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ANALYSIS OF THE GEOMETRIC ERRORS IN EXTERNAL CYLINDRICAL GRINDING OF 100CR6 STEEL WITH SEEDED-GEL AND CBN GRINDING WHEELS IN HIGH PERIPHERAL SPEEDS

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Abstract. *Companies have difficulties defining the type of grinding wheel with the best cost x benefit, considering geometric errors in high quality grinding process with high peripheral speeds. This research was carried out to compare the performance of grinding wheels with seeded-gel and CBN abrasives in the process of external cylindrical plunge grinding of 100Cr6 steel in the range of high peripheral speeds. Experiments were performed on a Bahmueller External Cylindrical Grinding Machine model XPRO2-HGS equipped with automatic load system and automatic balanced system for the grinding wheel from Dittel Company model M5000. Different specific material removal rates and high peripheral speeds were used and geometric errors were verified. The results showed that the roundness error was lower at higher peripheral speeds for all evaluated material removal rates, due to the smaller undeformed chip thickness. The straightness error was much lower than 1 µm, the dressing frequency chosen was very small and because of this the workpieces maintained the profile. Seeded-gel alumina grinding wheel maintains the grain sharpened and can be a good process alternative due to relative lower price and short delivery time in comparison with CBN grinding wheel.*

Keywords: *Grinding, grinding wheels, CBN, seeded-gel*

1. INTRODUCTION

Every time that a new grinding process need to be develop for small parts that requires high quality of geometric errors in equipment with high peripheral speeds, companies around the world struggle to define which type of grinding wheel is more suitable for that specific process.

Sintered seeded-gel and sol-gel aluminum oxide abrasives present significant advantages in comparison with their fused counterparts, particularly in terms of life-time and cost, they are much less expensive than super abrasives. When properly used, sintered abrasives can also result in significantly increased volumetric removal rates, reduced forces, lower work surface temperature and lower geometric errors during grinding. It is frequently a viable alternative to CBN, particularly easier in grinding and dressing, and the initial wheel cost (Webster and Tricard, 2004).

Klocke (2009) evaluated the wear mechanism of sol-gel abrasive grains using single grit scratch test. The severe plastic deformation and the crack bridging contributed to the wear of the sol-gel abrasives. Also, the improved tribological behavior of these abrasive grains was due to the presence of surface oxide layer. Selvakumaran et al. (2018) compared the performance of sol-gel alumina grinding wheel and White alumina grinding wheel by calculating the cutting force, chip morphology, surface roughness, grinding wheel wear and the Grinding ratio (G-ratio).
Nadolny and Kaploneck (2016) evaluated the effect of wear phenomena of grinding wheels with sol-gel alumina on chip formation during internal cylindrical plunge grinding and geometric errors of 100Cr6 steel.

High cutting speeds and low material removal rates lead to a low overall environmental impact due to tool wear. The peripheral speeds of grinding with vitrified grinding wheels increased significantly, in the years 1980 a cutting speed of 60 m/s was considered as high speed. In the years 1990 it became common grinding with 80 m/s and in the years 2000 cutting speeds of 120 up to 200 m/s were reported (Winter et al., 2015; Marinescu et al., 2016).

Grinding tools are not in a usable condition as delivered or after a longer period of use. Grinding wheels exhibit macro geometrical faults (e.g. roundness deviation, waviness, macro-wear, loss of profile), which lead to problems in the grinding process or to deficient dimensional accuracy of the components worked upon. Micro-wear, i.e. dulling of the grits, is associated with an increase in the grinding forces as well as the required grinding power (Klocke, 2009).

According to Shaw (1994), one single workpiece is never perfectly cylindrical, since all workpieces might show roundness errors, which are the main causes for such non-perfect cylindrical situation. Deviations from a perfect circle have to be kept under certain tolerances, especially in case of shafts, axles, crankshafts and roller bearings. High values of roundness in these components can lead to excessive noise, vibrations and component failure (Sing et al., 2014). Straightness tolerance controls the deviation of the shape of the feature from its true shape. The tolerance zone, according to NBR6409, is defined by the straightness of the axis of a solid of revolution. In this case the tolerance zone is a cylinder whose diameter is the tolerance value. When the tolerance zone is the area between two parallel straight lines, in the plane containing the controlled edge, the tolerance value is the distance between the two lines. The straightness errors in the components are one of the important factors that directly influence the accuracy of the machines.

Previous works were carried out by comparing conventional aluminum oxide grinding wheels with microcrystalline seeded-gel grains or CBN grains. However, they were not evaluated in the high peripheral speed bands where it is possible to use both grinding wheels in small parts. In this context, the present work analyzes the geometric errors (roundness and straightness) in the process of external cylindrical grinding of 100Cr6 steel in high peripheral speeds with seeded-gel and CBN grinding wheels.

