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THE INFLUENCE OF DRESSER TYPE ON GRINDING PROCESS OF INCONEL 718 WITH SILICON CARBIDE GRINDING WHEEL

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Abstract. *Grinding is an abrasive machining process generally applied to guarantee a combination of good surface finishing and tight tolerances to the machined surface or component. Besides the cutting parameters, the grinding wheel topography plays an important role in the final conditions of ground surface and, therefore the dressing operation is crucial to the process. In this context, this work aims to analyze the grinding of Inconel 718 under different cutting conditions of workpiece speed and depth of cut, using a conventional SiC grinding wheel dressed with two different dressers: single point and fliesen. The output parameters analyzed in this work were the surface roughness (Ra parameter), the electric power during grinding, and scanning electron microscope (SEM) images of machined surfaces. The results showed that although the surface roughness, electric power and SEM images presented the expected behavior related to the variation in workpiece speed and depth of cut, the dresser type showed no significant effect on the results and, therefore, the difference between them is related only to the dressing time, which is about 70% lower using the fliesen one.*

Keywords: *Grinding, Inconel 718, Dresser, Surface Roughness, Electric Power*

1. INTRODUCTION

The machining operations with geometrically defined cutting tools cannot always provide the necessary finishing to a given surface or component and, therefore, in many cases an abrasive machining process is necessary to improve the surface quality in general. Among the different kinds of abrasive processes, the grinding operation stands out due its capable of manufacturing components that require high surface quality and accuracy of dimension, which is the case for many advanced difficult-to-machine materials (Cearsolo et al., 2016).

According to Machado et al. (2015), the final condition of a machined surface is a result of a process which involves plastic deformations, shearing, elastic recovery, heat generation, mechanical vibrations, residual stresses and even chemical reactions. In the grinding process, the machined surface is also affected by the states of the abrasive grains and voids on the grinding wheel surface (Kim and Ahn, 1999).

The condition of the grinding wheel surface, or its topography, must be, therefore, correctly prepared and the operation used to do so is called dressing. This operation is necessary before the first use of the grinding wheel and it is done periodically to restore its abrasive capability that lows due excessive wear after some time of usage (Godino et al., 2017). According to Marinescu et al. (2007), besides the function of obtaining a new set of sharp cutting edges on the grinding wheel surface, the dressing operation is also used to clean out any metal embedded or “stuck” in the wheel cutting face.

The profile formed on the grinding wheel surface due dressing operation is a function of the relative motion between grinding wheel and the dresser, and the material type and geometric characteristics of the dresser are the main factors that influence the process results. The parameter normally used to specify the topography condition of the grinding wheel is the overlap ratio (U_d), which is the relation between the effective dressing width (b_d) – associated to dresser geometry and dressing depth of cut (a_d) – and the dressing lead (S_d), which is the dresser axial velocity (V_{fd}) divide by the grinding wheel rotation (n_s). The relations that define the grinding wheel overlap ratio (U_d) are shown in Eq. (1).

$$U_d = \frac{b_d}{S_d} = \frac{b_d}{V_{fd}/_{n_s}} = \frac{b_d n_s}{V_{fd}} \quad (1)$$

Among the types of dressers, the diamond single point one is the most employed due its low cost and high versatility in providing a widely number of different topography profiles in different grinding wheel types. However, although this type of dresser is the most employed nowadays as already mentioned, its effective dressing width (b_d) increases with the diamond wear (Harimkar et al., 2006), which can adversely affect the precision of the dressing operations whether the tool is not periodically analyzed in an optical microscope to check its b_d. On the other hand, the dresser known as fliesen, which is another type of diamond stationary dresser, has the advantage of working initially with a high value of effective dressing width, presenting a much lower variation in b_d according to the diamond wear, which results in fewer optical microscope analysis. Moreover, according to Odebrecht (2003), the fliesen dresser can present a similar or even better efficiency when compared to the conventional single point one.

Besides the grinding wheel topography and cutting conditions, the workpiece material is also an important factor that interferes in grinding process efficiency. Although the steels, specially the hardened ones, can be stated as the main type of material submitted to grinding operations, the literature has been reported a significant increase of non-ferrous components that require grinding in some stage of its manufacturing process, as the superalloy Inconel 718 for instance. Such material has been employed in aeronautic, automobile and petrochemical industries due its good combination of mechanical and corrosion resistance that are kept even in high temperatures (ASM International, 2000; Thakur and Gangopadhyay, 2016). Applications examples of Inconel 718 are: turbine blades and other components of aeronautic engines, connecting rods of internal combustion engines, as well as nuclear reactor components.

