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AIR FLOW FIELD AROUND THE GRINDING WHEEL

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Abstract: Control of grinding zone temperature is of prime importance to obtain defect-free ground work surface. Failure to lower this temperature is likely to cause a number of thermal damages in the workpiece. Beside this, intense wheel loading on the grinding wheel may happen due to rise in grinding temperature. Application of the cutting fluid is an important aspect to reduce the various thermal damages and to improve product quality in grinding. But, the presence of the air layer around a rotating grinding wheel impedes the entry of cutting fluid into the grinding zone. Many new and innovative measures have been carried out to suppress the formation of this air layer and to remove the ill effects of the air layer. The present work reviews some of the past works that explored the formation of the air layer and that investigated different ways and means to combat the hindrance caused by this air layer to promote supply of grinding fluid close to the grinding zone for effective control of grinding temperature. It also suggests some probable avenues of future research.

Keywords: Grinding, grinding wheel, air flow field.

1. INTRODUCTION

Increasing demand forhigh form and dimensional accuracy with good surface finish lead to the rapid employment of grinding operations in modern manufacturing industry [1]. But the process of chip removal by the tiny grits of the grinding wheel is often associated with the high heat generation which ultimately results in the loss of the dimensional accuracy. The workpiece may also lose its precise shape, surface integrity etc. [2, 3]. Cutting fluid is applied hence, in the intent to reduce the accumulation of high heat and lubricate the work and wheel surfaces. But the presence of the air boundary around the wheel impedes the proper entry of the fluid jet into the mating surfaces. Thus, application of the grinding fluid becomes inefficient which in turn affects the product quality and productivity.

This paper reviews the past research works about the characteristics of the air band formed around the wheel during its rotation and the methods to avoid or minimize such development. The review concludes by showing the prevailing trends in air pressure measurement method and prevention of the formation of the air boundary.

2. NEED FOR AIRFLOW ANALYSIS

The difficulties in the application of grinding fluid in the grinding led to the study of airflow around grinding wheel [4-6]. The previous research works indicate the effect of an air band or boundary layer around the wheel. This air layer contains the debris that can abrade the workpiece by the combined effect of the chip. These chips move along the periphery of the wheel in the boundary layer and collide with the workpiece from the behind. It is usually believed that there is a turbulent region above the workpiece by the effect of this boundary layer effect of the air around the grinding wheel. This turbulent region hinders the application of the grinding fluid in the grinding zone [7-10].

Morgan et al. have observed that only 25-30% of the applied fluid is able to enter the grinding zone, rest go waste owing to the formation of the air boundary layer which not only increases the production cost, the product quality is also hampered significantly [11]. A wedge-shaped zone is created where the wheel meets with the workpiece. Zhang has shown that at the wedge-shaped zone apart from the air flow along the wheel, a return flow of air also takes place [12]. The direction of this return flow of air is in the opposite direction of the applied cutting fluid jet. It further impedes the cutting fluid to entrain the grinding zone. So, reducing this flow of air around the wheel is an interesting solution which may improve the tribological aspects by enhancing the lubricant flow through the interfaces of the wheel and the workpiece and thus reduces the energy loss, improves the surface quality of the work material.

3. CHARACTERISTICS OF AIR FLOW

It was pointed by Fisher that an air band at the surface of the rotating wheel is created and this air layer moves with approximately the same velocity as the wheel speed of 33m/s. It is also found that the air band is moving with a speed of 19.2 m/s at a distance of 12.5 mm from the wheel surface of the wheel rotating at a speed of 33 m/s [13]. The measurements of air velocities near the wheel surface of the rotating grinding wheel have been performed by many researchers [14]. The effects of the air boundary layer on the grinding process were evaluated by Ebbrell et al. [15]. It is pointed that at the approach of the grinding zone, there is a change in direction of the boundary layer which hinders the flow of fluid provided under the flood conditions. Majumdar et al. [16] pointed that the penetration of the grinding fluid exactly at the grinding zone is tedious because of the air layer formed the rotating grinding wheel.

