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COHESIVE STRENGTH ANALYSIS OF CEMENTED CARBIDES

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ABSTRACT
Cemented carbide is a composite material produced by the reaction of tungsten metal powder and carbon powder in a metal binder at temperatures of 1,400-1,500°C. This process enables high hardness and abrasion resistance in all directions. Cutting tools made of the cemented carbides achieve impressive results in fast and precise machining as well as leaving a remarkable surface finish. Rectangular and single edge V-notched beam (SEVNB) specimens were cut by laser from bulk circular cemented carbide disks. The mode I fracture behaviour of these specimens was investigated as a function of loading rate and temperature.
After the series of fracture tests have been conducted, the relevant properties at initiation determined and appropriate numerical model developed, capable of reproducing the obtained experimental results, analysis has been performed in order to relate the cohesive strength values for two different grades of material at different loading rates.
Keywords: Cemented carbide, Fracture, Cohesive strength, Critical distance, Finite volume analysis

1. INTRODUCTION
Cemented carbide is a composite material produced by the reaction of tungsten metal powder and carbon powder in a metal binder at temperatures of 1,400-1,500°C. The manufacturing process begins with the composition of a specific tungsten carbide powder mixture, tailored for the application. In a high-temperature sintering furnace, the tungsten carbide structure of the blank is shaped at precise temperatures for strictly defined periods. During this heat treatment, the tungsten carbide blank undergoes shrinkage of some 50% in volume, being compacted into a form. The sintered cemented carbide component gains its final finish by additional grinding, lapping and/or polishing processes.
This sintering process enables high hardness and abrasion resistance in all directions, so that these materials have a countless number of applications. They can be used in tough materials machining as well as in situations where other tools would relatively quickly wear away, along with withstanding higher temperatures than standard high speed steel tools. Their properties make cemented carbides one of the most successful composite engineering materials ever produced. Cutting tools made of the cemented carbides achieve impressive results in fast and precise machining as well as leaving a better surface finish.
Considering their application and known range of properties, main disadvantage of cemented carbides is appearance of their sudden fracture during machining process. This is caused by the low toughness at dynamic rates and overcoming this problem is yet to be researched further. In order to understand these limitations and provide suggestions for the improved design of the material, series of experimental tests have been performed in laboratory conditions. The combined experimental and numerical analysis is currently being undertaken at the continuum and microstructural levels leading to a better insight to the fracture phenomena in these materials.

2. MATERIALS

Two different material grades were used in this analysis containing tungsten-carbide (WC) and cobalt (Co) as the main elements. Small additions or trace levels of other elements can also be found as added to optimize their properties. These grades differ in mean WC grain sizes and amounts of cobalt. They are referred to as:

- fine grade (FG), containing 4 µm average WC grain size and
- coarse grade (CG), containing 20 µm average WC grain size.

Rectangular and single edge V-notched beam (SEVNB) specimens, shown in Figure 1, were cut by laser from bulk circular cemented carbide disks. The length, width and thickness of the specimens were 28.5mm, 6.25mm and 3.0mm, respectively, with average notch root radius of 155µm. Mechanical and fracture properties have been experimentally obtained [1,2,3] testing these specimens at a wide range of loading rates which are representative of typical working conditions. Loading rate was varied from quasistatic of 1mm/min up to dynamic of 5m/s. Using standard equations, the fracture toughness, fracture energy, flexural strength and Young's modulus were determined according to linear elastic fracture mechanics.

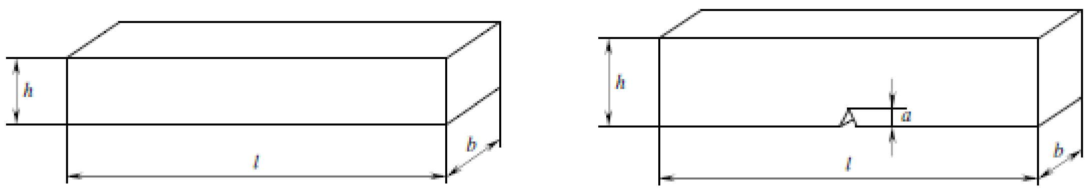

Figure 1. Geometry of rectangular (left) and SEVNB (right) specimen

3. MODEL DESCRIPTION

Numerical modelling is being increasingly employed to predict the behaviour of materials under various conditions and solve complex real-life engineering problems. A number of numerical models have been developed for analysing continuum mechanics problems using governing equations, constitutive relations and specifying appropriate boundary conditions. In order to validate the accuracy of the model, experimental data are employed.