The Inconel 718's property of maintaining high mechanical and corrosion resistance at high temperatures combined to its low thermal conductivity, strongly contribute to the heat generation and development of high temperatures at chip-tool interface, which make the machining process of this superalloy to be more complex when compared to other materials (Ezugwu et al., 2003, 1999). Regarding the grinding process with conventional abrasives, the challenge in machining Inconel 718 is even higher, since the abrasive grains also present low thermal conductivity. Furthermore, the chips that are formed in grinding are very small, which also makes the heat dissipation more difficult.

The study of dressing operation is still scarce in the literature, especially in the grinding of Inconel 718 using conventional grinding wheels. The correct selection of a dresser in the grinding of this superalloy can increase the process efficiency in terms of cost-benefit, either by reducing the dressing time and frequency, or improving the machined surface quality through the grinding wheel topography optimization. In this context, this work aims to analyze the grinding of Inconel 718 with silicon carbide (SiC) grinding wheel dressed using two different types of dresser, but with the same overlap ratio (U_d). The cutting conditions (workpiece speed and radial depth of cut) were also varied and the output parameters used were the surface roughness of machined surface (Ra parameter), the electric power during grinding process and scanning electron microscope (SEM) analysis of ground surfaces.

2. METHODOLOGY

The grinding experiments were carried out in a surface grinding machine P36, MELLO, which has a nominal power of 2.25 kW, constant rotation of 2400 rpm and 5 µm resolution in grinding wheel radial axis. The grinding wheel employed was a silicon carbide (SiC) grinding wheel from Norton-Saint Abrasives, with mesh 60, vitrified bond, dimensions of 305 mm x 25.4 mm x 76 mm (external diameter x width x internal diameter) and specification of C60K6V. The workpiece used in this work was the superalloy Inconel 718 (40 ± 2 HRC) with dimensions of 40 mm length and 7 mm width in the section selected to grinding, and 17 mm height.

Two different synthetic diamond dressers were employed in the grinding wheel dressing operations: a single point one and a fliesen. For each dresser, the dressing parameters were selected in order to guarantee an overlap ratio (U_d) of 4 with a dressing depth (a_d) of 20 µm. To do so, the effective dressing width of both dressers were measured with a stereomicroscope SZ 61, Olympus, as shown in Fig. 1.

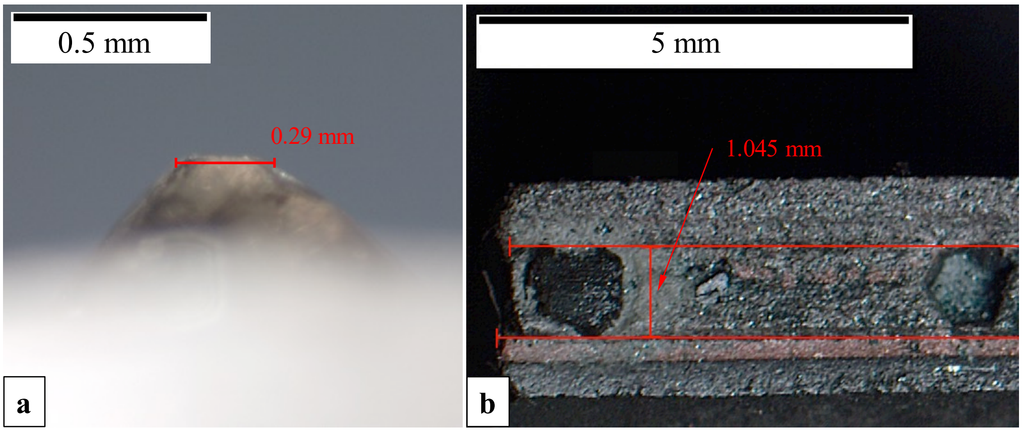

Figure 1. Measurement of the effective dressing width for both dressers: (a) single point, (b) fliesen.

