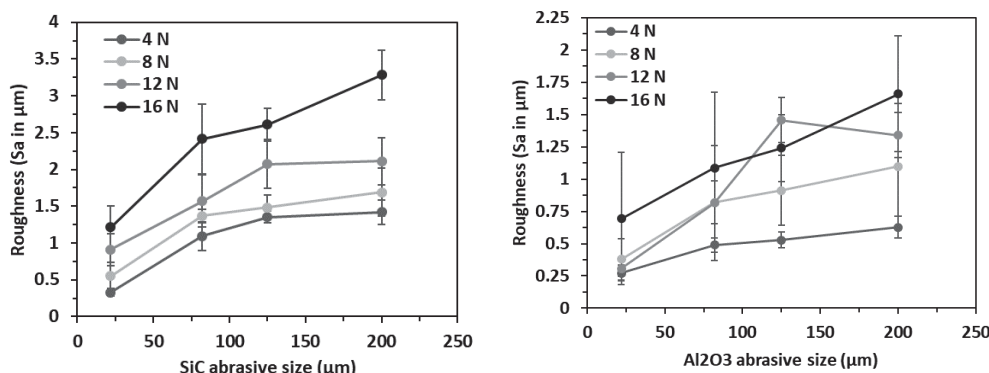


Figure 7. 3D surface roughness of WC-Co worn surface against different abrasives

Fig. 7 illustrates the topographical result of WC-Co under different abrading conditions. The results confirm that the 3D surface roughness of WC-Co increases highly under SiC abrading condition compared to Al<sub>2</sub>O<sub>3</sub> abrasives. The effect of particle size also influences the roughness of the WC-Co surface. The fine abrasive (22 µm) shows smooth surface comparatively to the other coarse abrasives. This could be due to the increasing load in case of the fine abrasives leads to the preferential removal of binder (Krakhmalev, 2007). The coarse grade abrasive (200 µm) illustrates high arithmetic mean deviation in both abrasive types. This may be due to the extensive grooving and pull out grain exerted by binder removal as observed from SEM observation.

### Comparison with literature data

From wide range of literatures followed by ASTM G65 and ASTM B611 for WC-6%Co (similar microstructure and mechanical properties) (Gant et al., 2006; O'Quigley et al., 1997; Pirso et al., 2011; Roebuck et al., 2007; Thakare et al., 2012), the calculated volume loss has been extracted and compared with the present experimental results, which is graphically represented in Fig. 6. The graph clearly represents the wear in terms of volume loss increases logarithmically when changing the experimental factors such as load, abrasive size, abrasive type, sliding distance, etc. ASTM G65 results specifies the lower volume loss especially when the load (0.2 N) and abrasive size of the particle (4.5 µm) reduced for both SiC, SiO<sub>2</sub> abrasives, which is comparatively lower than the present experimental results. In the case of high load (20 N) and larger SiC abrasive particle (180 µm) at 942 m sliding distance the ASTM G65 result shows the obtained volume loss was 15.07 mm<sup>3</sup>. The present study shows the volume loss of WC-Co against 200 µm SiC abrasive at 16 N with a sliding distance of 30 m is 5.3 mm<sup>3</sup>. The comparative study clearly confirms the volume loss of the cemented carbide in terms of load and abrasive particle influences more in case of two body contact configuration than three body. ASTM B611 always shows higher amount of material volume due to the fixed experimental

conditions. Generally, the load (200 N) and abrasive particle (600 μm) used in this operation is always higher than the other two standards.

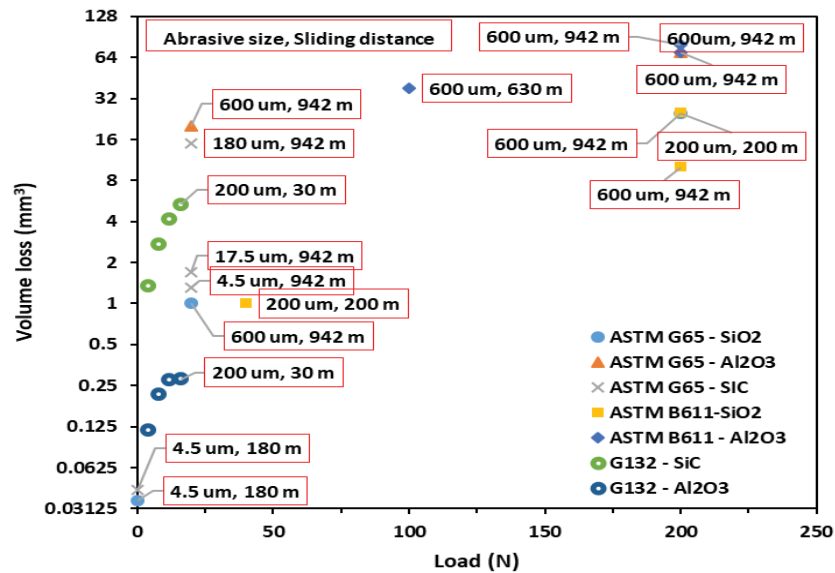


Figure 6. Literature data comparison with the present experimental

## Conclusions

The present experimental study concludes the importance of pin abrasion tester in hardmetal testing especially for different abrasive contact using ASTM G132. The test results showed that the effect of abrasive particle size influences highly on the wear in terms of volume loss of WC-Co matrix comparative to the applied load. An influence of different abrasives also shows the effect of wear loss related to the abrasive particle hardness. The wear mechanism concludes the effect of load and particle size of both SiC and Al<sub>2</sub>O<sub>3</sub> abrasives leads to the failure mainly fracture of grain, pull out of grain followed by binder extrusion. The experimental results also compared with the widely available literatures and summarized that the pin abrasion tester most effective two body abrasive method to test the hardmetal in lab scale.

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