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ANALYSIS OF ROUGHNESS IN SYNTHETIC DIAMONDS USED IN THE SINGLE POINT DRESSING OF ALUMINUM OXIDE GRINDING WHEELS

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Abstract. *The dressing can be defined as the operation of the grinding tool grinding, the grinding wheel. In this study, we attempted to observe the performance of synthetic diamonds used in dressing single point with different dressing overlap ratio (U_d) to determine which one provides major and minor roughness. The methodology employed was to dress a grinding wheel aluminum oxide to 20, 70, and 120 paces and grind a piece of steel. The initial U_d was equal to 1. After this, the roughness of the steel was calculated. Finishing this circle, a new test was made, but with a different U_d = 5. The roughness was higher for the ratio equal to 1, with presenting bigger roughness for 20 paces: 0.49um for U_d = 1 and 0.44um for U_d = 5; and less roughness for 120 paces: 0.27um for U_d = 1 and 0.18um for U_d = 5. Thus, using the dressing overlap ratio of 5 provides better roughness.*

Keywords: *dressing; grinding; wear dresser.*

1. INTRODUCTION

The rectification is a machining process which uses a grinding wheel rotating at high speed for removing a volume of less hard material. This is a key technology for the production of advanced products and surfaces in a wide range of industry (Marinescu *et al.,* 2007).

The grinding process is mainly used for the production of parts with high quality, to ensure high accuracy and minimum tolerances. It is mainly applied to ensure high precision and quality (Gao *et al.,* 2007).

As one of the last stages of machining, grinding requires a great precision to finish with a minimum value of possible defects.

Conduct by any grinding process is very dependent on the performance of the tool. This performance can change significantly during the grinding process and this makes it difficult the prediction about the behavior of the process during its progress. (Gao *et al.,* 2007). The grinding wheel, besides change during the grinding process, it may lose its ideal conditions in their own manufacturing process.

Thus, the results of the rectification are directly related to the topographical conditions of the working surface of the wheel. With these modified conditions, the dressing operation becomes crucial to the process.

Dressing is the process of conditioning the surface of the grinding wheel in order to be restyled when it lost its original form by wear. (Xue *et al.,* 2002). It is the joint operation of profiling and sharpening of conventional grinding wheels. (Marinescu *et al.,* 2007).

The dressing conditions can cause a great influence on the performance of the grinding operation. To have an idea of this influence, suffice it to say that the grinding forces may vary around 500%, only varying the conditions of dressing in the same type of operation (Oliveira, 1988)

The tool used for the recovery of the wheel is the dresser. Due to the large number of variables that influence the process, there are a very large number of tools (dressers) that have been developed, and each of these tools is responsible for coverage of a limited number of cases.

Dressers single point and are used for profiling and dressing grinding for precision operations such as grinding flat, cylindrical, centerless and internal. Simple Tips of diamond, when used in grinding wheels hard, wide, large diameter, may be with flat areas, which blind the grinding wheel in dressing subsequent operations. The monitoring of this process then becomes necessary to improve and better knowledge about the techniques to be used to obtain a better performance.

Being the knowledge of the dressing operation underexplored, with bibliographies limited, this is still superficial. To deepen this knowledge about a specific type of dresser, among the various existing, proposed in this work Trials monitored with single point dressers, are the major material study CVD diamond national.

2. THE DRESSING OPERATION

Understanding the processes of mechanisms of grinding wheels dressing is critical to obtaining a good grinding process (Marinescu *et al*., 2007). The topography and shape of the macroscopic wheel are initially generated by the preparation, before or during, the grinding process, the grinding wheel by dressing and tillering (Malkin, 2008).

Profiling - the English "truing" - is the process that has as objective to form concentric to the wheel and can also generate a specific profile on the wheel. Also used to clean chips and debris that are on the wheel (Marinescu *et al*., 2007). In other words, tillering want to form a good accuracy to the grindstone (Marinescu *et al*., 2004).

Dressing is a joint process between the profiling and dressing grinding wheel. Grinding is a process where the binder removal occurs between the abrasive grains (Marinescu *et al*., 2007).

Thus, the dressing is intended to restore the cutting efficiency of the tool Marinescu *et al*., 2004).