All these findings agreed that the velocity of the air is more near the wheel surface and reduces gradually from the wheel surface to radially outward direction. The velocity of the rotating air increases with the increase in the speed of the wheel [17, 18]. The characteristics of the flow field around different kinds of wheels were also brought in forefront by Majumdar et al. Three kinds of wheels namely, a grinding wheel, modified grinding wheel by pasting an impermeable cloth on both the side faces and a cast iron solid wheel were utilized in their work. The pressure around the solid wheel was observed to be the least among those. The author showed that the presence of roughness and porosity on the grinding wheel enhanced the airflow [16].

An empirical formula was established by Radhakrishnan [14] for finding the velocity of the air around the rotating wheel:

V = 0.116 $$V = 0.116\, v^{1.05} \frac{R_t\ 0.215}{t^{.220}} \quad (1)$$

where,
t = Distance from grinding wheel surface, mm
v = Peripheral velocity of grinding wheel, m/s
Rt = Grinding wheel surface roughness, mm
V = Air velocity around grinding wheel surface, m/s.

Majumdar et al. have derived [19] a relation between the pressure around the wheel (p) and the distance from the wheel surface (y) from the Navier-Stokes equation.

$$p = -11131\,y + 218254\,y^2 + 151.2359 + 457.8499\,e^{-0.2374y} \quad (2)$$

A typical air velocity pattern with the width of the wheel is shown in Fig. 1. The tangential velocity measured was plotted by Wu et al. [20]. Two peaks can be observed in the curve pattern which is more dominant near the wheel surface. However, in this experiment, the symmetry is considered about the mid-section of the wheel and the data of the left-hand side is mirrored to the right.

On the contrary, the FEA analysis by Wang et al. showed [21] the peak pressure is at the mid-section (Fig. 2). On the other hand, Zhang showed [12] that there is a backflow of the air from the grinding zone as shown in Fig. 3. It acts opposite to the entraining cutting fluid.

