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ELID SINGLE SIDE GRINDING WITH LAPPING KINEMATICS OF CERAMICS MATERIALS

Ahmed B. Khoshaim, Zonghua Xu, Ioan D. Marinescu
Precision Micro Machining Center (PMMC)
University of Toledo, Toledo, Ohio, USA

ABSTRACT

The demand for Silicon Carbide ceramics has increased significantly in the last decade due to its reliable physical and chemical properties. Sometimes, single side grinding for ceramics is preferable over surface grinding, because single side grinding has the ability to produce flat surfaces. However, the manufacturing cost is still high because of the high tool wear and long machining time. Additionally, most of these grinding processes are followed by a lapping process. One of the ways to address the high costs is to eliminate the final lapping process by the use of electrolysis in process dressing technique (ELID). Part of the solution also entails investigating the influence of different variables on the material removal rate and workpiece surface finish. This paper presents the influence of different grain size on the roughness. Also, the paper presents first a small introduction to fundamentals of ELID. The aim of the paper is to analyze the influence of the grit size upon the surface roughness. In order to do this, a full factorial experiment was designed. Based on the experimental results, a module was developed for each grit size (wheel) on three levels of each variable: the spindle and wheel speed, the applied load and the eccentricity of the workpiece holder.

Keywords: Silicon Carbide, Fine grinding, Material removal mechanism, Electrolytic In-Process Dressing (ELID)

1. INTRODUCTION

Machining ceramics is challenging because of ceramics’ high hardness and low fracture toughness, which limits the machining process in the ductile mode; however, with the proper selection of machining properties, the operation still can be administered in ductile mode. With the use of single side grinding with lapping kinematics, the workpiece will have constant pressure throughout the process [1, 2]. Grinding Silicon Carbide (SiC) with three different spindle and wheel speeds, three different pressure loadings, and three eccentricities, which will be explained in the next subsection, will determine the significant factors among these variables.

This experiment aims to find a model that can predict the roughness and identify the significant factors among all the variables in addition to the influence of different grain size.

X.1 Eccentricity

The workpieces will be held in a workpiece holder, which can hold up to 3 workpieces at the same time to ensure better flatness and guarantee more accurate results. Three workpiece holders have been designed with different eccentricities, which is the distance between the center of the workpiece and the center of the workpiece holder “e”. The three eccentricities designed were 17mm, 13mm, and 9mm.

2. ELID TECHNOLOGY

The Electrolytic In-Process Dressing (ELID) technique does not require the grinding operation to stop for dressing. However, it can be performed during the grinding operation [4]. This technique can be applied to any grinding machine without special equipment. This technique uses an electrode, an electrolyte, and an electrical DC pulse source. First, the negative pole connects to the electrode, and the positive pole connects to the wheel with a smooth brush [5]. There will be a gap between the wheel and electrode of about 0.1 to 0.3mm [6]. With the presence of the coolant fluid, the electrical circuit is complete, and it will work as an electrolyte to remove the metal bond from the wheel. Removing the metal bond exposes the surface of the wheel to be oxidized. An oxide layer of Fe_2O_3 will then accumulate on the wheel. This layer acts as an electrical insulator. Consequently, accumulating this layer increases the electrical resistance and decreases the electrical current. At a point, the system will reach equilibrium. During grinding, the oxide layer starts to wear out, causing the electrical resistance to decrease and the current to increase, which will creating another oxide layer to achieve equilibrium [3].

3. SETUP AND EXPRIMENTAL PARAMETERS

In addition to the three workpiece-holders, three diamond grinding wheels with mesh sizes #400, #1000, and #2000 will be running counter clockwise at three different speeds, 1/2, 1/4, 1/8 of the spindle speed, and the spindle will be running clockwise with 3 different speeds, 150, 175, 200rpm. Each of these combinations will be applied with three different loads. Table 1 illustrates the variables.

