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An experimental study of the effects of dressing parameters on the topography of grinding wheels during roller dressing

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ABSTRACT

Vitreous-bonded grinding wheels are widely used for machining features on aerospace components achieving high material removal rates under high pressure coolant. Dressing is a vital stage in the grinding process to ensure a consistent wheel topography and performance. However, the effects of roller dressing on functional performance of vitreous grinding wheels as well as its influence on different abrasive grit morphologies have not been fully characterised. This paper studies the influence of dressing parameters on the topography, morphology and characteristics of the surface of different vitrified abrasive wheels in order to better understand the process and therefore optimise the preparation of grinding wheels for industrial machining. Alumina grinding wheels with conventional and engineered grit shapes were dressed at two different infeed rates over a range of seven different speed ratios (from −0.8 to +1). An experimental methodology has been developed incorporating a range of known techniques to define the abrasive wheel condition including measured power consumption and ground graphite coupons as well as using optical microscopes to measure grain fracture flats, peak density and abrasive grain shape. It has been found that power consumption of the grinding wheel spindle increases at higher infeed rates and speed ratios. This leads to increased fracturing of the grains and whole-grain pull out. According to the results the infeed rate has a more substantial effect on wheel topography than speed ratio and the response of engineered grit morphologies to dressing is dependent on grit orientation.

1. Introduction

Grinding is a widely used machining process utilised for both high material removal roughing processes as well as high quality finishing operations. A vital stage in this process is wheel preparation whereby the grinding wheel is prepared for cutting by truing (to remove wheel run-out), dressing (to sharpen abrasive grains) and forming (to generate a particular shape in the wheel) [1]. Dressing is also used to remove any loaded or built-up workpiece material deposited on the wheel surface.

The dressing process can be performed in a number of ways including traditional techniques of single point and roller dressing, as well as more recent methods such as Electrolytic in-process dressing (ELID) and Laser [2]. Saad et al. [3], who examined both point and roller dressing, highlighted the influence of overlap ratio on component surface finish. For this investigation roller dressing was studied due to its common use in industry when form grinding for aerospace component applications.

Roller dressers consist of a cylindrical body with a single layer of diamond particles impregnated in a metal matrix. Dressing rolls can also be made to specific forms which will then be generated in the surface of the abrasive wheel, therefore enabling the grinding of complex features onto the workpiece [4]. This leads to a much faster dressing process and longer lifetime for the dresser in complex feature grinding compared with a single point method [5].

There are three key variables that affect the dressing operation including infeed rate, rotational direction and speed ratio [2]. The effect of each of these was investigated.

- Infeed rate – the rate at which the dresser moves normal to the circumference of the wheel.
- Rotational direction – describes the direction the dresser turns relative to the wheel, synchronous (wheel and dresser spin in

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opposite directions, the angular velocity of the dresser over the wheel is negative) and asynchronous (wheel and dresser spin in the same direction, the angular velocity of the dresser over the wheel is positive).
- Speed ratio (q_d) – the relative surface speed of the dresser to the surface speed of the abrasive wheel.

Although the mechanics and simulation of single point dressing is relatively well covered [4], [6–8], there is a less knowledge about the mechanisms involved in roller dressing and its influence on the topography of vitreous grinding wheels. It is well known that crush dressing occurs at high positive speed ratios ($q_s = 1$) i.e. the dresser and grinding wheel surface speeds are equal. This is the only active mechanism that causes grain fracture at the surface of the wheel and generates a fresh topography on the cutting edge. In this condition the wheel and dresser are subjected to a high normal force due to the wheel/roller pressing into one another with little abrasive removed by cutting [1].

Malkin and Murray [9] have found that in rotary dressing of aluminium oxide grinding wheels the vertical and horizontal force components peak when the speed ratio is at unity. They also demonstrated that specific dressing energy reduces by an increase of the infeed rate. SEM imaging suggested that the interference angle of the dresser on the abrasive wheel will influence dressing specific energy. Interference angle was defined as the angle of the trochoidal path of the diamond relative to the surface of the abrasive wheel and it can be altered by the infeed rate [9].

Several models have been developed to simulate grinding wheel behaviour during dressing. This includes considering it as a tribological system and calculating the ideal engagement volume of a dresser diamond against the abrasive wheel. Linke [10] used this to understand the influence of speed ratio on the normal force and acoustic emission output when dressing. When dressing at unity, the normal forces were high and caused shattering of the grinding layer through whole grains breaking off the surface. A Finite Element Modelling (FEM) study followed treating the wheel as a homogenous body and creating a two-dimensional model based on the linear elastic stress state. The results indicated that previous dressing strokes can weaken the abrasive wheel bond and result in high wheel wear directly after dressing, this effect was observed even after a 'finishing' dressing stroke [11]. Saad [3] compared two different empirical surface roughness models to understand the impact of dressing parameters on workpiece surface integrity. This showed the influence of interference angle on component quality. A good summary of grinding wheel topography models is given by Doman et al. [12] which highlighted that the mechanics of dressing has not been studied in great detail.