As it can be observed in Figure 1, the values of effective dressing width (b_d) were 0.29 mm and 1.045 mm for the single point and fliesen, respectively. Therefore, the dressing velocity (V_{fd}) and, consequently, the dressing time, was selected for each tool according to Eq. (1), considering $U_d = 4$ as already mentioned. Thus, for the conditions used in this work, the dressing times were 8.76 s for the single point, and 2.43 s for fliesen dresser. It is important to mention that the grinding wheel was dressed before each grinding experiment in order to avoid the influence of its wear.

Four different cutting conditions were used in the grinding experiments: two values of depth of cut (a_e) – 15 µm and 30 µm, and two values of workpiece speed (V_w) – 5 m/min and 10 m/min. As two dressers were used and each test was replicated, a total of sixteen (16) grinding experiments were performed. The cutting speed (Vs) was 38 m/s, kept constant for all grinding experiments. The grinding experiments as well as the grinding operations were performed using the conventional cooling-lubrication technique with flow rate of 9 L/min. The cutting fluid employed was the semisynthetic Vasco 7000, from Blazer Swisslube, diluted in water at 1:19 (5% concentration).

The output parameters analyzed in this work were the surface roughness (Ra parameter), the electric power during grinding and SEM images of ground surfaces. The Ra parameter was measured with a Mitutoyo surface tester SJ-201 P/M, using a cut-off of 0.8 mm and 5 sampling lengths; three measurements were done in the ground surface, perpendicularly to grinding direction, and the average values and standard deviations were calculated and used for analysis. The electric power during grinding was calculated through the instantaneous signals of voltage and current of one phase of the spindle motor. The signals were measured with Hall Effect sensors using a data acquisition module from National Instruments (NI-6001) and LabView software. An acquisition rate of 3.3 kHz was employed, and the software Octave was used for signal processing. The ground surfaces were assessed using a scanning electron microscope, HITACHI, TM-3000, with 5 keV.

The grinding conditions, including the output parameters are summarized in Table 1.

Table 1. Grinding conditions and output parameters.

Grinding machine	P36, MELLO, 2.25 kW, 2400 rpm, 5 µm resolution
Grinding wheel	C60K6V
Workpiece	Inconel 718 (40 HRC)
Dressers	Single point and fliesen (synthetic diamond)
Dressing parameters	a_d = 20 µm U_d = 4 Dressing time (s): 8.76 (single point) and 2.43 (fliesen)
Cutting speed (V_s) [m/s]	38
Radial depth of cut (a_e) [µm]	15 and 30
Workpiece speed (V_w) [m/min]	5 and 10
Cutting environment	Conventional cooling-lubrication technique (flood) Flow rate: 9 L/min Cutting fluid: semisynthetic
Output parameters	Surface roughness (Ra parameter) Electric power SEM images analysis

3. RESULTS AND DISCUSSION

The surface roughness results (Ra parameter) are shown in Figure 2 as a function of radial depth of cut (a_e), after grinding using the SiC wheel dressed with the two dresser types, for both workpiece speed (V_w).

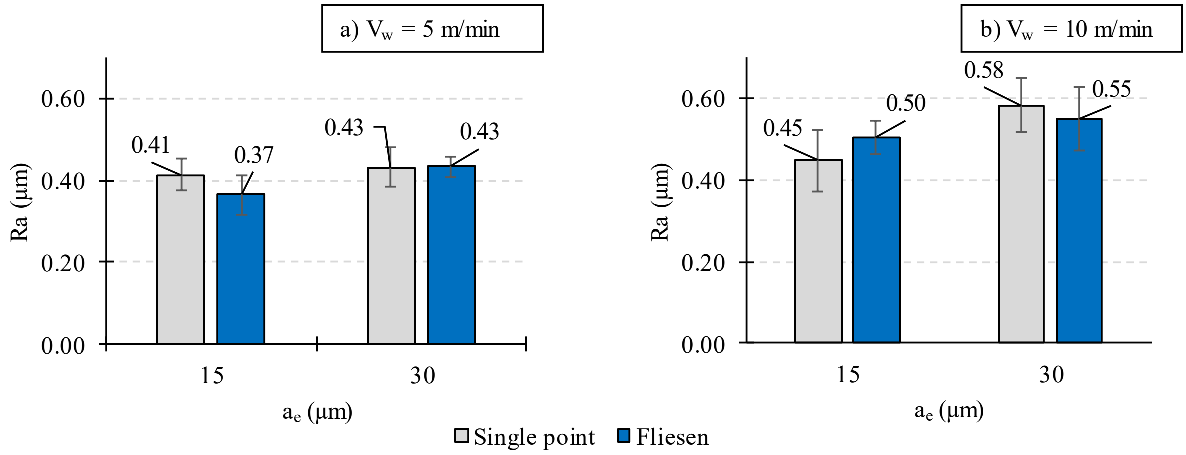

Figure 2. Ra parameter as a function of radial depth of cut for both dressers used in this work: (a) V_w = 5 m/min, (b) V_w = 10 m/min.

