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Technical Paper

Experimental and numerical analysis of thermal phenomena in the wear of single point diamond dressing tools

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ABSTRACT

Grinding technologies represent a critical step in the production of high added-value and high precision parts for strategic industrial sectors such as aerospace, automotive, biomedical, and wind generation. Whilst a number of factors related to the grinding wheel are important for optimizing the grinding process, there is no doubt that the wheel surface topography is the most influential factor. Surface topography is induced not only by the nature of the wheel itself, but also, more importantly, by the dressing process. Dressing is periodically carried out in order to recover the abrasive capacity of the wheel once excessive wear of abrasive grits has occurred. The high temperatures and contact forces present in dressing lead to wear of the diamond dressing tool, which in turn damages the topography of the wheel surface. Although the scientific literature has paid attention to the phenomena involved in dressing tool wear, some issues are still in need of explanation. Thus, the aim of the present study was to address the unresolved issue concerning the relationship between dressing temperatures and dressing tool wear. Using a combined empirical and modeling approach, the work reported here shows that temperatures on the surface of the dressing tool can be reduced by as much as 35% when using high conductivity materials in the tool holder. In addition, a methodology has been devised in order to estimate accurate values of the heat partition ratio towards the diamond dressing tool. The results show that the heat partition depends primarily on the dressing mechanism involved. Its values range from 0.97 (when friction between the dressing tool and the grinding wheel prevails) to 0.54 when grain breakage and pull-out occur at higher dressing depths. It has been analyzed and measured the wear suffered by the diamond under interesting designed tests. It has been demonstrated that the effective reduction of temperatures during process led us to take a lower wear rate of the diamond.
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1. Introduction

In modern industrial practice, grinding is a very important abrasive machining process, designed to achieve smooth surfaces and tight tolerances on ground parts. It is a key technology for the production of high added-value components in a wide range of sectors such as aerospace, automotive, and energy generation. The correct design of the process is of critical importance in producing parts of the required quality, and involves several issues such as the specification of the grinding wheel, grinding fluid application, and the grinding parameters. However, previous research has indicated that wheel surface topography (or the abrasive capacity of the wheel) is undoubtedly amongst the most influential factors [1–5].

During grinding, the wheel progressively loses its cutting ability due to the high thermal and mechanical loads applied on the wheel-workpiece interface. Three wear mechanisms are commonly identified during grinding: attritious wear, grain fracture, and bond fracture [6,7]. Excessive wheel wear leads to unexpected increases in power consumption, loss of workpiece surface quality, and the occurrence of grinding burns (thermal damage on the work surface). Dressing is then carried out to re-generate abrasive wheel topography so that optimum performance can again be achieved.

Dressing performance is critically dependent upon the dressing parameters and shape of the dressing tool. In industry, various types of diamond dressers can be found, such as stationary single-point, stationary multi-point or rotary dressing tools [8]. In many cases, single-point dressing tools are an optimum choice because obtained surface of the grinding wheel can be easily controlled by the dressing parameters [6]. When these dressing tools are used, the critical parameters are the dressing depth (a_d), the active width

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Nomenclature

a_d	Dressing depth [mm]
b_d	Active width of dressing tool [mm]
U_d	Overlap ratio
γ_d	Dressing tool sharpness ratio
f_d	Diamond axial dressing feed [mm/rev]
v_s	Grinding wheel peripheral speed [m/s]
G_t	Dressing wear ratio
b_s	Wheel width [mm]
w_d	Diamond width
P	Power consumption during dressing [kW]
k	Thermal conductivity [W/m K]
h	Convection coefficient [W/m^2]
ρ	Density [kg/m^3]
c	Heat capacity [J/kg K]
v_d	Dressing feed speed [mm/min]
v_s	Wheel peripheral speed [m/s]
T_{exp}	Experimental temperature [K]
T_{sim}	Simulated temperature [K]
A_d	Wheel-diamond contact area [mm^2]
P_d	Total heat flux to the diamond [kW]
q_t	Total heat flux density in dressing process [W/m^2]
q_d	Heat flux density entering to the diamond in dressing process [W/m^2]
R_d	Heat partition to the diamond
γ_d	The dressing tool sharpness ratio
R^2	Adjustment parameter in a minimum square adjustment
v_w	Workpiece peripheral speed(for cylindrical grinding) [m/min]
a_e	Infeed [mm]
vf	Grinding feed speed [mm/min]
Q'	Specifica material removal rate [mm^3/mm s]
q_s	Speed ratio between wheel and workpiece

of the dressing tool (b_d), the overlap ratio (U_d) and the dressing tool sharpness ratio (γ_d) [5].