According to Malkin (2008), profiling is responsible for adjusting the topographic shape of the grinding wheel. In superabrasive grinding wheels, this operation must be performed beyond the dressing. Already in conventional grinding, profiling can be neglected due to the fact that the topographic adjustment is acquired at the time of dressing.

Because of the friability, the abrasive particles should theoretically become automatically sharpened when worn, but what occurs is they come off the wheel or fracture, exposing new particles with new cutting edges. To maintain the features and functionality of the wheel, it is necessary that we have a regular dressing. The dressing produces a particular surface - depending on the type and material of the dresser - on the cut surface of the wheel, where about 10% of the grinding wheel is worn in the machining process and the remaining 90% with dressing (Jackson *et al*., 2007.)

2.1 Dressing and topography

According to Lin *et al*. (2008), the number of cutting edges is what characterizes the topography of the grinding wheel. So this topography influences on the geometry of the trough produced, and subsequently in the grinding process as a whole. A change in topography helps to explain the effects of grinding parameters on process performance and allows them to be controlled. The fracture of the grain, in turn, generates sharper cutting edges, a phenomenon called self sharpening of the grinding wheel (Malkin, 2008).

Can be then consider the grinding process as a process that involves the dressing and own grinding. From the viewpoint of material removal, the properties still more important of the topography of the wheel are the parameters related to the cutting edge and its distribution. These parameters are sharpening, width and density of edges. Being the width and density related to the number of active cutting edges per unit surface area of the grinding wheel. The surface of the wheel is generated by the fracture of the grain or the binder (Saleh *et al*., 2009).

The number of active edges will depend on the conditions imposed dressing. As the grinding wheel will wear out, the strength increases, which increases the worn area on its surface. This occurs during the rectification, due to grain develop sharp edges flattened, while the already flattened become the effect more pronounced wheel wear and provide a greater adhesion of particles. Therefore, the friction becomes an important part of the wear, which accounts for increasing strength and blinding of the grains. Based on this and according to Azizi *et al*. (2009), the benefits of grain CBN can only be extracted knowing good condition dressing.

2.2 Dresser single point

The dresser single point is a dressing method most used in the dressing of grinding wheels (Salmon, 1992). It is also simplest dressing tool (Marinescu *et al.*, 2007).

The dressing through of a diamond single point is also known as dressing mechanical (Harimkar *et al*., 2006).

The single point dresser carries a single diamond. There should be an angle between the diamond and the grinding wheel. The diamond single point cutting the periphery of the wheel and requires an angle of attack cleared that the dressing process be efficient (Salmon, 1992).

Whether the diamond is perpendicular to dressing the wheel, the diamond will be quickly spent. If the angle of the diamond is equal to surface angle of the tip of diamond will generate much heat (Salmon, 1992).

The main disadvantages of the method of dressing is single point the diamond wear, loss of operating time and cost increase by stopping the process for several dressing (Harimkar *et al*., 2006).

Dressing In a single point, the diamond should receive some precautions. It should be rotated to suffer the same wear around his tip. The diamond should not be impacted - beats -, falls or excessive heat. If the tip of the diamond suffers chipping or distortions caused by lack of care, the accuracy of the system is critically damaged (Salmon, 1992).

The single-point dressing creates tensions in the abrasive grains and cause deep cracks in the material. Because of these voltages, there is loss of fragments of the grains, reducing the effective number of edges. Thus, the single-point dressing does not produce a good topography in the wheel, should not be used for this purpose (Jackson *et al.*, 2007).

According to Malkin (2008), the dressing operation single point - mechanical - produces surfaces composed of macro and micro effects, which are defined as:

Macro effects, generates from the shape of the dresser, the depth of penetration of dresser and the passes of dressing. This phenomenon determines the position where the edges of the abrasive grains are located on the surface of the grinding wheel;

Micro effect: generated by the union of the grains eroded - with low anchorage in alloy - and due to fracture of the grains which are not completely eroded, where new cutting edges are generated by the dresser.

In effect mark there is a small amount of abrasive grains that are active and which are responsible for removing large amounts of material. Therefore, the stress on each grain must be large - a fact that does not preclude the performance of the process - by the fact of the reduction in losses with plastic and elastic deformation of the material in the cutting region to minimize the total energy involved in the process (Hassui *et al.*, 2003).

