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In-process Topographical Evaluation of CBN wheel surface

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ABSTRACT

In surface grinding, the conditions of the grinding wheel has much more significant effect on the machined workpiece as compared to other metal removal processes. The contact between the grinding wheel and the workpiece introduce heat and resistance, which restrict the self-dressing of the grits and result in burrs cracks on the workpiece. Therefore, before or during the grinding operation, it is necessary to self-dressing the grinding wheel for more accurate performance.

In general, however, the choice of the dressing time has made by the operator's own decision or the condition of the workpiece. In this paper, a new method for finding the optimal dressing time of the grinding wheel is proposed. In order to develop a more sophisticated methodology, a non-contacting in-process optical measurement method using a laser beam has been introduced to find the glazing, loading, and spilling of the grinding wheel. Simultaneously, a three-dimensional computer simulation of the grinding operation has been attempted based on the contact mechanism between the grinding wheel and the workpiece. The grains of the grinding wheel are simulated and the optimal dressing time is determined based on the amount of grain wear and work surface roughness.

1. Introduction

In the mass production of accurate mechanical parts, surface grinding is one of the most frequently used machining operations. The characteristics of the abrasive are the most important components of the grinding process because of their direct contact with the workpiece. Therefore, the characteristics of the abrasive such as its hardness, wear, and shape are crucial and the development of the proper grains necessary. During the grinding process the direct contact between the abrasives and the workpiece causes glazing, loading, and spilling of the grinding wheel.

Numerous authors conducted research on the cutting edge of the dressed grinding wheel(1), the detailed geometric structure and motion of the grains(2), the effects of the bonding material(3), and a measurement of grain wear(4-7). The main objectives wear to find the distribution, spacing, and area of the grains. However, it is still very difficult to define the relationship like the irregular spacing and stiffness of the grains.

During the grinding process, glazing, loading, and spilling of the grinding wheel repeatedly happen. When the grains are no longer available as working cutting edges are generated by self-dressing. But it is not unusual to renew the cutting edges by a dressing operation when the performance of the wheel deteriorates. After the dressing operation, careful observations have to be made because the working condition of the grinding wheel decides directly the surface finish of the workpiece. CBN wheels with high hardness have long dressing intervals compared with the A and C type wheels and have an advantage for machining hared materials including quenched materials.

Optimal applications of CBN wheel have been investigated but the method of truing and dressing are difficult to optimize because of the wheel's high hardness and high price. In general, the dressing of the CBN grinding wheel can be accomplished by a single-crystal diamond dresser, rotary diamond dresser, stick dresser, or glass dresser, etc. and numerous techniques have been tried and designed.

Basically, truing and dressing operations are achieved by adjustments of the cutting edges to optimize the wheel performance depending on the machining goal. In order to decided the optimal dressing conditions and time, a careful investigation of the generation of the cutting edges on the grinding wheel should be made. At the present, a few studies are made on wheel's performance by investigating the asperity of the cutting edges but there is no systematic research on the optimal dressing time.

The main objective of this paper is to introduce the new methodology which applies the scattering intensity distribution of the laser beam to establish optimal dressing times for resin bonded CBN wheel through on-the-machine measurements can be determined by the measurements of grinding forces, scattering intensity distribution of the laser beam, surface roughness of the workpiece, and photograph of the grinding wheel. In addition, the proposed method has been approved and achieved the reliable conclusion by comparison of the obtained data such as the variations of the grinding forces, the surface roughness of the ground surface, and the topography of the grinding wheel.

Simultaneously, three-dimensional computer simulation of the grinding operation has been attempted based on the contact mechanism between the grinding wheel and the workpiece. The wear of the grinding wheel is simulated and optimal dressing time has been obtained by the grain wear and work surface roughness.

