CIRP Annals - Manufacturing Technology 62 (2013) 363–366

Contents lists available at SciVerse ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Improved coolant supply through slotted grinding wheel

Jan C. Aurich (1)*, Benjamin Kirsch

Institute for Manufacturing Technology and Production Systems, University of Kaiserslautern, Germany

ARTICLE INFO

Keywords:
Grinding
Cooling
Tool development

ABSTRACT

A suitable coolant supply in grinding is mandatory to comply with the demanded workpiece quality, to avoid thermal damage and to reduce tool wear. In this paper, the development of a slotted grinding wheel with optimized coolant supply is described. This simple but efficient approach was based on previous investigations on external and internal supply methods, which are briefly described. The performance of the slotted grinding wheel in comparison to two other grinding wheels, applying the same coolant nozzle for each, revealed significant improvements in the cooling efficiency.

1. Introduction

Grinding is applied for surface finishing and to achieve high material removal rates (MRR). For both, a suitable coolant supply is mandatory to achieve the required workpiece quality, to avoid thermal damage and to reduce tool wear. As a consequence, the coolant supply in grinding has always been a well-researched topic [1]. This led to the development of improved nozzle-designs such as the Webster-nozzle that provides a higher jet-quality to enhance the cooling efficiency [2]. Other fundamental insights were concerned with nozzle positioning, also highly influencing the cooling performance [3].

In addition to investigations on external nozzles, the coolant supply through the grinding wheel itself, the internal coolant supply, has been suggested as an ideal strategy. The coolant is delivered to the abrasive layer, directly into the contact zone where it is needed the most, thus providing advantages in particular at high contact lengths. Despite this theoretical superiority, the internal cooling method is only marginally investigated; high MRR or grinding wheel speeds not at all [4].

A variation of the internal cooling supply is the supply through gaps in the grinding wheel topography. These include engineered wheels with radial grooves in the grinding wheel body near the abrasive layer where the coolant is delivered into; the coolant is then transported through the radial grooves to the abrasive layer [5]. Another simple form of this supply method are segmented grinding wheels [6], where the segments support an increased amount of coolant in the contact zone. Similar to the more complex internal cooling supply, the impact of the cooling on the process and process results remains unclear; in most cases reference processes are missing or the impact on the surface integrity is not examined.

In this paper, the development of a slotted grinding wheel with optimized coolant supply is described. The design is derived from previous experiments including internal coolant supply.

2. Experimental setup

All surface up-grinding experiments presented in this paper were conducted using a high performance grinding machine at grinding wheel speeds of 63 m/s. All wheels used the same electroplated B251 abrasive layer. The workpiece material was hardened heat treated steel AISI 4140 (635 HV 0.3).

Five parameter combinations were investigated. At a feed rate of 1000 mm/min, depths of cut of 0.50, 0.75 and 1 mm were applied. This allowed for the examination of the influence of rising material removal rates at constant times of heat impact. To evaluate the influence of the feed rate, 1000, 2000 and 3000 mm/min were applied, each at a depth of cut of 0.50 mm. In doing so, the influence of the time of heat impact with constant amount of removed material could be evaluated.

Forces were recorded during stationary grinding, while forces caused by the coolant supply have been subtracted from these values. For this purpose, separate grinding passes of each parameter combination were performed, and feed motion was stopped during stationary grinding. The resulting forces were used as an offset to the forces recorded during normal grinding.

A piezoelectric pressure transducer was mounted on the workpieces to determine the maximum pressure that occurs directly in front of the contact zone in the lubrication gap. This value can serve as an indicator for the amount of coolant transported through the contact zone [7]; higher values promote a better cooling efficiency.

The workpiece quality was evaluated mainly by the condition of the surface layer, identified by measurements of microhardness. The threshold value used to identify the transition from tempered zone to workpiece core was 500 HV 0.3. This corresponded to 80% of the core hardness, a threshold commonly used to determine the hardening penetration depth of heat treatments.

The measurement for all data was repeated three times. The resulting average standard deviation σ of the values can be found in the respective figures.

* Corresponding author.

0007-8506/$ – see front matter © 2013 CIRP.
http://dx.doi.org/10.1016/j.cirp.2013.03.071

3. Previous work

Previous experiments included the development of a grinding wheel with internal cooling supply [8] and its application with pure internal [9] as well as with an additional external cooling supply [4,10]. In contrast to other approaches, the coolant is not only delivered by the centrifugal force but by the grinding wheel itself. The cooling channels inside the wheel are designed similar to those of centrifugal pumps. This ensures the coolant supply at high grinding wheel speeds (for more details concerning the design refer to Ref. [8]).

This wheel provided 36 cooling channels, each with a cross-sectional area of approximately 66 mm^2. The coolant was supplied through all channels and the exit was not limited solely to the area of the contact zone. For the experiments, a complete amount of 300 L/min was delivered, resulting in about 8.3 L/min for each channel (more details can be found in Section 5).

3.1. Results and discussion

The performance of the grinding wheel with internal coolant supply in both pure internal and combined internal/external mode was compared to a standard electroplated grinding wheel with a free-jet nozzle (FJN).

