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Damage of different tungsten carbides under impact-sliding motion

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ABSTRACT

Research on tungsten carbides, used for drag bits inserts in tunnel boring machine, has been going on through decades for the improvement of mechanical and wear properties. The microstructure, the toughness, the hardness as well as the design of inserts are the main parameters in their functionalities and lifetime. This study emphasizes the behavior of tungsten carbide inserts in impact-sliding conditions. In order to test materials under an impact-sliding motion, a test rig has been developed, with a ball on flat configuration. The ball undergoes a vertical sinusoidal motion derived by an electromagnetic shaker. A piezoelectric force sensor and a laser displacement sensor permit the monitoring of the impact energy. Two vertical foils initiate the sliding when the ball impacts the sample, with a given angle. The impact angle variation dampens or accentuates the impact effect over the sliding component. Three types of tungsten carbides with different chemical compositions, production processes and mechanical properties have been tested: a tungsten carbide used nowadays in tunnel boring machine as inserts in drag bits, and two tungsten carbides under development. Two types of ball materials are considered: steel and silicon carbide. Main damages observed in wear scars are abrasive and adhesive wear combined with fatigue cracking. Damage mechanisms are quantified as a function of impact energy, impact angle, number of cycles and counterbody material, with a view to comparing the different tungsten carbides. Wear volume results show that inserts material currently used in the industry has a wear factor ten times higher than the two others, but is less prone to cracking. A numerical simulation with ABAQUS Explicit gives an insight of the wear process. Compressive and tensile stresses at the contact explain the cracks formation at the top of the wear scar. Tensile stresses may promote cracks formation and their propagation.

1. Introduction

Cutting tools wear has been studied for the past decades for the optimization of their hardness and their toughness [1–6]. Those tools, generally made of tungsten carbide in drilling application, are subjected to different mechanical and thermal loads occurring simultaneously [7–14]. Consequently, dragbits inserts in Tunnel Boring Machines (TBM) end up damaged by mainly abrasion mechanisms with some features noticeable such as cracks, worn out inserts and broken inserts. Drilling involves multiple impacts between the cutting tool and the rock, generating hard rock spalls that run back against the cutting tool. On top of that, friction mechanisms derived by all those impacts during drilling combined with the foam injected in the contact zone contribute severely to the damage of those materials [3,8,9,15–19]. It goes without saying that thermal conditions at the drilling contact area add up significantly in the wear process of those tungsten carbide inserts. There is a need to stop drilling operations and to replace the dragbits. Those maintenance operations are not only time consuming and dangerous for operators but also financially prohibitive, which make an efficient upgrade of the lifetime of those materials urgent and necessary.

In that respect, those materials should be well resistant, by having a good compromise between toughness (for impact resistance) and hardness (for wear resistance) properties. Many studies focused on the design [20], the nanostrucuture [2,21,22], and mechanical properties of tungsten carbides. The design depending on the drilling application could change the drilling efficiency and enhance the lifetime of cutting tools [23]. In this regard, different cutting tools are used in the rotating face according to their functionalities. The rock face is fragmented by roller disk cutters, with their circular geometry and hardening face, before being excavated with tungsten carbide tools incorporated in dragbits. In addition to that, the grain size as well as the metallic matrix composition [24] and its quantity in the composite alter relevantly toughness and hardness properties of tungsten carbide.

This study intends to highlight three aspects of the impact-sliding solicitations of those materials in order to understand the effect of the impact energy and the number of cycles in inserts

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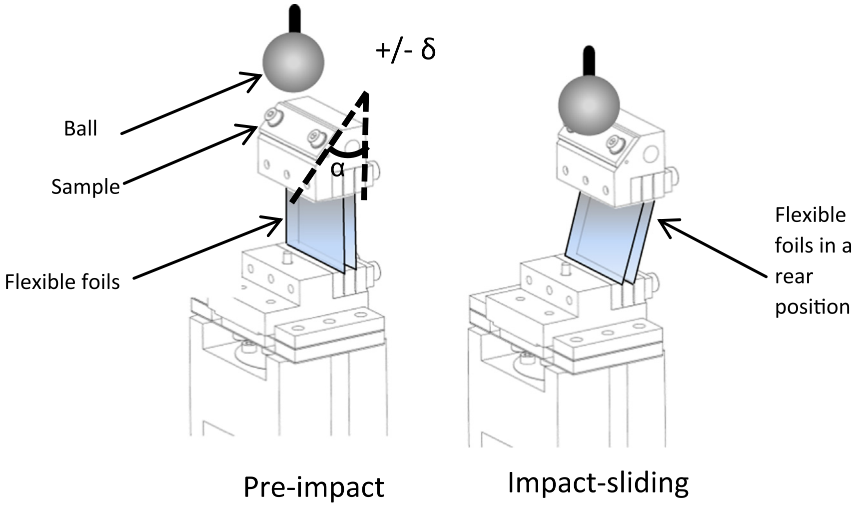

Fig. 1. Scheme of the test rig with the « pre-impact » state and the « impact-sliding » state.