As it can be seen from Figure 2, the Ra parameters obtained after machining with the grinding wheel prepared using different dressers were similar, presenting no significant differences when considering the standard deviations. This result was expected according to literature, since the grinding wheel overlap ratio (U_d) was the same for both dresser types (Marinescu et al., 2007). Furthermore, it can be observed from Fig. 2 that the Ra parameter showed a tendency to increase with both radial depth of cut (a_e) and workpiece speed (V_w). According to Malkin and Guo (2008), increasing a_e and/or V_w increases the material removal rate of the process and consequently its severity, which contributes to deteriorate the surface finishing. Da Silva (2017) also observed this relation between surface roughness and workpiece speed after grinding Inconel 718 with similar cutting conditions.

The electric power results for each dresser type are shown in Figure 3 as a function of radial depth of cut (a_e), for the two workpiece speeds used in this work. Regarding the dresser type, from Fig. 3 it can be observed that the electric power during grinding was, in average, slightly higher (less than 7% of increase) when the grinding wheel was prepared with the fliesen tool, except for the condition using V_w = 5 m/min and a_e = 30 µm that presented an increase of 13%. However, considering the standard deviations, it can be inferred that the dresser type influence on power was nearly null, similar as observed for the surface roughness results.

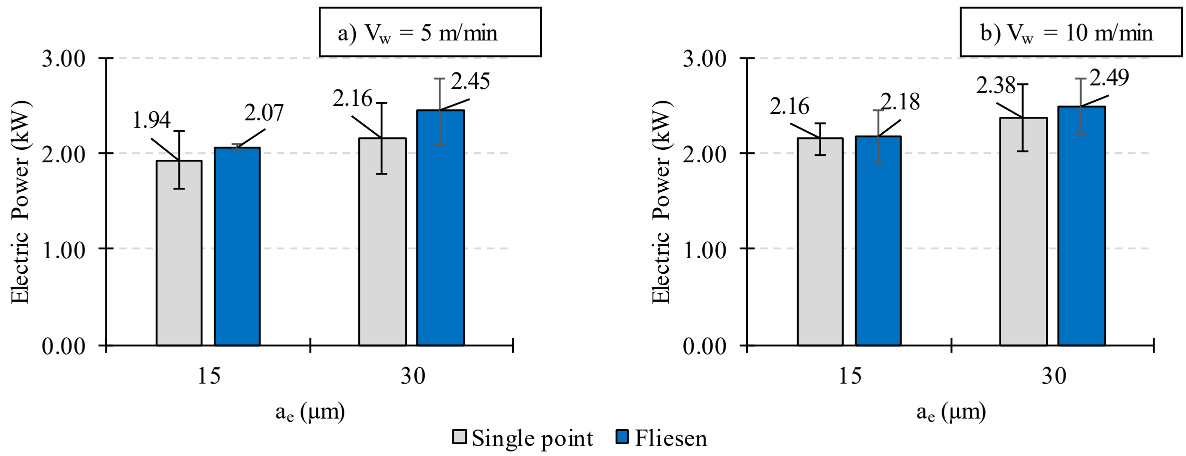

Figure 3. Electric power as a function of radial depth of cut for both dressers used in this work: (a) V_w = 5 m/min, (b) V_w = 10 m/min.

In respect to the effect of radial depth of cut (a_e) and workpiece speed (V_w) on electric power results, it can be observed from Fig. 3 that the power during grinding operation increased with both a_e and V_w, irrespective to the dresser type. For V_w = 5 m/min, increasing a_e from 15 µm to 30 µm resulted in an increase (in average) of 15% on power. For V_w = 10 m/min, such increase was about 12%. The increase on power with a_e and V_w is related to the increase in undeformed chip thickness, which has a negative effect in cutting forces as observed by Yao et al. (2014). The higher the undeformed chip thickness, the higher the cutting forces, and the higher the power during grinding as a result. Tian et al. (2017) analyzed the electric power during surface grinding of Inconel 718 using a similar monitoring system (effect hall sensors) as employed in this work. The authors also observed that the power increased with radial depth of cut (a_e).