An implicit Finite Volume (FV) numerical method was employed [4] to predict the behaviour of SEVNB specimens using OpenFOAM for simulation, an open source FV based software. The conservation of the linear momentum equation was used to describe the behaviour of the continuum.

The test specimen was modelled as a half of the actual SEVNB specimen, due to the plane symmetry, and with the unit thickness. The striker loading was represented by specifying a constant striker velocity boundary condition, while the support cells were fixed. All other surfaces were modelled as stress free boundaries. Plane strain conditions were assumed. Attempts were made to simulate SEVNB experiments using experimental values of separation energy G and cohesive strength σ_{max} from mechanical and fracture tests [2]. The Dugdale cohesive zone model was applied on symmetry plane to describe the damage/failure process of the cemented carbide in terms of the local material traction-separation relationship in the vicinity of the crack tip. When the normal traction on the plane reaches a cohesive strength σ_{max}, the Dugdale cohesive boundary condition is activated to describe the damage region ahead of the crack. In this case, the traction is assumed to be constant everywhere in the cohesive region ahead of the crack tip.

The main assumption used in this analysis is that linear elastic fracture mechanics (LEFM) can provide a reasonable description of the stress field at initiation of fracture. This is supported by the observation that the mean load-time traces are almost linear up to crack initiation [2], thus the small scale yielding condition at the crack tip prior to initiation is satisfied.

4. RESULTS AND DISCUSSION

The impact speed and measured material properties were provided as input parameters and the cohesive strength for each grade of material was determined across the range of loading rates used in the experiment. The cohesive strength values resulted in a good agreement between the numerical and experimental values [2,3]. The 2D models used for obtaining these values also showed the suitability of the finite volume method for modelling the fracture of superhard materials, where the obtained cohesive zone model parameters were confirmed to be accurate and valid for simulation of realistic parts. Obtained cohesive strength is graphically presented in Figure 2 where the decreasing trend can be noted with an increase in the loading rate.