At the micro effect, the aggressiveness of the new edges formed depends largely on the friability of the grain and the conditions of dressing. In the thin dressing, for example, where it is low penetration depth and advancing dresser, is the removal or fracture of very small grains, which provides the formation of the flat cut sections of the same making them less aggressive. By contrast, in the dressing thick, with high penetration rates and the advancement of dresser, a large portion of the abrasive grains are broken, forming larger and sharper edges (Hassui *et al.*, 2003).

In dressing of conventional grinding wheels, it is usual to pass through the dressing tool by rotating wheel, as shown in Fig. 1.

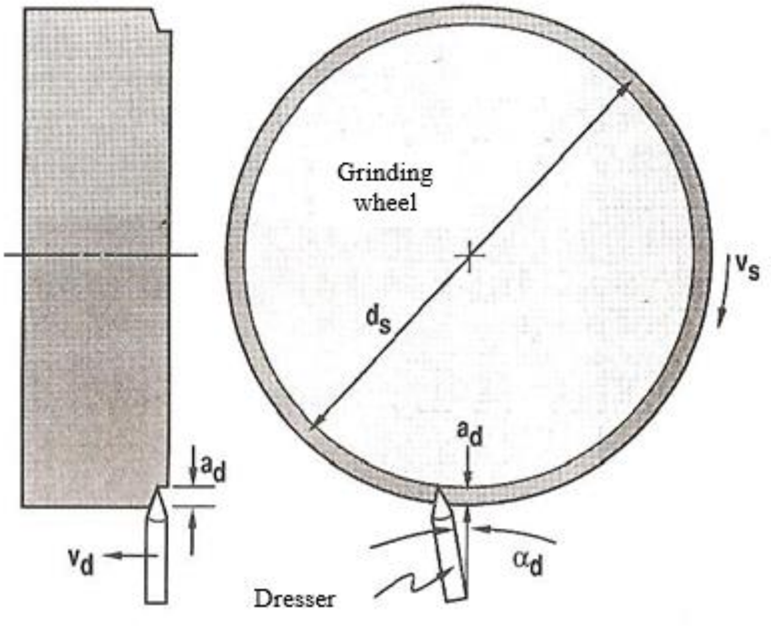

Figure 1. Dressing of a grinding wheel through a single point dresser (Malkin, 2008).

According Malkin (2008) during each pass the dresser through grinding wheel, is removed to a depth ad of the radius of the wheel. This type of movement dressing is analogous to turning. The dressing tool per revolution is called of direction dressing, sd, and is given by Eq. (1).

$$s_d = \frac{\pi . d_s . v_d}{v_s} \tag{1}$$

Where:

v_d [mm/s] is the speed dressing of dresser by the grinding wheel;
v_s [mm/s] are the speed of cutting from the grinding wheel;
d_s [mm] are the diameter of the grinding wheel.

Figure 2 is a dressing scheme where the parameter sd can be easily visualized.

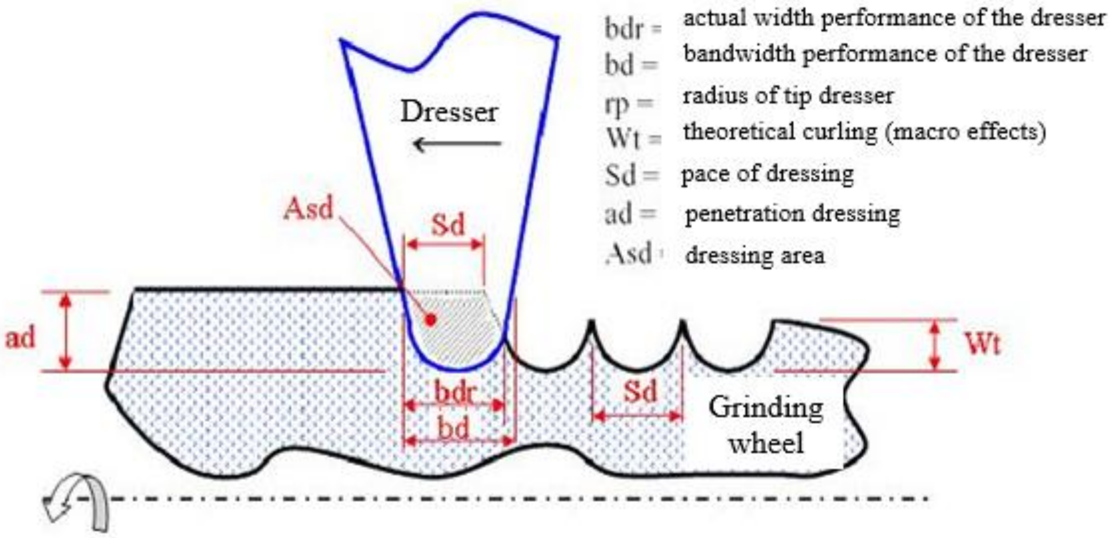

Figure 2. Layout of the dressing operation (Hassui & Diniz, 2003 - Modified).