In order to determine whether the dresser type has a significant effect on the output parameters analyzed in this work, a statistical analysis (ANOVA) was made and its results (mean values and p-values) are shown in Fig. 4.

As it can be seen in Figure 4, the dresser type presented a p-value of 0.870544 and 0.283224 for the surface roughness (Ra parameter) and electric power, respectively. Therefore, considering a confidence interval of 95%, the dresser type was not statistically significant for the results found in this work, which supports the discussions already made regarding Figs. 2 and 3.

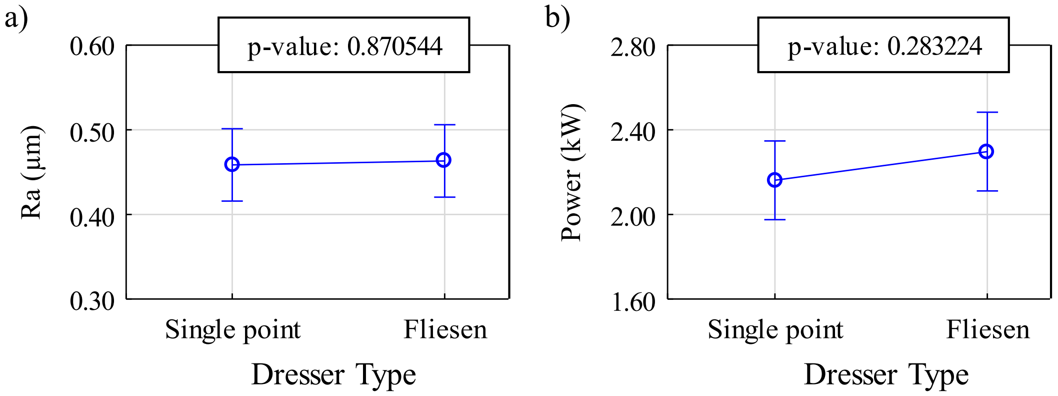

Figure 4. Results of ANOVA (mean values) for: (a) surface roughness – Ra parameter; (b) electric power.

The SEM images of the workpieces surface after grinding are shown in Fig. 5. From this figure can be noted that surfaces ground with the wheel prepared with the single point dresser (Figs. 5a-b) presented similar texture that those ground with the wheel prepared with the fliesen dresser (Figs. 5c-d).

From Figure 5 can be seen that surfaces ground in the mild condition (Figs. 5a and 5c), irrespective of the dresser used to prepare the grinding wheel, presented more occurrence of the microploughing wear mechanism that those ground in the rough condition (Figs. 5c and 5d). This phenomenon can be related to the low value of depth of cut (a_e) used in the mild condition, which contributes to the plastic deformation instead of cutting (Klocke, 2009). However, the surfaces ground in the rough condition (V_w = 10 m/min and a_e = 30 µm) presented wider grooves when compared with those ground in the mild condition (V_w = 5 m/min and a_e = 15 µm). This was expected since the depth that abrasive grit penetrates in the workpiece surface increase with the a_e parameter (Malkin and Guo, 2008).