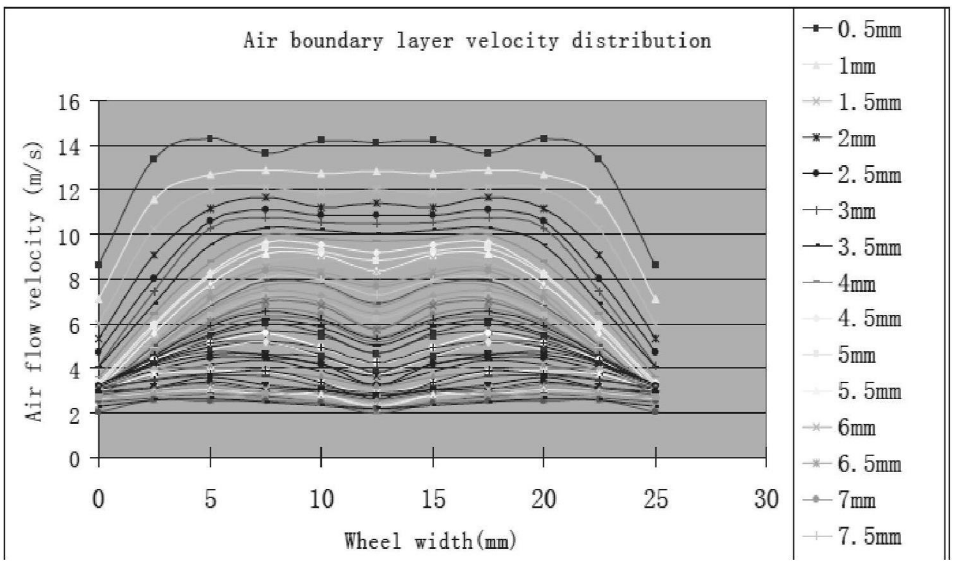

Fig. 1 Tangential velocity distribution along the thickness of the wheel

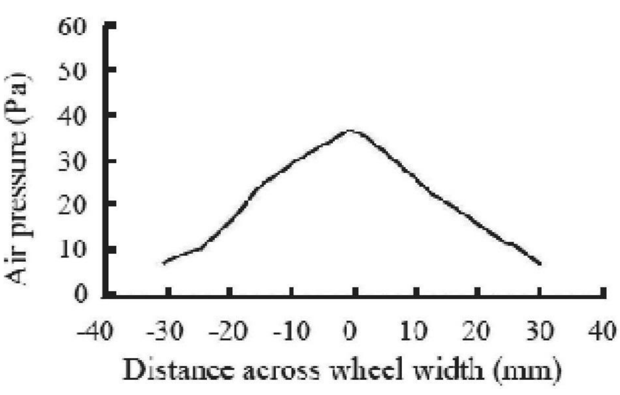

Fig. 2 Variation of air pressure along the thickness of the wheel [21]

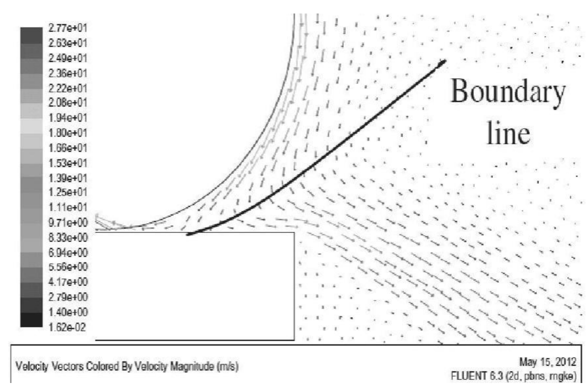

Fig. 3 velocity vector figure in wedge-shaped zone [12]

4. THE PRINCIPLE OF AIR FLOW

Many of the previous research work did not give importance of a very crucial phenomenon of the formation of a boundary layer of the air around the rotating grinding wheel. It is revealed from fluid dynamics that when a flat disc rotates in a static fluid environment and there is no slip condition, then the fluid layer adjacent to the disc is carried along with the disc and thrown outward by the centrifugal force. New fluid particles are instantly pulled towards the disc and thrown centrifugally again [15]. The grinding fluid is restricted from the grinding zone by this air boundary layer and thus there is a waste of the grinding fluid. In the recent development of this theory, the surface force, centrifugal force and air effect are held responsible for the formation of the air flow pattern. The generation of two peaks little away from both the side faces of the wheel, when the flow pattern is observed along the thickness of the wheel, occurs due to the presence of air (Fig. 1) [19]. These findings indicate that to remove the air boundary around the wheel, the fundamental causes for the formation of it may be checked.

5. TYPES OF AIR FLOW

The flow around the grinding wheel is typically either laminar or turbulent, primarily depends upon the speed of the wheel. When the air flow follows a parabolic velocity profile with Reynolds Number less than a critical value then the flow was reported [17] to be laminar flow. The air flow is termed as turbulent when the airflow increases abruptly with exponential velocity profile with Reynolds Number greater than a critical value. The flow behaviour was also dependent upon the roughness and porosity of the wheel [16]. According to Mandal et al. [22], the air flow occurs only in the radial outward direction of the wheel. Some have commented that there is some flow in the side faces of the wheel also [7, 23]. However, the flow of air at the radial direction of the wheel is the main cause of concern as it prevents the proper entry of the cutting fluid into the grinding zone. The flow of air at the side faces of the wheel becomes apprehensive when it is sucked by the side faces and passes through the pores of the wheel of the wheel and is thrown radially due to centrifugal force on the air particles [22].