Usually between two and five dressing paces is required to enliven the conventional grinding wheel, can logically be required more paces to remove chips and dirt from past corrections (Malkin, 2008). Also according to Malkin (2008), as a final step, it is necessary the "spark-out" or arcing, where the dressing tool must pass through the grinding wheel without increasing the depth of dressing. For each pace of the final step, less material is removed and improves the final topography of the wheel.

The dresser single point is usually installed with a relative angle between the tool and the grinding wheel αd between 10° and 15° (Malkin, 2008).

The wheel aggressiveness can be express by the overlap fator. Accord to Puerto *et al.* (2013), the overlap factor (U_d) is the relation between the dressing width (b_d) and the feed rate (S_d), with is shown in Eq. (2).

$$U_d = \frac{b_d}{S_d} \tag{2}$$

The overlap factor is important for considerer the feed rate, depth, and geometry together. For a dressing of constant width and variable feed rate, is possible to see how the overlap fator will draw in the suface of the wheel in Fig. (3). For higher overlap fator, small is the distance between each pace of the dresser, generating a less aggressive wheel surface (Puerto *et al.*, 2013).

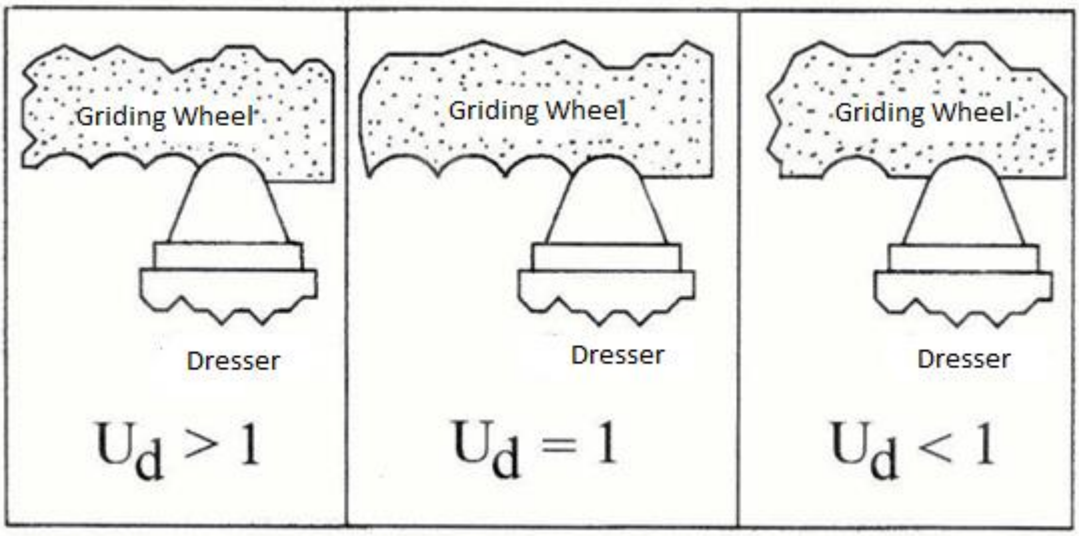

Figure 1. Overlap factor action (Badger *et al.*, 2010).

2.3 Synthetic Diamonds for dressers

The technique of manufacturing of synthetic diamonds at high pressures was already dominated by several companies in the 50s and 60s; these pressures were above 60.000atm and temperatures above 2000K (Davis, 1993). THE main applications of this synthetic diamond were tools of cutting and polishing surfaces. In the 70's that began to emerge academic research papers that sought to obtain thin layers of diamond from gas that had carbon in its composition (Brookes *et al.,* 2010).