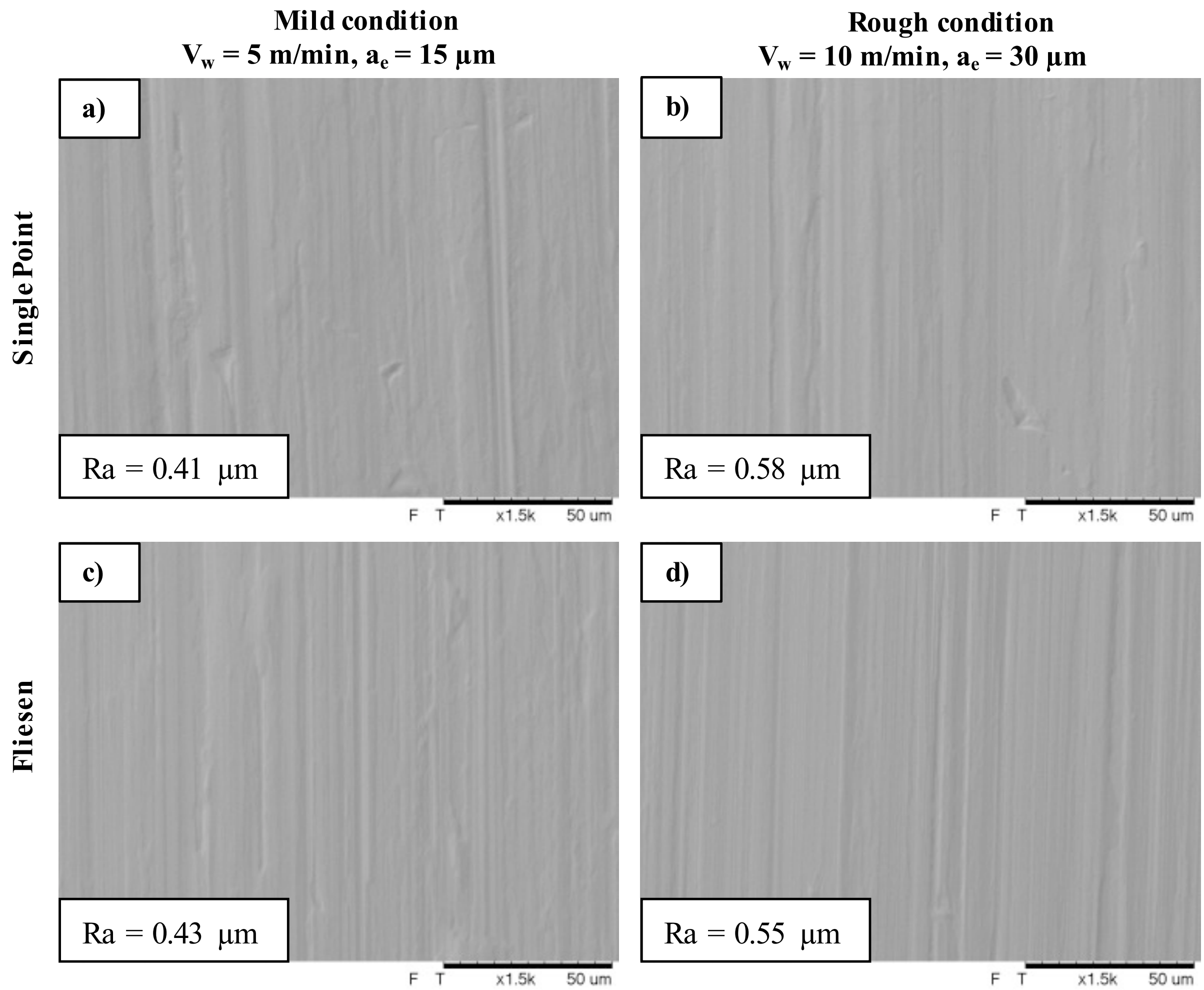

Figure 5. SEM images of the ground surfaces after dressing the wheel with the single point dresser for the (a) mild condition and (b) rough condition and after dressing the wheel with the fliesen dresser for the (c) mild condition and (d) rough condition.

All the results discussed in this work indicated that there are no significant differences between the grinding operation performed after dressing the wheel with the two-different dressers analyzed. However, it is important to emphasize that the fliesen dresser presents an advantage over the single point one, that is the higher and constant value of b_d, which contributes to a much lower dressing time, about 70% lower for the conditions tested in this work. On the other hand, the fliesen dresser presents a higher cost when compared to the single point one.

4. CONCLUSIONS

Considering the results of surface roughness (Ra parameter), electric power during grinding and the SEM images presented in this work, the following conclusions can be made:

i. Considering a confidence interval of 95%, the dresser type used to prepare the grinding wheel prior its usage did not present a statistically significant effect on Ra parameter and electric power for the conditions used in this work;
ii. Similar as observed for surface roughness and electric power results, the machined surface topography assessed by SEM images showed no differences regarding the dresser type;
iii. The effect of radial depth of cut (a_e) and workpiece speed (V_w) on surface roughness and electric power was as expected according to literature. The higher these input parameters, the higher the material removal rate and undeformed chip thickness, which has a negative effect in both surface roughness and electric power during grinding;
iv. Since no significant difference was observed regarding the dresser type for the conditions used in this work, using the fliesen one is advantageous due the dressing time, which is about 70% lower compared to the single point dresser.

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