2. Experimental Apparatus and Method

Experiments were carried out on a surface grinding machine. The objective of these experiments were to investigate how the grains of the wheel surface change after the grinding process through the toolmaker's microscope and to find the optimal dressing time of the grinding wheel based on the grinding force, scattering intensity of the laser beam and surface roughness of the workpiece.

Figure 1 is a schematic of the measuring apparatus. The experimental apparatus consist of three parts. The first part is a laser system with a laser source, a photo detector, an optical power meter and a DSP. The second one is the grinding force measuring system consisting of a tool dynamometer, a change amplifier and an oscilloscope. The last one is the wheel working surface measuring system consisting of a toolmaker's microscope and a camera.

The He-Ne laser source is set up at the wheel cover that makes it possible to uniformly radiate the laser beam onto the wheel working surface. The diameter of the laser beam is 1mm. Since the grain diameter of the CBN wheel is about 90 $\mu m \sim 100 \mu m$, the change of the grains on the working surface can be easily detected. The scattering beam, depending upon the shape of the wheel surface, can be observed by the silicon photo detector and the surface intensity distribution can be obtained.

The photo-detector is attached to the wheel cover in order not to interrupt the laser beam and is installed where the incidence angle equals to the reflection angle.

The grinding forces are obtained by the measuring system, which consist of a tool dynamometer (KISTLER 9257B), charge amplifier (KISTLER 5019A) and oscilloscope(LeCroy 9304A). Table 1 explains the experimental conditions of grinding process. Figure 2 show the dimension and the shape of the workpiece. Figure

3 shows the flowchart of the computer simulation

Table 1 Experimental conditions

Grinding wheel	CBN80N75B(175*20*31.75)
Wheel speed	1897 m/min
Table speed	9 m/min
Depth of cut	0.05, 0.1 mm
Number of pass	20 pass
Workpiece	SKD 11 (HRC 63)

3. Results and Discussion

The grinding process is carried out twenty times with respect to each depth of cut by the condition at Table 1. After quenching, the hardness of the workpiece (SKD 11) is HRC 63, which is inappropriate for the conventional grinding wheel because of its low machinability, rough surface finish, and high grinding force. However, the resin bonded CBN wheel used in this experiment can grind the hard workpiece at high speed and large depth of cut.

Figure 4 shows the grinding forces depending on the number of passed at different depths of cut. In case of a 0.1mm depth of cut, the grinding force is increased during the first 5 pass (initial grinding period), decreased at the 6 pass, and increased again at the 7 pass. The experimental results show the lowest grinding force at the 10 pass. There are no remarkable changes after that but the grinding force is decreasing at the 19 and 20 pass once again.

Engaged cutting edges of the grinding wheel after initial dressing increase the grinding forces. At the sixth pass, the grinding forces are reduced because the initial sharp cutting edges adapt themselves to the better contacts with the workpiece. The reason why the grinding forces are reduced at the tenth pass is that the worn cutting edges are no longer effective in grinding the workpiece. After that, no remarkable changes are found in grinding forces. At the nineteenth and twentieth passes it can be found that the process occurred in the ninth and tenth passes are repeated.

It has been shown that the grinding forces corresponding to a 0.05mm depth of cut are smaller than of 0.1mm. The smaller depth of cut reduces the contact area between the cutting edge and the workpiece, which results in smaller grinding forces. In case of the 0.05mm depth of cut, there are no apparent changes during initial pass. At the tenth pass, the grinding forces are reduced at the value of the sixth pass of 0.1mm because of the smaller depth of cut. After the tenth pass, however, the grinding process. This phenomenon is called "loading".