These layers, called films were produced at lower pressure than the atmosphere and at temperatures below 1200K, embedded in substrate with diamond dust. From this, the technique of obtaining diamond from a precursor gas spread around the world as a much easier and more productive method than that used in the 50 and 60. This synthetic diamond arising out this technique has to call CVD diamond (Angus *et al.,* 1988).

The great interest in the synthesis of diamond is its physicochemical properties. The diamond is the hardest known material, with 10 by the Mohs scale. It has low density - 3.5 g/cm^3 and low coefficient of thermal expansion - 0,8x10^{-6} /°C at 293 K. Also, high refractive index - 2.42, higher thermal conductivity than any other material at room temperature – 20 °C.W/cm, and optical transparency ranging from the region infrared to visible light, is an excellent electrical insulator, chemically inert, has biological compatibility and when doped becomes a good semiconductor (Angus *et al*., 1995).

There are various methods of production of CVD diamond which differ essentially by the procedure used in the decomposition and activation of the gas mixture, which result in the ionized gas, known as plasma. The known techniques are the plasma generated by microwave - MWCVD - (Borges *et al.,* 1995), hot filament - HFCVD - (Matsumoto *et al.,* 1983), called acetylene and oxygen - ATCVD - (Ravi *et al.,* 1990), plasma jet - AJCVD - (Ohtake *et al.,* 1990).

Despite the large number of techniques used to obtain films with good quality, these processes are still in the process of continuous testing, where a vast amount of works are being published (Latch-Airoldi *et al.,* 2002).

The manufacture of synthetic diamond films can be divided into two stages: the nucleation and growth. In the nucleation occurs the formation of nano diamond crystals from the vapor phase. In general, the density of cores in the CVD process depends on both the substrate material and its preparation and the deposition parameters. At the stage of nucleation, the survival rate of the cores is critical, therefore they have to pass a critical size for growth is faster than its wear for chemical attack and by diffusion in the substrate (Brookes *et al.,* 2010).

After the initial stage of nucleation there is growth phase of the cores which can be divided into two stages. The first step is where the cores grow until they touch covering the entire surface of the substrate - coalescence -. The second stage ranges from coalescence until the completion of deposition. At this stage, the film thickness increases, growing in columnar form. Each plane crystalline has a rate of particular, growth resulting in different morphologies depending on the ratio between the rates of growth of the planes {111} and {100}. This ratio depends mainly on the concentration of carbonaceous gas and the temperature of the substrate (Kim *et al.,* 1990).

The main difficulties are encountered in the production and applications of CVD diamond are in the influence of the chemical properties of the substrate, increasing the rate of nucleation and adhesion of the film (Brookes *et al.,* 2010).

To minimize these difficulties, is that for the chemical properties of the substrate are used various materials such as silicon blades, which seek to form substrates with highly perfect surfaces, but the process becomes slower and the beginning only after a long period time (Williams *et al.,* 1988). Other substrates may also be used, such as molybdenum (Mo), tantalum (Ta) and tungsten (W) (Brookes *et al.,* 2010).

If the carbon that reaches the surface is rapidly removed by diffusion into the substrate, the nucleation occurs is delayed. Chemical reactions between substrate and reagent gases, like carbon and hydrogen - atomic and molecular - have an important influence on nucleation (Joffreau *et al.,* 1988).

Grooves on the surface of ceramics and metallic substrates produced by particles of diamond, Sic, B4C or other hard materials increase the nucleation density of diamond (Brookes *et al.,* 2010). If it has not this increase in nucleation rate will be much most difficult to produce thick films, since most methods the nucleation in many natural substrates is not high enough.

The adhesion of the films is strongly associated with the stress between the interfaces, depending mainly on the difference between coefficients of thermal expansion of the layer and the substrate (Davis, 1993). Different interactions between the substrate and the gas phase may also influence the adhesion between them. The formation of gaseous species influences not only the nucleation, but also adhesion of the of diamond layers (Davis, 1993).

A reasonable interaction between the coefficients of expansion and domination of the substrate reactions are not sufficient conditions to ensure a degree of adherence satisfactory to many applications in protection and coating (Davis, 1993). In this case, at least some chemical bonding sites may be needed. Although he has found good results, there is still much to do to improve adhesion of diamond films on several substrates (Latch-Airoldi *et al.,* 2002).