It is well known that the performance of a grinding wheel during cutting is directly linked to wheel topography [13]. As dresser interaction with the grinding wheel influences the wheel cutting surface, topography therefore can be used as a measure of dressing effectiveness. To measure the response of the grinding wheel to different dressing parameters, a robust technique must be identified to capture its topography. Different contact and non-contact based systems have been used in literature including Backer et al. [14] who used a soot-track method. A wheel was rolled on a glass plate coated with carbon-black to determine the number of contacting grains per area as soot would be removed where the grains contacted the glass. Although indicating possible active grains this method gives no information on the shape of the cutting edges. To conquer this many papers have utilised a stylus technique [15–18] including Butler and Blunt [19] who used 3D stylus profilometry to determine density of summits, summit curvature and root-mean-square roughness.

Research has also been conducted using image processing methods to assess wear and fracture on abrasive wheels. Lachance et al. [20] introduced a technique to identify wear flat area using charge coupled device camera images of a grinding wheel and LabView image processing software. Arunachalam and Ramamoorthy [21] as well as Yasui et al. [22] completed similar work determining flat regions on abrasive grits. Application of replica techniques has also been investigated by Bhaduri et al. [23] who used both graphite and resin compound to obtain positive and negative profiles of the wheel. Summit density was determined from this as well as average roughness by using a Form Talysurf stylus on the positive profiles. Cai and Rowe [18] also used resin replicant to measure cutting edge density and cutting edge dullness of four different Cubic Boron Nitride (CBN) wheels. This proved that resin replicas are best measured under optical interferometry.

To the best knowledge of the authors, the literature is limited on the effect of roll dressing on characteristics of vitreous grinding wheel topographies, especially the influence of different abrasive grit morphologies (wheels with engineered grains). This work aims to develop the fundamental understanding of the process and define the effect of abrasive grit morphology on the response of a grinding wheel to different roller dressing parameters including infeed rate, rotational direction and speed ratio.

2. Experimental framework

Three different alumina grit wheels (as indicated by wheels A, B and C in Fig. 1) with a fine, #80 mesh, grit size, a medium porosity and manufacturers hardness grade H were tested over seven different speed ratios (−0.8, −0.6, −0.4, 0.4, 0.6, 0.8, 1) and two infeed rates (0.002 mm/rev and 0.0005 mm/rev) using a flat roller dresser. A full, random factorial Design of Experiment with a full set of repeats was used to determine the test order.

The as received grinding wheels were dressed prior to the experiments to true and dress the wheel surface to a controlled parameter set to remove the influence of variation in wheel manufacture processes. A second dress was performed with a total dress depth of 0.3 mm and power during dressing was measured. The total dress volume was constant for each dressing condition. The background power conditions where the spindle was in free rotation at speed (not in contact) was also measured and net power consumption of the grinding spindle was calculated as power during dressing minus background power conditions. A Load Control Incorporated Power Monitoring kit (4–20 mA output) with a National Instruments 9201 DAQ box was used to capture the data at a sampling rate of 20 kHz. Each recorded reading was an average of 1000 data points. A single grinding pass (1200 mm/min feed rate, 50 m/s wheel speed) on a graphite coupon (Grade GD4430) was performed after dressing to measure the 'average' wheel 2D surface profile topography. The surface roughness of the graphite coupon was then measured in the lay direction (perpendicular to the feed direction), which is representative of the average surface topography across the grinding wheel width, using a portable roughness probe. Measurements used ISO1997 standard with a 5N applied probe force and evaluation length of 4.0 mm together with a cut-off wavelength (λs) set at 0.8 mm. To ensure the statistical validity of the results the measurements were repeated five times for each coupon and the average surface roughness, Ra, was calculated. The area surface topography of the grinding wheel was further investigated using different techniques explained in Section 2.1.

All dressing trials were conducted on a Makino A100 universal horizontal machining centre using the 5-axis VIPER grinding capability and standard Hocut 768 coolant (at a percentage of 6–8% and a pH of 8.5–9.5). The dresser spindle was directly driven with 11 kW max power, 8000 rpm max speed, torque of 14Nm and continuous dressing capability.