Figure 5 shows the variation of surface roughness of the workpiece, which follows that of the grinding force. During the early passes for the 0.1mm depth of cut, the surface roughness is deteriorated until five pass. At the sixth pass, a normal grinding process is established, which results in a better surface roughness. At the seventh pass, the surface roughness of the grinding wheel deteriorates again because of the increment of grinding force. At the tenth pass, since the worn grains are excluded from the outmost grinding wheel, only the sharp cutting edges participate in the grinding process and improve surface roughness. For a 0.05mm depth of cut, the surface roughness of the wheel gradually improves in comparison to the initial passes. This can be explained by the fact that at smaller depths of cut the engaged cutting edges have the negative rake angle. At the tenth pass, surface roughness increase rapidly because of severe wear and apparent loading. It varieties the distribution and the spacing of the following cutting edges and deteriorates surface roughness of the workpiece. For a 0.1mm depth of cut, the loading cannot affect surface roughness because of the increment of the grinding force and area. However, for 0.05㎜ depth of cut, it can be understood that the frequent loading dramatically deteriorates the surface roughness.

Figure 6 shows the scattering intensity distribution of the laser beam. It can be seen that the scattering intensity drops at the sixth and tenth passes of 0.1㎜ and at the seventh and tenth passes of the 0.05㎜, respectively. The results correspond to those of the surface roughness and grinding force. When the laser beam reflects from the engaged cutting edge, the acquired light intensity from the photo detector becomes lower because of the sharp cutting edges. Therefore, changes of the grains can be expected when the measured light intensity increases or decreases. The increment of the light intensity is induced by the wear and the flatness of the engaged cutting edge. Meanwhile, the decrement of light intensity is induced by spilling, the wear of the engaged cutting edge, and disappearance of the worn cutting edge at the outmost grinding wheel surface. If the light intensity is constant or increases gradually, it tells that there is no considerable self-dressing. Namely, the dressing is required. From the above phenomena, the dressing time can be predicted by using the light intensity distribution.

Figure 7 and 8 show the simulated grains on the grinding wheel after dressing and after 10 passes, respectively. Figure 9 and 10 show the simulated surface roughness by the grinding wheel after dressing and after 10 passes, respectively. Figure 11 shows the comparison of the simulation method and experimental method of surface roughness. The difference between two profiles is caused by the spilling, wheel vibration, and the wear of the bonding materials, which are not considered in the simulation. However, the values of the surface roughness are close to each other.

Figure 12 shows the wheel working surface from the dressing to the tenth pass obtained by a toolmaker's microscope and a camera. Figure 12(a) shows the distribution of the CBN grains with bright boundaries, which represents Ni coating. In addition, there are no apparent worn grains. However, in Figure 12(b), marks 1 and 2 illustrate the ongoing wear and these grains influence the increment of the grinding force and surface roughness. In figure 12(c) mark 3 indicates the grain of ongoing wear. Mark 4 shows the new cutting edge underneath the completely worn removed grain, marked 2 in Figure 12(b). Marks 6 through 9 in Figure 12(d) show worn grains that affect the grinding process. In Figure 12(e) a few worn grains are observed but the new cutting edge, presented at mark 10, and spilling of the worn grains, marked 11, reduce the grinding force and improve the surface roughness.

Therefore, throughout this study, the dressing time monitoring using the laser beam has been introduced in comparison of the surface roughness of the ground surface and the grinding forces. In addition, on the machine measurement considering the light scattering intensity makes it possible to predict the variation of the characteristics of the ground surface, the grinding force, and the engaged cutting edge, which tells the optimal dressing time of the grinding wheel.

4. Conclusion

The following results are obtained through this research:

1. A new measuring system to predict the optimal dressing time of the CBN wheel by using the laser beam has been developed and its reliability has been proved by the variation of the grinding force, surface roughness, and topography of the grinding wheel.
2. The proposed method using the light scattering intensity distribution predicts the optimal dressing time of the grinding wheel. Through the experiment, the dressing needs at 310mV of the light intensity.
3. The computer simulation in cooperation with the experiment makes it possible not only to model the relationship between the workpiece and the grinding wheel by applying the contact mechanism but also to estimate the shapes of the worn grains of the grinding wheel and the ground surface.