Furthermore, none of the films have been produced have a regular crystalline large-scale natural diamonds. The diamond. The mechanical, electrical and optical properties of diamonds films already synthesized approaching those of the rough diamond, but still not in a highly satisfactory (Callister, 2002).

3. EXPERIMENTAL METHODOLOGY

The experimental work was performed at the Laboratory of Machining Abrasion (LUA) of the Department of Mechanical Engineering, "Universidade Estadual Paulista Júlio de Mesquita Filho" - UNESP, Bauru. For the tests, we used six single-point dressers made with synthetic diamond type CVD CDD, one flat grinding machine manufactured by "Sulmecânica", model 1055E, a rugosimeter Taylor Hobson Surtronic 3+, and a steel VP80 as the grinding body test. For the tests, were also used three wheels manufactured by the company NORTON, made of conventional abrasive aluminum oxide, with vitrified binder, hardness L - medium - size 150 - very fine - and structure with dimensions of 355.6 x 25 4 x 127 mm.

Among the main parameters used for grinding and dressing, is that the transverse speed of the wheel was kept constant for the tests of three types of dressers. The speed of the drive motor of the grinding was constant for the tests as well as frequency. Thus, it has to traverse speed equal to 3.45 mm/s, the drive speed equal to 450 rpm and 60 Hz frequency of dressing depth (d) was equal to 40 micrometers. The dressing parameter of overlap factor (U_d) was equal to 1 (one) and 5 (five).

The tests consisted of dressing the conventional wheel, first with the dressing parameter U_d equal to one, after 20, 70, and 120 paces, grind the body test, and measure the roughness. Concluded this part, the parameter U_d is changed to five, and the process repeat, with the measurement of the roughness in the surface of the body test. With the roughness measurements for both parameters in hands, we analyzed and discussed the results.

4. RESULTS AND DISCUSSIONS

Table 1 shows the roughness measurements found for the overlap factor (U_d) equal to one and five.

Table 1. Mean roughness values for the single point dresser with overlap factor o one and five.

Pace numbers	Roughness (Ra), µm	
	U_d = 1	U_d = 5
20	0,49	0,44
70	0,29	0,17
120	0,27	0,18

The values of Tab. 1 are showing in Fig. (3) for better view.

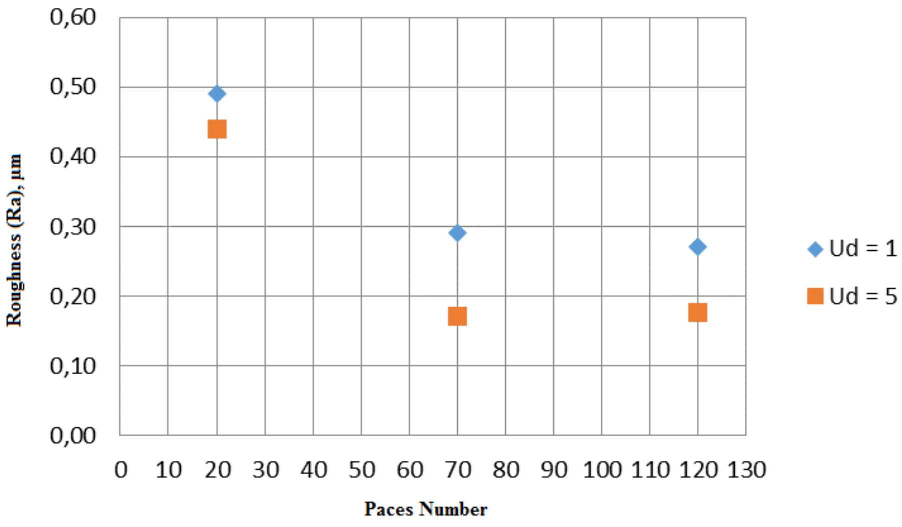

Figure 42. Relation between the number of paces and the mean roughness for both overlap factors.

Looking the values of Tab. 1 and Fig. (4) is possible to see that the data found for the higher overlap factor is better than for the small value of that parameter. Both curves kept a decrease tendency, but for U_d equal of 5, the roughness values was smaller than for U_d equal to one.

This result can be explained as the higher the overlap factor, less aggressive the dressing will be on the surface of the grinding wheel. Thus, less roughness on the surface of the body test should be showing, as indicated by Fig. (4).

