Wear 303 (2013) 533–540

Contents lists available at SciVerse ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Wear mechanism of iron-base diamond-impregnated tool composites

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ARTICLE INFO

Article history:
Received 8 September 2012
Received in revised form
3 April 2013
Accepted 15 April 2013
Available online 22 April 2013

Keywords:
Diamond
Metal-matrix composite
Cutting tools
Abrasion-induced martensite
Abrasion

ABSTRACT

The main objective of the present work was to determine the effect of abrasion induced martensitic transformation occurring in the matrix of diamond-impregnated tool composites on their wear behaviour under quasi-industrial conditions. Various iron-base and cobalt-base powder mixtures were consolidated to a virtually pore-free condition by hot pressing at 850–900 °C. The specimens were subsequently checked for density and tested for resistance to both 3-body and 2-body abrasion. A series of diamond-impregnated specimens (segments) was also produced and tested for wear rate on abrasive sandstone using a special testing rig. The statistical analysis of wear data showed increased resistance to abrasion of alloys containing unstable austenite which could transform to hard martensite under tribological straining. The wear rate of diamond-impregnated composites was mainly affected by the diamond concentration, whereas statistically significant contribution of the matrix resistance to 3-body abrasion to the wear rate of the diamond containing material was exclusively found in iron-base composites containing austenite.

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1. Introduction

Nowadays diamond blades and wires are commonly used for sawing natural stone, concrete and ceramics. The cutting section of the tool consists of synthetic diamond crystals embedded in a metal, or metallic, matrix by various powder metallurgy (PM) fabrication routes [1]. While sawing the rigid diamond grits pass over the machined surface wearing away its mineral constituents which abrade and erode the matrix to expose fresh diamond crystals which take over the cutting action from mechanically degraded and dislodged ones.

In order to attain the economically best sawing conditions, an ideal balance between the tool life and cutting rate has to be achieved. The tougher and more difficult to cut the workpiece the finer and stronger the diamond type to be selected is a general rule while the matrix has to wear at a rate corresponding to the rate of diamond breakdown. An incorrect choice of the matrix characteristics or diamond type, size and concentration yields a tool that wears away excessively or refuses to cut altogether.

In practice, there are always several mechanisms of tool wear operating in concert. The interactions between the diamonds, workpiece, workpiece debris, and matrix occur in a variety of forms depending on size and amount of the abrasive swarf, its shape, hardness and cleavage properties, diamond strength and loading conditions, matrix resistance to wear, etc. Therefore it is convenient to confine the scope of theoretical analysis to two extreme cases such as circular sawing of difficult to cut granite and frame sawing of abrasive sandstone.

1.1. Circular sawing of granite with segmented blades

The most difficult to cut types of granite are wet sawn in many passes with a reciprocating movement of the saw blade, which alternately operates in the up-cutting and down-cutting modes, as shown schematically in Fig. 1.

The depth of cut (a) ranges between 0.4 and 20 mm whereas the feed rate (v_f) is chosen to comply with the saw blade characteristics, machine rigidity and power, and to avoid overloading of the steel core. Typically, cutting rates (av_f) of between 100 and 300 cm^2/min are employed.

In circular sawing of granite, the blade rotates in a constant direction at peripheral speeds (v_s) of between 25 and 35 m/s. This leads to the development of a matrix tail behind each working diamond crystal, as shown in Fig. 2, which acts as a support during cutting.

In down-cutting the working diamond particle penetrates into the stone to full depth while coming in contact with it. Thereafter as the diamond tracks across the abraded surface layer it emerges progressively and finally loses contact with the stone. In contrast to down-cutting, in the up-cutting mode diamonds gradually increase the depth of penetration to achieve the maximum values

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http://dx.doi.org/10.1016/j.wear.2013.04.016