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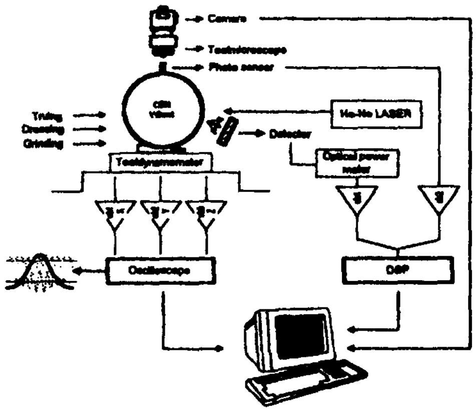

Fig. 1 Schematic of the measuring apparatus

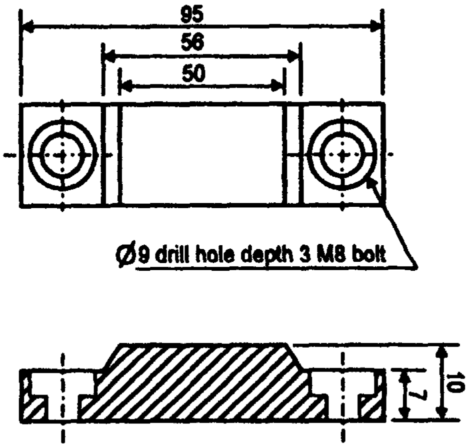

Fig. 2 Dimension of the workpiece

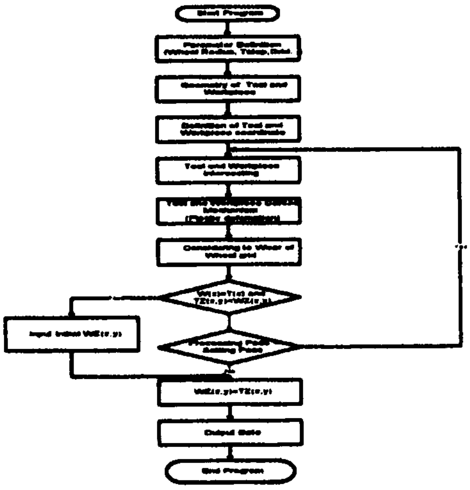

Fig. 3 Flowchart of the computer simulation

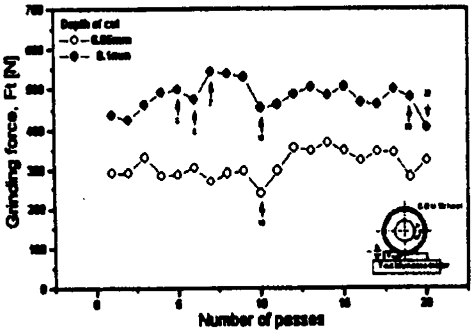

Fig. 4 Grinding forces depending on number of passes

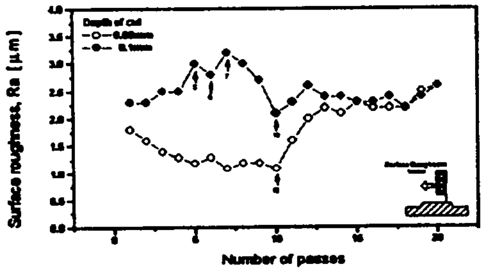

Fig. 5 Surface roughness depending on number of passes

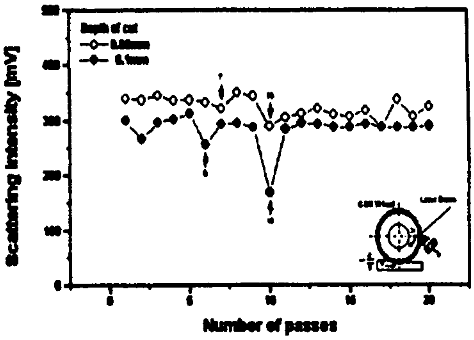

Fig. 6 Scattering intensity depending on number of passes

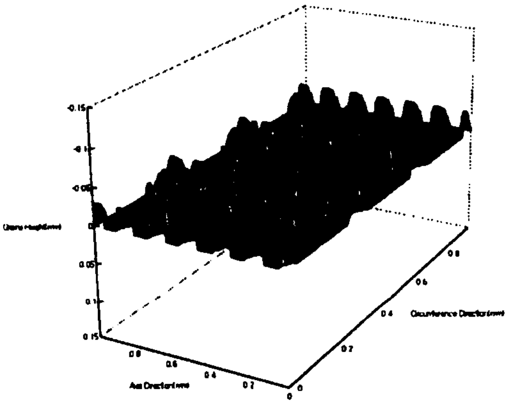