Much attention has been paid in the scientific literature to the influence of the dressing process on the performance of grinding operations, and a key focus of research since the early 1980s has been the influence of the dressing parameters on grinding performance. Inasaki and Okamura [9] concluded that the most influential parameter is the dressing feed (f_d). This parameter is the feed of diamond per wheel revolution in axial direction. In particular, these authors found that the higher the f_d, the higher the final average surface roughness (*Ra*) of the resulting ground components. In their work, Inasaki and Okamura also proposed the use of Acoustic Emission (AE) signals for the monitoring of the dressing process, and noticed that the AE signal could be correlated with the *Ra* value of the ground surface. However, in that study, no attention was given to the wear mechanisms of the dressing tool.

In later work, Coelho et al. [10] studied the relationship between dressing parameters and sharpness of the grinding wheel for both single-point diamond dressers and synthetic mono-crystal diamond dresser (MDD) logs of constant width. Their results confirmed those of Inasaki and Okamura [9] and showed that, for single-point diamond dressers, it appears a direct relationship between the dressing parameters, the AE signal, and wheel sharpness. According to their results, the frontal dressing area (defined as the product of $f_d \cdot a_d$) was directly proportional to both the wheel sharpness and the RMS level of the AE signal. Again, this study did not consider the issue of dresser wear.

Still in the 1980s, Tkhagapsoev et al. [11] reported some very interesting research on the relationship between high temperatures and wear of the diamond tool. They found evidence that wear starts in a small area fractured during the first dressing strokes, and this contact area continuously grows during subsequent dressing strokes. They concluded that the generated heat led to thermal fatigue, which is primarily responsible for tool damage.

Two studies conducted by Shih et al. [12,13] provide a more in-depth analysis of diamond wear. The former study [12] was the first to consider the direct influence of a_d and f_d on the wear of the dressing tool, using the dressing wear ratio G_t as wear indicator. In their work, vitreous bond SiC grinding wheels and diamond blade tools were used. For the values of a_d used in the experimental work (1–10 μm), it was found that the higher the value of a_d, the lower the wear of the diamond. The authors suggested that this could be explained by the brittle fracture of the SiC abrasive and vitreous bond while truing at high values of a_d. The same conclusion was drawn for the influence of f_d, but the authors point out that these trends can only be confirmed within the range of dressing parameters used in their study.

In their second study [13], the authors observed that the development of dressing forces is rather unstable; large force variations are a consequence of micro and macro fracturing of the diamond tools that can be identified using the SEM micrographs. A worn diamond with a large worn flat surface (high values of b_d) becomes equivalent to using high values of U_d, leading to higher grinding forces and a finer surface roughness of the workpiece.

Further work related to the influence of dressing parameters on diamond wear was carried out by Linke and Klocke [3,15]. In accord with the findings by Shi [12] they found that increasing a_d led to less tool wear, although the frequency of collisions was higher when a_d increased, shattering the grinding wheel structure. The energy of the collisions is then spent on breaking bond bridges and less heat is generated. In contrast, when low values of a_d are used, friction between the diamond surface and the abrasive grits occurs, producing large quantities of heat that contribute to diamond wear.

However, the influence of f_d deserves closer attention. Linke and Klocke [3,15] found that the higher value of f_d, the higher the diamond wear. Although at first sight the results published by both Linke and Shi appear to be contradictory, this can be explained in terms of large differences in the ranges of variation of f_d. Whilst Shi used values of f_d between 0.007 and 0.069 mm/rev, Linke proposed values between 0.1 and 0.25 mm/rev. As a consequence, the phenomenon of bond-bridge shattering is predominant in the higher range of f_d, thus explaining why wear increases within this range of values.

From the review just outlined, it appears that the generation of heat and an increase in temperature are directly related to diamond tool wear. Taking into account the thermal nature of the dresser wear, Coelho et al. [16] proposed using numerical simulation (FEM) for estimating temperatures at the diamond tip using different tool holder materials. This model, however, has limitations and the results are far from accurate, due to the hypotheses used for estimating the heat flux entering the diamond. In fact, a clear definition of the heat partition entering the diamond has yet to be found in the scientific literature. Temperature measurements presented in [16] can only be taken as approximate, and the measurement of diamond wear was not considered. Nonetheless, this work was the first to use high conductivity materials and specific diamond holder geometric designs as an efficient strategy to reduce diamond wear, which in itself is a very valuable contribution for industrial dressing operations.

Although, as shown above, the scientific literature has paid attention to the phenomena involved in dressing tool wear, some facts are still in need of explanation. The research focus of the present work, therefore, is to explore the relationship between

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