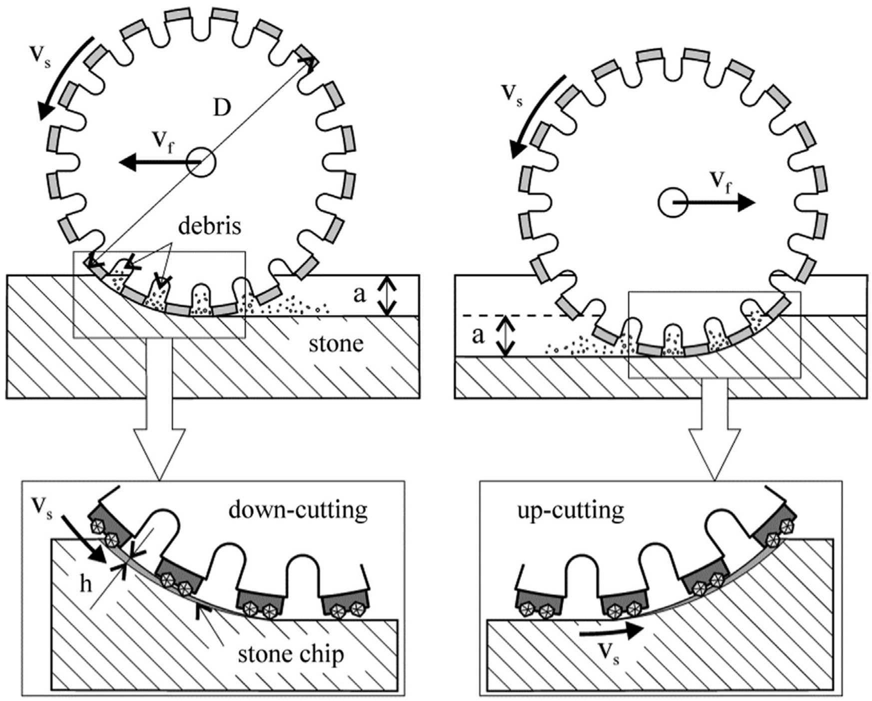

Fig. 1. Kinematic diagram of diamond crystals that come into contact with stone in down-cutting (left) and up-cutting (right) modes.

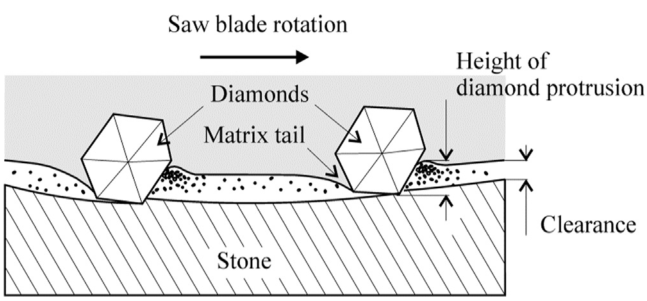

Fig. 2. Schematic representation of the cutting zone in circular sawing.

while leaving the kerf. Consequently, the diamond breakdown is facilitated by downward rotation of the blade that, by its nature, creates additional, pulsing impact forces acting on crystals which enter the cutting zone. Their magnitude is proportional to the maximum chip thickness (h_{max}) approximated as [2]

$$h_{max} \approx \frac{v_f a}{v_s C w} \sqrt{\frac{1}{aD} - \frac{1}{D^2}} \tag{1}$$

where

C—number of diamond crystals per unit surface and
w—average width of diamond crystals.

The failure of each diamond crystal is governed in a complex manner by its shape, orientation and ability to withstand impact forces, the magnitude of mechanical and thermal loading, and the matrix retention properties. With irregular and friable grits the tool wear is mainly governed by chipping of the diamond crystals which decreases their height of protrusion thus reducing the space for swarf accumulation and removal (see *clearance* in Fig. 2), and consequently, creating harsh 3-body and 2-body abrasion conditions. On the other hand, if blocky and robust grits are used the sawing conditions must be carefully chosen in order to facilitate their controlled micro-chipping. Otherwise, due to insufficient diamond penetration depths (h_{max}) the excessive friction leads to grit blunting as shown in Fig. 3 (steps I and II).

This results in high forces oriented 80–85° normal to the stone surface [3], which being transmitted to the matrix may cause its plastic deformation (step III in Fig. 3). As each working grit is subjected to cyclic loading, applied at 3–35 Hz intervals depending on the blade diameter (D) and peripheral speed (v_s), each time the yield strength of the matrix is exceeded the seat of the diamond crystal slightly opens and thereby the hold on the diamond is being gradually destroyed. Finally when pullout occurs the matrix tail is immediately removed by harsh 2-body abrasion (step IV in Fig. 3). The wear rate then decays over time as clearance increases, and other forms of wear, such as 3-body abrasion and erosion, take over.

1.2. Frame sawing of abrasive sandstone

In the frame sawing operation, schematically shown in Fig. 4, the blade moves forward and backward alternatively at a slow sinusoidal speed with a maximum of around 2 m/s.

Under such conditions, the removal of coarse and abrasive sandstone debris from the kerf is difficult. This creates severe wear conditions for the matrix and facilitates diamond pullout since forces act on diamond grits in alternate directions and build-up of the matrix tail becomes impossible.

Graphic illustration of the cutting zone characteristic of frame sawing is presented in Fig. 5.

In frame sawing the maximum chip thickness is attained while altering the movement direction and may be approximated as [2]

$$h_{max} \approx \frac{v_f}{n_s} arc\ \cos\left(\frac{l_s - 2L_3}{l_s}\right) \tag{2}$$

where

n_s—flywheel rotational speed,
l_s—length of stroke and
L_3—spacing of cutting edges.

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