Table 1. The experiment variables (all speeds are in rpm)

Spindle Speed								
150			175			200		
Wheel Speed			**Wheel Speed**			**Wheel Speed**		
75	38	19	88	44	22	100	50	25
Force								
101.04 N			148.13 N			187.37 N		
Eccentricity								
17 mm			13 mm			9 mm		

The machine used was the double sided Lapping/Fine Grinding Melchiorre machine (210-3P). Because this experiment is concentrated on a single side grinding, some modifications were made to the machine to match the desired concentration. The experiment pauses, and the workpiece is then taken out and measured after 5, 10, 20, and 30 minutes. All the collected data are to be placed in a full factorial design of experiment model to identify the significant factors among the variables. Factor interactions are considered negligible in the calculations because of their low significance. Other parameters are kept fixed for the current experiment and will be considered for evaluation in future experiments.

4. EXPRIMENTAL RESULTS

The full factorial design analysis shows that while using the wheel mesh size #400 and #1000, both the load applied and the eccentricity have a significant affect on the results. The wheel mesh size #2000 has both the load applied and the wheel speed ratio as significant factors. All 81 experimental runs for the wheel mesh size #400 resulted in an average surface roughness of 0.094microns, with a maximum of 0.137microns, and a minimum of 0.08microns. Wheel mesh size #1000 results have an average roughness of 0.045microns, with a maximum roughness of 0.061microns, and a minimum roughness of 0.033microns. Wheel mesh size #2000 results have an average roughness of 0.021microns with a maximum roughness of 0.031microns and an astonishing minimum roughness of 0.013microns.

5. MODEL AND CALCULATIONS

The main purpose of this part is to find the exponents that fit the proposed equation. The equation has four exponents *(C, α, β, and γ)* [7]. By considering the roughness as the out come, the proposed equation that solves any similar operational conditions is:

$$Ra = C\,.V^{\alpha}.\,F^{\beta}.\,e^{\gamma} \tag{1}$$

Where (V) is the speed, (F) is the force, (e) is the eccentricity. The speed used depends on the significance level. For example, the spindle speed is used for the wheel mesh size #400, while the wheel speed ratio is used for both the wheel mesh sizes #1000 and #2000.

Since the experimental results, keeping the time constant, gives 81 proposed equations, the Multi-Correlation theory was used to consider all the data and fit them into four equations. Applying all the data on the four equations, leads to the final model for all grinding wheel mesh sizes. The models for the wheel #400, #1000, and #2000 are equations 2,3,and 4, respectively.

$$Ra = \frac{0.7422 e^{0.2204}}{V^{0.2869} F^{0.2884}} \tag{2}$$

$$Ra = \frac{0.07013\ V_r{}^{0.0018} e^{0.1725}}{F^{0.1810}} \tag{3}$$

$$Ra = \frac{2.122\ V_r{}^{0.0941} e^{0.0056}}{F^{0.9136}} \tag{4}$$

These models have been verified on the experimental results and have proven within the acceptable error percentile of less than 15%.

6. INFLUENCE OF GRAIN SIZE ON THE OUTCOMES

After conducting the experiment, an analysis is performed to find the influence of different grain sizes on the roughness results. Figure 1 illustrates the behavior of the roughness results with time for all three grinding wheel mesh sizes.

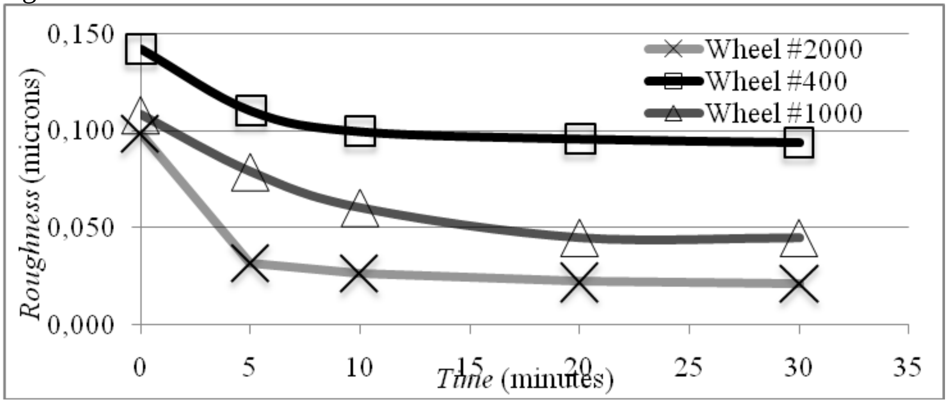

Figure 1. The bath of the roughness with time

Figure 8 illustrates how the surface quality improved significantly at the beginning of the process. After approximately ten minutes, the improvement of the surface quality slows down. The surface roughness, after machining the workpiece for twenty minutes, remains almost unchanged. Employing the same method applied on finding the models above (equations 2,3,4), a proposed model can be established to include the influence of different grain size on the results. The projected model has an additional variable "*G*", where "*G*" is the wheel average grain size. The final model proposed is:

$$Ra = \frac{0.018135 . V_r{}^{0.0281} . e^{0.1824} . G^{1.0864}}{F^{0.4402}} \tag{5}$$

The prediction for the roughness using this equation is true within the wheel mesh sizes used. To have a better prediction, higher and lower wheel mesh sizes should be experimented with. This model has a higher error percentage for a couple of reasons. For one, the speed used was the wheel speed ratio. This variable was not as significant as the spindle speed while using the wheel mesh size #400.

7. CONCLUSION

In the present experiment, multiple conclusions can be taken:

a. The load applied was inverse proportional to the roughness results. From the models proposed, increasing the load will always reduce the roughness outcomes. However, this relation is valid for any load between the tested experimental loads. Because of the creation of the oxide layer, an increase of the load results in lower surface roughness because the load pushed the abrasives to penetrate through the oxide layer.

b. The eccentricity was proportional with the surface roughness on all three grinding wheel mesh sizes. Grinding the workpieces with a smaller eccentricity will result in a lower surface roughness. This is because the workpieces ground by smaller eccentricity will have a lower linear speed. Based on the trajectory of the grains with different eccentricities, larger eccentricities will travel along the whole grinding wheel and will cover the entire area of the grinding wheel. This will expose the workpieces to more fresh abrasives, which helped to increase the material removal rate, but did not produce better surface roughness.
c. The spindle speed was used in the wheel mesh size #400 model since it was significant on the factorial design. The relationship is inversely proportional between the spindle speed and the roughness results. However, wheel speed ratio was used on both grinding wheel mesh sizes #1000 and #2000 models, as it was significant in their factorial designs. Wheel speed ratio is proportional to the roughness results.
d. A model has been established and tested for the ability to predict future roughness results for each grinding wheel mesh size experimented. The models proposed are effective within the range of the variables tested.
e. A model has been established with the influence of the grain size that predicts the roughness. This model has 20% of unacceptable results. The acceptable results have about 20% tolerance. However, if the grain size used is similar to any of the wheels used in this experiment, using its specific model is recommended for more precise results.

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9. REFERENCES

[1] Itoh N., Ohmori H., Kasai T., Karaki-Doy T.: A study of smooth surface finish by ELID-lap grinding and metal-resin bonded wheel. The Third International Conference on Abrasive Technology, 135-140, 1999.
[2] Barylski Adam, Deja Mariusz: Finishing of ceramics in a single-disk lapping machine configuration. Solid State Phenomena, 165: 239-243, 2010.
[3] Lim H.S., Fathima K., Senthil A., Rahman M.: A fundamental study on the mechanism of electrolytic in-process dressing (ELID) grinding. International Journal of Machine Tools and Manufacture Design, 42: 935-943, 2002.
[4] Spanu Cristian E.: Electrolytic in process dressing (ELID) applied to double side grinding of ceramic materials. PhD Dissertation, The University of Toledo, Toledo, U.S.A, 2004.
[5] Marinescu Ioan D., Brian Rowe W., Dimitrov Boris, Inasaki Ichiro: Tribology of abrasives machining processes. William Andrew Publishing Norwich, New York, U.S.A., 2004
[6] Pavel Radu, Pavel Madalina, Marinescu Ioan: Investigation of pre-dressing time for ELID grinding technique. Journal of Materials Processing Technology, 149: 591-596, 2004.
[7] Dorin Al.C., Marinescu I.D.: The establishment of the cutting capacity of the diamond wheels in the plane grinding. Annals of the CIRP, 30/1, 1981.