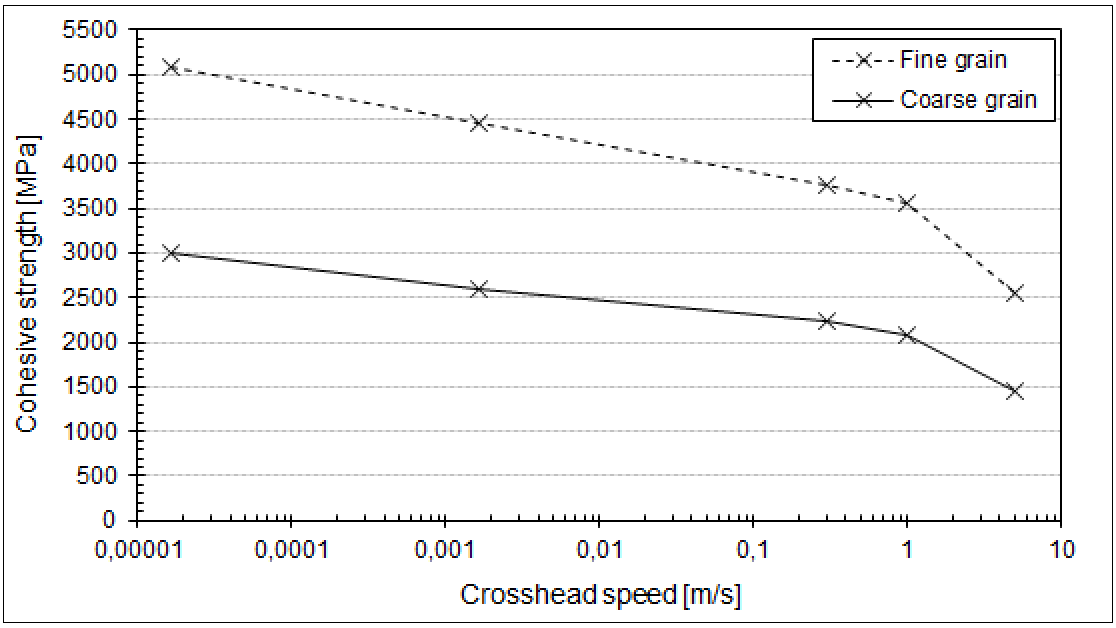

Figure 2. Cohesive strength in function of loading rate

It can be noted that the ratio between σ_{max} of FG and CG remains at a constant ratio of about 1.7 for the whole range of loading rates. This can be explained by the classical relation for the stress at the critical distance r_c:

$$\sigma_{yy} = \sigma_{c(r=r_c)} = \frac{K_{Ic}}{\sqrt{2\pi r_c}}, \qquad \text{... (1)}$$

where K_{Ic} is the mode I critical stress intensity factor (the true fracture toughness). Dividing the strength of FG by the strength of CG, the following relation can be obtained:

$$\frac{\sigma_{\max,FG}}{\sigma_{\max,CG}} = \frac{K_{Ic,FG}}{K_{Ic,CG}} \sqrt{\frac{r_{c,CG}}{r_{c,FG}}}. \qquad \text{... (2)}$$

Assuming the critical distance r_c to be proportional to the average grain size d_g for both materials, the following ratio always remains constant:

$$\frac{r_{c,CG}}{r_{c,FG}} = \frac{d_{g,CG}}{d_{g,FG}} = 5. \qquad \text{... (3)}$$

The fracture toughness determined in the experiments is “apparent” fracture toughness whose values depend on the notch root radii. Following the guidelines from the literature regarding the limiting notch root radius being twice the grain size, below which the fracture toughness stays unchanged, as well as the estimations possible to be obtained by a point method and a line method of the theory of critical distances [5], the true fracture toughness K_{Ic} can be obtained. The K_{Ic} of the FG material was determined experimentally sharpening the notch root [2,6], while the K_{Ic} of the CG material was determined using the theory of critical distances, due to difficulties and unreasonable time consuming involved in sharpening the CG specimens. The ratio between true K_{Ic} values of the two cemented carbide materials at quasistatic rates and room temperature equals to $K_{Ic,\ FG} / K_{Ic,\ CG} = 0.728$, giving $\sigma_{\max,\ FG} / \sigma_{\max,\ CG} = 1.63$.

5. CONCLUSIONS

Analysis of the cohesive strength values obtained numerically by calibration of experimental results for two different grades of cemented carbide at different loading rates was presented in this paper. The cohesive strength for each grade of material was previously determined across the range of loading rates used in the experiment, based on the impact speed and measured material properties that were provided as input parameters for modelling.

It was found that the ratio between cohesive strengths for two carbide materials used in this work satisfies the classical equation for the stress at the critical distance, assuming the critical distance being proportional to the material average grain size. Cohesive strength also follows a falling trend with an increase in the loading rate as observed experimentally.

6. REFERENCES

[1] Petrovic M., Ivankovic A., Murphy N.: The mechanical properties of polycrystalline diamond as a function of strain rates and temperatures, Journal of the European Ceramic Society, 32:3021-3027, 2012.

[2] Petrovic M., Voloder A., Ismic Dz.: Numerical simulation of fracture behaviour of cemented carbides, Journal of Trends in the Development of Machinery and Associated Technology, 17:65-68, 2013

[3] Petrovic M., Voloder A., Ismic Dz.: Flexural strength reduction in cemented carbides, Proceedings of ICCESEN 2014, Turkey, pp. 425, 2014.

[4] Jasak H., Weller H.G.: Application of the finite volume method and unstructured meshes to linear elasticity, International Journal for Numerical Methods in Engineering, 48:267-287, 2000.

[5] D. Taylor. The theory of critical distances: A new perspective in fracture mechanics. Elsevier, Oxford, 2007.

[6] ASTM. Standard test method for measurement of fracture toughness. ASTM E1820-01, 2001.