Significant differences were detected in the resulting alteration of the workpieces' surface layer. Applying pure internal coolant supply, the deepest alterations of surface layer and the deepest rehardening zones occurred. Both could be reduced using the additional external cooling via a FJN, confirming that the pure internal mode provides a poor bulk-cooling effect. Nevertheless, using the same FJN (with the same settings) in combination with the standard grinding wheel, the resulting alteration of surface layer was considerably lower than that of the internal/external combination, completely avoiding rehardening zones in the middle of the workpieces.

The worse cooling effect for the grinding wheel with internal coolant supply was led back to the differences in the macro topography of the wheels. As illustrated in Fig. 1, using the standard grinding wheel, a lubrication gap is formed in front of the contact zone. In this gap, the coolant is under higher pressure, providing two major advantages: raising the boiling point of the coolant and pressing the coolant into the contact zone. A higher boiling point delays the appearance of film-boiling. When film-boiling is reached, cooling efficiency is deteriorating rapidly [11].

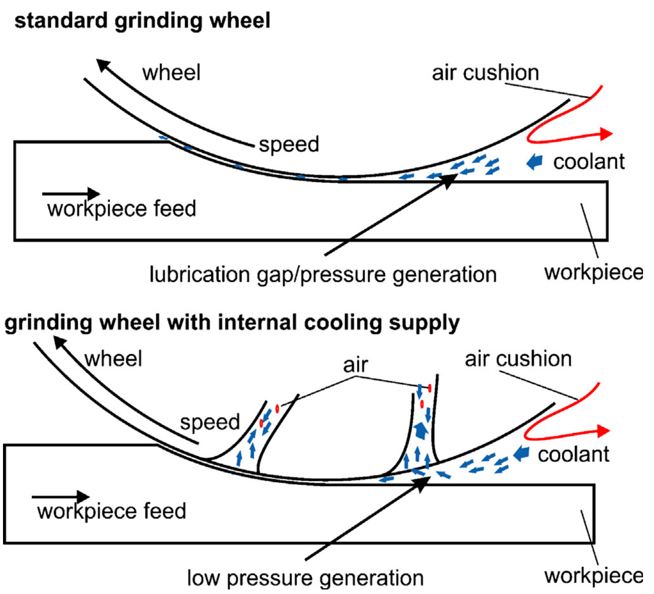

Fig. 1. Differences in the formation of the lubrication gap.

The channels inside the grinding wheel with internal coolant supply diminish the formation of this lubrication gap (see Fig. 1). As a consequence of the comparably low amount of coolant delivered through each channel, in combination with the high circumferential speeds, air is sucked into the channels. This leads to the formation of an oilmist, resulting in a low pressure inside the channels. Additionally, the coolant delivered by the supplemental FJN can evade into the outlets of the channels positioned at the circumference of the wheel. A low amount of coolant inside the contact zone, where it is needed the most, is the consequence.

The lower coolant pressures of the grinding wheel with internal coolant supply can result into film boiling at the outlets of the channels. An evaporation of the coolant results into a film between the workpiece and the outlets, hampering heat transfer and the ability of the coolant to enter the area between two outlets in the contact zone.

Although coolant is constantly delivered to the contact zone through the channels, the fluid does not flow through it; this effect is comparable to the coolant in a vitrified bond that is present, but does not participate in the cooling action.

The same is true in applying the additional external cooling via a FJN. Despite a reduction of the alterations of surface layer due to a better bulk-cooling of the workpieces, the performance of the standard grinding wheel was still significantly better, highlighting the importance of the macro topography of grinding wheels and their influence on the lubrication gap.

3.2. Requirements for improved coolant supply

The grinding wheel with internal coolant supply demonstrated the importance of the lubrication gap for coolant pressure and the influence of the macrotopography of the grinding wheel. Nevertheless, the amount of coolant transported through the contact zone using the standard grinding wheel was still insufficient. Despite the lower alterations of surface layer compared to the internal modes, the alteration still reached depths of up to 1100 μm (see Fig. 5).

To improve the cooling performance, two main requirements must be met:

- increasing the amount of coolant transported through the contact zone and simultaneously.
- providing a high coolant pressure.

These considerations led to the development of a new type of slotted grinding wheel, described in the next sections.

4. Development of a slotted grinding wheel

In contrast to standard segmented grinding wheels, where the slots are implemented over the entire width of the wheel, the requirement was to restrict the slots to the width of the workpiece. In doing so, the coolant cannot evade to the sides of the wheel and is instead captured inside the slots. In connection with small depths of the slots, high coolant pressures should be achieved. At the same time, owing to the slots, the amount of coolant transported through the contact zone is increased in comparison to standard wheels with continuous layer.

A total of 70 slots were milled inside the wheel, shifted symmetrical alongside the centerline of the grinding wheel axis, slightly rotated by an inclination angle of 15° (illustrated in Fig. 2).

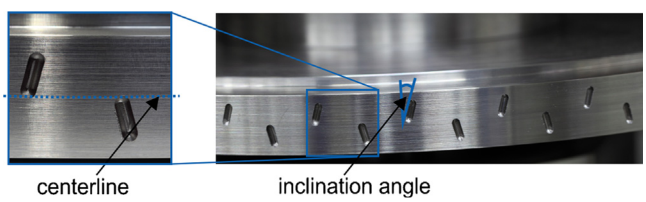

Fig. 2. Arrangement of the slots (unlayered grinding wheel body).