6. THE PROCEDURE FOR MEASURING THE AIR FLOW

The measurements of airflowhave been achieved by the simulation using Computer Fluid Dynamics (CFD) or experimental investigations in wind tunnel [17]. FEA technique is also utilized by Wang et al. to predict the air velocity. In an experimental investigation, pitot tube along with the U-tube manometer is widely used [15, 16, 22].

Using Laser Doppler Anemometry (LDA), the measurement of the air boundary layer on the rotating grinding wheel was done by Wu et al. [20] and it was presented that the radial air velocity value had been lesser than the tangential velocity of the air.

7. PREVENTION OF AIR FLOW

As the detrimental effect of the air band formation is accepted as a serious cause of concern, its removal has now become imperative not only to improve the process performance, alsoto increase the surface quality of the component. Several methods have been developed and most of them have emphasized on breaking this bond of air than the removal of its cause of formation. The scraper plate, shoe nozzle, deflector plate, air jet etc. have been employed towards this direction of breaking the air-bond [11, 12, 24-31]. These are placed in the path of the air flow and cause the stream of it to divert from the grinding zone. The pasting of an impermeable cloth at both the side faces of the wheel has been tried to remove one of the causes of its formation [22]. Further, works are also found on the optimizing the position of those air breaker [19]. The positioning of the scraper board at the optimized location has been reported to remove 100% of the air disturbance from the grinding zone.

Some literature suggested for the optimizing the position of the nozzle and jet velocity. Few suggested for using the solid lubricant and MQL (Minimum Quantity Lubrication) where the lubricants were applied prior to the cutting action. The harmful effect of the boundary air layer could be avoided by these [32, 33]. Chocklingam et al. [34] pointed to the problem of low-pressure flood grinding. In this grinding operations, the flood cooling systems delivered a large amount of grinding fluid (5–50 litre per minute) using low pressure bendable plastic nozzles. This arrangement permitted high material removal rate until thermal constraint was faced in such a manner that workpiece would burn irrespective of the amount of the grinding fluid applied. Actually, the useful flow rate was found to be 5–20 % of the applied flow rate because of high fluid jet dispersion and non-coherence outside the contact zone in the grinding. The dense air boundary layer around the grinding wheel causes the fluid dispersion that may result in the deflection of the path of grinding fluid.

Irani et al. [35] suggested the optimized nozzle design which got a coherent, laminar jet flow and reduces the drift of grinding fluid droplets away from the wheel periphery for better results of the process. The optimized nozzle design was required because the average spray droplet diameter of size 100 μm as seen in aerosol sprays was lighter to drift to along the air currents. On the other hand, Tawakoli et al. [36] pointed out that the nozzle setting location was an important controlling factor in the performance of MQL grinding of 100Cr6 hardened steel with oil mist performance. Nozzle angled at 10° – 25° with respect to the workpiece was noted to be the most effective in penetrating the grinding fluid into grinding zone. Webster [37] designed a new round nozzle which was inspired by the design of Ruse et al. [38]. This nozzle allowed separating flow with high pressure and turbulence resulting in better coherence. The main reason was pointed to the reduction in boundary layer growth.

But these methods suffered from the setback of either non-economical, high wheel loading or less dissipation rate of generated heat etc. Therefore, there is a scope for improving the grinding performances by proper removal of air boundary by enhancing the entry of the cutting fluid into the grinding zone.

8. CONCLUSION

The present review work can be helpful in understanding the characteristics of air flow around the wheel and its effect in grinding. The surface force, centrifugal force on air particles, etc. are the causes of the formation of the air boundary around the grinding wheel. The strength of the air boundary is governed by the speed of the wheel, porosity, roughness, etc. At the same speed of rotation, the strength of the air band is less in the solid wheel than a grinding wheel.

It also describes the past research works about the methods of preventing this flow of air. Air breaker has been mostly used to prevent the flow. Locating the scraper board at the optimized position has been found most effective. More methods can be explored further to improve this work.

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