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Fatigue life equality of polished and electrical discharge machined WC-Co hard metal achieved solely by wet blasting

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ABSTRACT

WC-Co hard metals are materials widely used in wear applications, metal machining and highly fatigue loaded tools. Shaping tools and components made of hard metals often requires electrical discharge machining (EDM) that is well-known to negatively influence the material's fatigue properties.
The current work demonstrates that it is possible to achieve a fatigue limit of electrical discharge machined specimens equal to the one of finely ground and polished reference samples. This is achieved by the application of advanced wire EDM technology combined with a sole surface post-treatment step of abrasive blasting. Stress amplitude-life curves were determined in a four point bending test setup. Depth profiles of residual stress were determined by means of X-ray diffraction for electrical discharge machined samples prior to and after blasting. Surface defect size was documented in metallographic cross sections by scanning electron microscopy. The surface residual stress state was found to be crucially important regarding the observed fatigue behavior. If the applied EMD technology produces cracks shallow enough to allow for their removal by abrasive blasting and compressive residual stress is introduced as deep into the surface as damage reaches, the negative effect of EDM on the fatigue limit is neutralized.

1. Introduction

WC-Co hard metals provide a unique combination of resistance to abrasion [1], plastic deformation [2] and fatigue loads [2,3]. Therefore, they represent well-established materials of choice to meet requirements of economic competitiveness in many fields of industrial production. For a long time that was the case mainly in wear applications and metal machining. In more recent years, the use of hard metal tools has also been established in production processes with highly fatigue loaded tools such as blanking and fine blanking [4]. One of the main benefits of high strength materials in such applications is the avoidance of localized plastification under compressive loading close to the cutting edge of e.g. blanking [5] or milling tools [6]. Localized tensile residual stresses arise as a result, which are superimposed with load stresses and foster the nucleation and growth of fatigue cracks. This can lead to tool fracture before the material's wear resistance capabilities can be exploited. Strong support for this view is the fact that the locations of the emerging localized tensile residual stress fields can be correlated with the origins of tool failure close to the cutting edge [5,6].

The application of hard metals as tool materials in e.g. fine blanking tools often requires complex tool contours that cannot be shaped by conventional grinding due to economic constraints or general feasibility. An alternative shaping method of choice is electrical discharge machining (EDM) in technology variants such as wire-EDM or die sinking. It involves local vaporization and melting of the machined surface, leaving behind a damaged surface recast layer containing cracks [7] and tensile residual stresses [8]. Since brittle materials such as WC-Co hard metals show defect controlled fracture behavior [9,10], this circumstance is detrimental to their fracture behavior under static [11] and cyclic loading conditions [12].

In recent years, major technological advances have been made in EDM technology concerning the reduction of the thickness of the damaged surface layer [13], mainly through the reduction of discharge pulse duration [11] and energy. In particular, wire-EDM machines that use oil instead of deionized water as a dielectric can achieve a very small damaged surface zone due to three main reasons:

a) Absence of a corrosive medium in the machining process that would chemically attack the cobalt binder, causing surface defects.
b) Smaller possible discharge energies due to a significantly lower capacitance between electrode (e.g. the wire) and workpiece - relative dielectric constants ε_r of oil and water have respective values of 3

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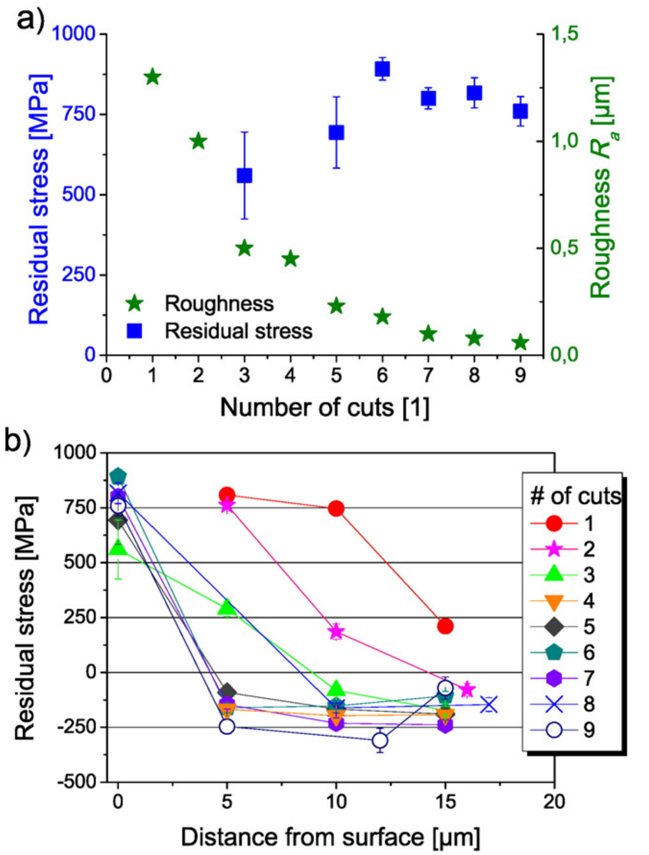

Fig. 1. Change in a) average surface roughness R_a and residual stress at WC-Co specimen surface; b) depth profile of residual stress under the specimen surface with the number (#) of consecutively applied EDM cuts.