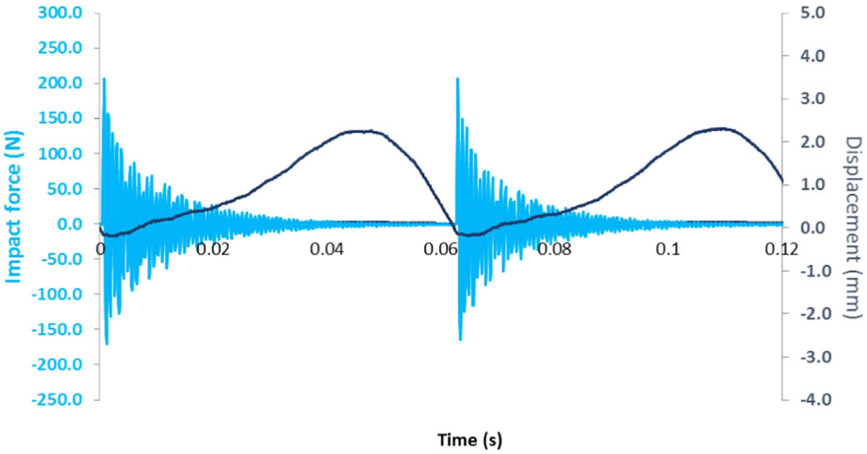

Fig. 2. Ball displacement and impact force evolution.

damage. Damage mechanism as abrasive wear and cracks formations are mostly observed depending on the material and testing conditions. Besides, ripples are also perceivable. Through ABAQUS Explicit modeling, numerical simulation will help to understand experimental tests. Accordingly, tensile and compressive stresses would be correlated with observations of wear scars.

2. Experimental analyses

A test rig was developed in the laboratory [25] in order to reproduce similar impact-sliding loads generated by the rock surface facing cutting tools. A 10 mm diameter ball impacts a tungsten carbide sample, with an electromagnetic shaker, configurable with a constant impact energy. Thus, the ball is driven by a sinusoidal movement δ regulated by the shaker. Two deformable vertical foils are placed underneath the carbide sample and thus allow the sliding motion to be generated during impact. The sample is fixed on a sloped support which allows different configurations of impact-sliding (Fig. 1). In fact, the stiffness of those vertical foils in addition to the impact angle α plays a crucial role in the sliding effect during the impact. The higher the impact angle, the greater is the impact component in comparison to the sliding component.

Two sensors are installed in the test rig: a laser sensor which measures the displacement of the ball, and a piezoelectric sensor, localized at the bottom of the flexible foils recording impact forces (Fig. 2).

Displacement data helps us to calculate the impact velocity when the impact is detected by the force sensor. The impact energy, regarded as a kinetic energy, is then calculated taking into account the impact mass.

This study will highlight the behaviour of three different tungsten carbides, one used in an industrial scale, namely, “E6”, and two others under development “WCR1” and “WNZVC”. Fig. 3 highlights the microstructure of those materials [22].

WCR1 is the only one of the three materials developed with reactive sintering technique involving different tungsten carbide grain sizes, for mechanical properties enhancement. It is a complex structure that helps improving the cohesion between WC grains.

Table 1 presents the compositions and mechanical properties of the materials [22] (ball and flat sample) used in this study.

It is quite interesting to note that the toughness and the hardness are both important parameters that are worth to be enhanced in order to get optimal tungsten carbide inserts with great properties such as a high resistance to wear. However, it is nearly impossible to get a dragbit insert characterized with a high toughness and also an exceptional hardness. Consequently, a compromise should be reached by taking into account the composition of the grains, the nature of the binder phase [26–28] and the nanostructure of the composite. In addition to toughness and hardness, dragbits inserts should be resistant to corrosive