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Angus, U.C., Buck, F.A, Sunkara, M., Groth, T.F., Hainan C.C., 1995, “Diamond growth at low pressure”. MRS Bull, October.

Azizi, A., Rezael, S.M., Rahimi, A., 2009, “Study on the rotary cup dressing of CBN grinding wheel and the grinding performance”. In *Internacional Journal of Advanced Manufacturing Technology*.

Brookes, C.A., 2010, “Diamond in perspective: a review of mechanical properties of natural diamond. Diamond and related materials”. Vol. I, pp 13-17.

Callister, W.D., 2002, “Estruturas e propriedades das cerâmicas. In Ciência e engenharia de materiais: uma introdução”. 5 ed., pp. 275-300, Ed. LTC, São Paulo, Brasil.

Gao, R.X., 2007, “Monitoring Systems for Grinding Processes, Springer Series in Advanced Manufacturing”, pp. 83-107.

Harimkar, S.P., Samant, A.N., Khangar, A.A., Dahotre, N.B., 2006, “Prediction of Solidification Microstructures During Laser Dressing of Alumina- Based Grinding Wheel Material”. In *Journal Physics*, Vol. 39, pp. 1642–1649.

Hassui, A.; Diniz, A.E., 2003, “Correlating surface roughness and vibration on plunge cylindrical grinding of steel”. In *International Journal of Machine Tools & Manufacture*, Vol. 43, p. 855–862.

Jackson, M.J., Khangar, A., Chenc, X., Robinson, G.M., Venkatesh , V.C., Dahotre N.B., 2007, “Laser cleaning and dressing of vitrified grinding wheels”. In *Journal of Materials Processing Technology*, Vol. 185, pp. 17–23.

Joffreau, P.O., Haubner, R., Lux, B., 1988, Journal Reference Metalic-Hard Metals, Vol. 7, n. 4, pp. 186.

Kim, J.S., Kim, M.H., Park, S.S., Lee, J.Y., 1990, Journal of Applicated Physics. Vol. 67, pp. 3354.

Lin, Z.C, Lin, B., Xu, Y.S., Hu, J., 2008, “Experimental studies on grinding forces and force ratio of the unsteady-state technique”. In *Journal of Material Processing Technlology*, Vol. 129, pp. 76-80.

Malkin, S. 2008 *Grinding Technology: theory and applications of machining with abrasives*. 2nd edition. Industrial Press.

Marinescu, I.D., Hitchiner, M., Uhlmann, E., Rowe, W.B. Inasaki, I., 2007 *Handbook of machining with grinding wheels*. 1st Edition, Boca Raton, FL: CRC Press, Taylor & Francis Group.

Marinescu, I.D.; Rowe, W.B.; Dimitrov, B.; Inasaki, I. 2004 *Tribology of abrasive machining processes*. 1st edition. Norwich, William Andrew Inc.

Oliveira, J. F. G., 1988, "Análise da ação do macroefeito de dressamento de rebolos no desempenho do processo de retificação". Tese de Doutorado – USP, São Carlos,SP, Brasil.

Ohtake, N., Yoshikawa, M., 1990, Journal of Electrochemical Society. Vol 137, n. 2, pp. 717.

PUERTO, P, FERNÁNDEZ, R., MADARIAGA, J., ARANA, J., GALLEGO, I. 2013 "Evolution of surface roughness in grinding and its relationship with the dressing parameters and the radial wear". In *The Manufacturing Engineering Society International Conference*, MESIC.

Salmon, S.C. 1992 *Modern Grinding Process Technology*. MacGraw-Hill.

Saleh, T., Bishwas, I., Rahman, M., 2009, "Efficient dressing of the wheel in ELID grinding by controllable voltage with force feedback". In *International Journal of Machine Tools & Manufacture*.

Trava-Airoldi, V.J., Corat, E.J., Santos, L.V., Diniz, A.V., Moro, J.R., Leite, N.F., 2002, Diamond Related Materials. Vol. 11, pp. 532.

Xue, L., Naghdy, F., Cook, C., 2002, "Monitoring of wheel dressing operations for precision grinding", FIEEE International Conference on Industrial Technology, Bangkok, pp. 1296-1299.

Willians, B.E., Glass, J.T., Davis, R.F., 1988, Micro-Optoeletronica Materials, Vol. 877, pp. 56-63.

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