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Application of the Murakami Approach for Prediction of Surface Fatigue of Cemented Carbides

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Abstract

The aim of present work is to link geometrical parameter of maximum area of structural defect $\sqrt{area}_{\max}$ *(proposed by Y. Murakami, 1983) with surface fatigue mechanisms. Determined relations allow making predictions of surface fatigue properties of cemented carbides (WC-Co hardmetal - H15 - 85wt% WC and 15wt %Co, TiC-based cermets - T60/8 - 60wt %TiC and Fe/8wt% Ni and T70/14 - 70wt %TiC and Fe/14wt% Ni) in conditions of rolling contact and impact cycling loading. Pores considered being equivalent to small defects. Three comparative defects conditions are distinguished: surface pore, just below free surface and interior pores. The Vickers hardness of binder (as main responsible for the fracture mechanism of hardmetal and cermets) assumed to be the basis of such assumption. The estimate of this prediction has been done by analyzing the pore sizes using the statistics of extremes. The lower bound of fatigue properties can be correctly predicted by considering the maximum occurring pore size.*

Keywords : cermets, hardmetals, surface fatigue, Murakami model, microstructure

1. Introduction

Surface cracks and defects are most likely to be found in many structures in service, and have been recognized as a major origin of potential failure of components. Wear resistant cemented carbides tend to contain natural structural defects: pores, non-metallic inclusions or inhomogenities and etc. Their existence is crucial for most mechanical properties and material selection.

Based on the experimental fact that the crack shape of propagating surface cracks in a plate under cyclic tension, bending or combined loading is approximately semi-elliptical [1] and using the geometrical parameter of maximum area of structural defect $\sqrt{area}_{\max}$ [2] surface fatigue parameters for cemented carbides can be predicted in combination with Hertzian contact theory [3] and Palmqvist model for indentation surface cracks [4].

2. Theoretical background

Contact between two solid bodies under cyclic stressing and rolling with impacts is described with Hertzian theory of fracture mechanics. Combination of the Hertzian and Palmqvist indentation with Murakami approach resulted in computational technique for surface crack geometry and surface fatigue life prediction for studied materials.

2.1. Fracture by Hertzian contact

For the surface with large number of small cracks, then the stress field around contact area will encompass a large number of ring-cracks, outside the contact path, of radius *d*, see Fig. 1.

The maximum pressure under the contact is p_m [5]:

$$p_m = \frac{3F_N}{2\pi d^2} = \left(\frac{3}{2\pi}\right)\left(F_N\right)^{1/3} \cdot \left(\frac{4E^*}{3R}\right)^{2/3} . \quad (2)$$

2.2. Crack geometry.

Fracture toughness analyses for brittle materials generally assune that indentation preckracks have the classic half-penny radial/median geometry. The subsurface lateral crack is orthogonal to the radial and Palmqvist cracks can intersect them. Propagation of lateral cracks gives way for surface fatigue debris formation.

2.3. Lower bound fatigue limit prediction

Prediction of fatigue limit (σ_f) and fracture toughness (K_{IC}) is based on the Vickers hardness (H_V) and inclusion maximum area (surface defects) values [2]:

$$\sigma_f = 1{,}43 \cdot \frac{\left(H_V + 120\right)}{\left(\sqrt{area}\right)^{1/6}}, \quad K_{1C} = 0{,}5 \cdot \sigma_0 \sqrt{\pi \sqrt{area}} .$$

3. Results and Discussion

Table 1 shows the mechanical properties of WC-hardmetals and TiC-based cermets.

Table 1. Structural characteristics and mechanical properties of carbide composites

Grade	Carbide, [wt%]	Binder composition, structure	H_V, [GPa]	R_{TZ}, [GPa]	E, [GPa]
H10	90	Co(W)	1,31	2,2	540
H15	85	Co(W)	1,13	2,9	600
T70/14	70	Fe+14Ni steel, austenite	1,27	2,2	410
T60/8	60	Fe+8Ni steel, martensite-bainite	1,11	2,3	395

3.1. Numerical prediction of surface fatigue life.

According to evaluation method described in Section 2.1 and taking into consideration results of Murakami model application for same materials for prediction of the lower limit of the fatigue strength [6] it can be proposed that surface fatigue life of WC-hardmetals and TiC-Fe/Ni cermets can be equated by:

$$N_{fs} = \frac{E \cdot E_i}{0,5 \cdot (1-\nu^2) \cdot \sigma_0 \sqrt{\pi \sqrt{area}}}. \quad (3)$$

Final results for studied materials are given in Table 2. The radius of indenter R is equal to 10 mm, and indentation load F is 10 N for every material. Impacts deformation speed 700 s^{-1}.

Table 2. Surface fatigue life prediction results of cemented carbides

Grade	Total ac-cumulate d energy E_i, [J]	Surface fatigue life N_{fs}, [cycles]	Maximum pressure p_m, [N/mm^2]	Mean pressure p_{mean}, [N/mm^2]
H10	27093	1032578	26,79	11,94
H15	35636	1118880	21,92	12,05
T70/14	27085	719325	26,00	11,07
T60/8	28269	701785	22,33	10,04

3.2. Predicted surface fatigue crack geometry.

Predicted crack profile almost perfectly overlaps with semi-ellipse crack shape (see Fig. 2), as it was shown by X. B. Lin and R. A. Smith [1]. For all four materials we got very similar surface crack depths and geometries (c=0,199-0,212 mm).

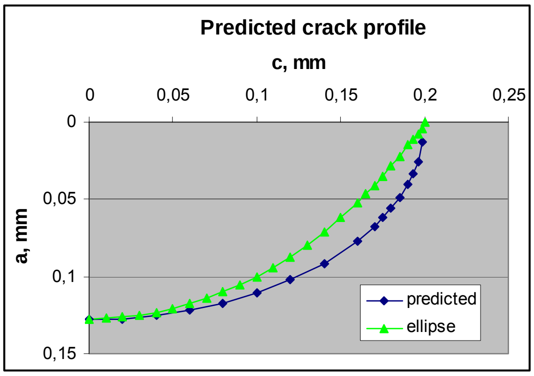

Fig. 2. Comparison of typical semi-ellipse crack with predicted crack shape (H10).

4. Conclusions

Proposed equation for evaluation of the surface fatigue life N_{fs} which correlates with geometrical parameter of maximum area of structural defect $\sqrt{area}$ is in the agreement with previously publicated results for cemented carbides.

To receive correct and reliable results many components must be taken into consideration and controlled, like: loading force (F), loading velocity, indentation depth.

Unfortunately, this method is not yet experimentaly pro-ved, but is based on the studies of the WC-Co and ceramic.

5. References

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