[14] and 80 [15].

c) Dedicated low energy–high frequency discharge generators work only in absence of an electrochemical agent such as water, i.e. with oil.

Still, the application of electrical discharge machined WC-Co hard metal in highly loaded tools and components requires the removal of the mentioned cracks and tensile residual stresses. For optimal fatigue performance, also a transformation of the tensile to a compressive residual stress state is desirable to obstruct crack propagation. Several surface post-treatment techniques have been proposed to meet these goals such as thermal treatment plus shot blasting [12] and physical vapor deposition of ceramic coatings [16]. Note that blasting is sometimes also referred to as micro-blasting [17]. In the literature, none of the mentioned measures by itself was reported to be capable of elevating fracture properties under static or cyclic loading to reference levels of ground or polished specimens [12].

The current work describes a combination of a variant of EDM machining plus wet blasting as a post-EDM surface treatment technique that produces specimens with fatigue properties equal to the ones of ground and polished reference samples.

2. Experimental setup

The material investigated in the current work is a WC-Co hard metal with a Co binder content of 9 wt.% and an average WC grain size of 500 nm to 800 nm. For additional information on the hard metal grade the reader is referred to [2], where it is named hard metal grade "×7". The investigated specimen geometry represents a cylindrical rod with a diameter of 3 mm and a length of 50 mm. Specimens were produced via different preparation procedures resulting in different surface states:

i) "Polished" that involved grinding and polishing to a mirror-like finish.
ii) Variants of EDM that involved wire-EDM in oil using a GFAC Georg Fischer AgieCharmilles Cut1000 EDM device. Nine variants were prepared with an increasing number of applied consecutive cuts performed after the initial main cut. To rationalize this procedure consider the following: the current work applied EDM parameters and cut sequences relevant to industrial machining practice in which short machining time is crucial to economic competitiveness. The desired high material removal rate at large values of discharge energy and duration is connected with a distinct recast layer. Minimized discharge energy and duration in turn result in less surface damage. As a compromise between an economically reasonable machining time and the aim for minimized surface damage, a gradual decrease of the applied discharge pulse energies and durations was imposed with increasing number of applied cuts. The variant with nine consecutive cuts, including the initial main cut, shall be referred to as "EDMed".
iii) "EDMed & blasted" that involved preparation as described in ii) with nine consecutive cuts including surface post-treatment by automated wet blasting with corundum particles of an approximate size of 40 μm, applied with a pressure of 3 bar.

The residual stress state of the prepared surfaces was characterized in the specimens' axial center in axial direction via X-ray diffraction. To this end, the widely used $\sin^2\psi$ method was applied [18] for the (102) diffraction maximum of the hexagonal WC phase at 135.8° 2θ. Using CrKα radiation, information on residual stress values was collected in a depth region ranging from the specimen surface to about

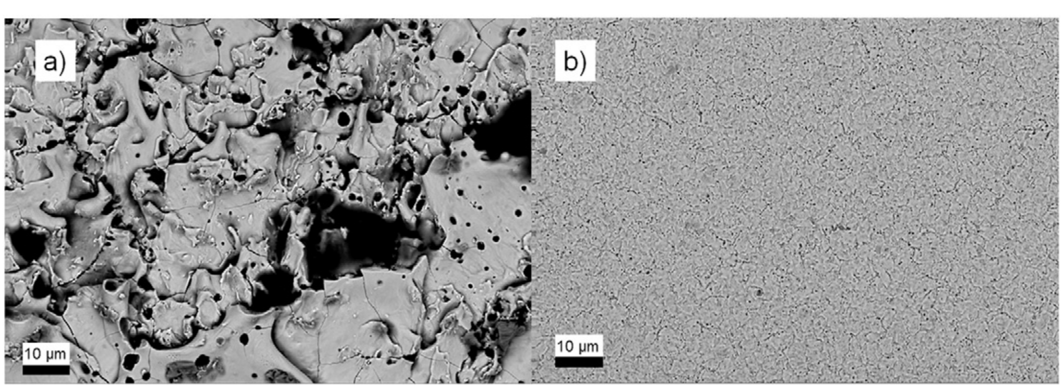

Fig. 2. SEM micrograph of a WC-Co hard metal surface after a) the initial; b) the ninth consecutive EDM cut in oil.