Fig. 7 Simulated grains on the grinding wheel after dressing

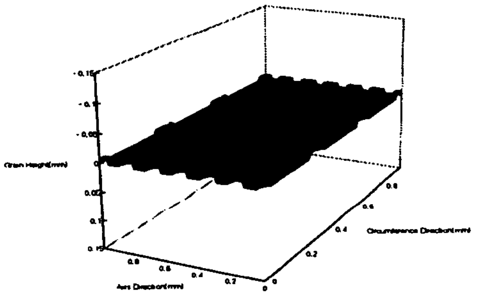

Fig. 8 Simulated grains on the grinding wheel after 10passes

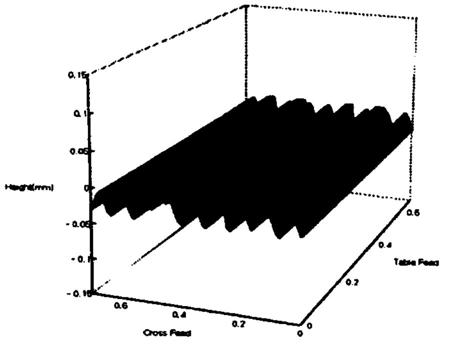

Fig. 9 Simulated surface roughness by the grinding after dressed

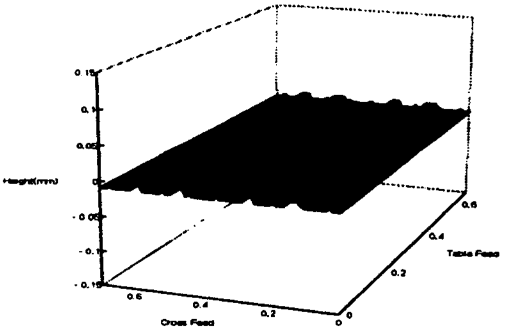

Fig. 10 Simulated surface roughness by the grinding after 10 pass

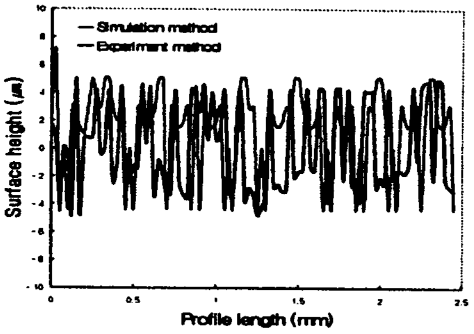

Fig. 11 Comparison og simulation and experiment method of surface roughness profile

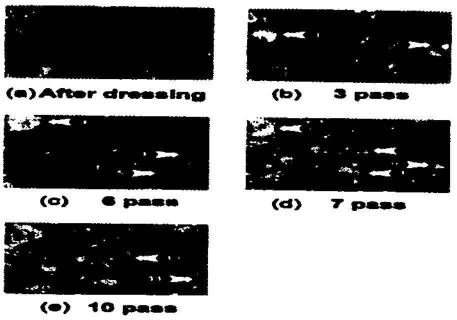
(a) After dressing
(b) 3 pass
(c) 5 pass
(d) 7 pass
(e) 10 pass

Fig. 12 Topography of Working surface on the wheel