2. EXPERIMENTAL PROCEDURE

The steel 100Cr6 is mainly used for small and medium sized bearing components, regularly used for other machine components that require high tensile strength and high hardness. The chemical composition of the material is given on Tab. 1.

Table 1. Chemical composition of 100Cr6 steel (62HRc) – DIN 100Cr6 (1.3505), AISI 52100.

Element	C	Mn	P	S	Si	Ni	Cr	Mo	V	Others
Wt(%)	0.98-1.1	0.25–0.45	0.025	0.025	0.15 – 0.35	-	1.30 - 1.60	1.30 -1.60	-	-

The experiments were conducted on 100Cr6 steel small samples with different diameters Fig. 1. The red lines indicate the grinded diameters and lengths (Ø4.82 mm x 8.9 mm and Ø2.92 mm x 6.1 mm). The tests were carried out with two types of grinding wheels, CBN (Fig. 2a) and seeded-gel (Fig. 2b), the CBN grains image are in Fig. 2c and seeded-gel in Fig. 2d. Developed in 2015 by Saint-Gobain Abrasives the bond Vitrium3 was used in the seeded-gel grinding wheel, others informations are on the Tab. 2.

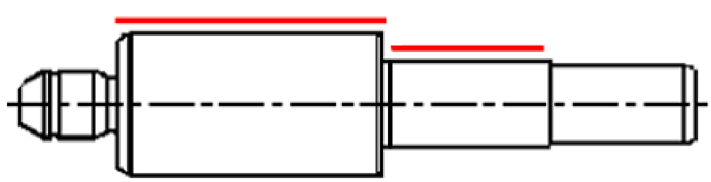

Figure 1. Workpiece design.

Table 2. Grinding wheel specifications.

Short name	Seeded-gel grinding wheel	CBN grinding wheel
Supplyer	Saint-Gobain Abrasives	Wendt GMBH
Technical designation of wheel	5NQP150M8VS3	J13X.000.012-M64-VR150N/20/T-127
Grains size (µm)	70 - 91	65 - 85
Composition	50% grains 25A + 50% grains 5NQP	100% grains J13X
Grinding wheel type	Straight	Straight
External diameter (mm)	400	400
Internal diameter (mm)	127	127
Width (mm)	17	17

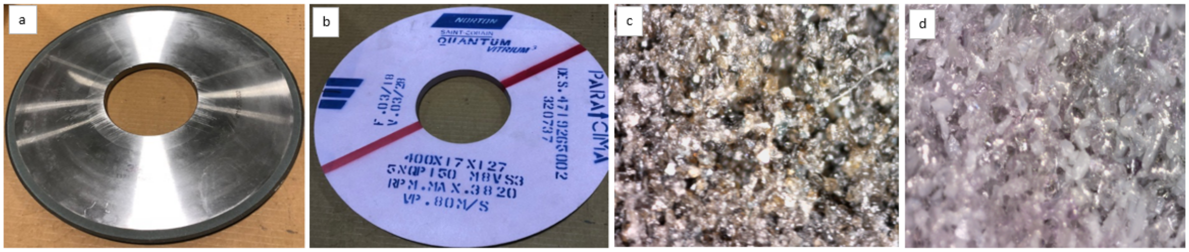

Figure 2. CBN and seeded-gel grinding wheels and grains images.

Experiments were performed on Bahmueller External Cylindrical Grinding Machine model XPRO2-HGS equipped with automatic load system and automatic balanced system for the grinding wheel from Dittel Company model M5000 (Fig. 3). It also has in process diameter measures from Movomatic model ES400, dressing spindle from Dr. Kaiser, clamping system by membrane and center with movement. Integral oil Ecocut HFN 5B from supplier Fuchs was used in the experiments.

Figure 3. Bahmueller XPRO2-HGS external cylindrical grinding machine.

Variable combination of 3 different specific material removal rate (Q'w) 100, 150 and 200 mm^3/mm.min and 3 different high peripheral speed 60 m/s, 70 m/s and 80 m/s were chosen for the tests Tab. 3. 75% of the raw material was removed during the rough feed-rate, at this phase the specific material removal rate was evaluated, during the finishing feed-rate 1, 2 and 3 and fine finishing feed-rate the process was controlled by Movomatic until reach the final diameter. The dressing parameters are in the Tab. 4.

Table 3. Grinding parameters.

Q'_w (mm^3/mm.min)	Material removal (%)	100	150	200
Raw material (mm)	Σ 100	0.12	0.12	0.12
Start rough position (mm)	75	0.30	0.30	0.30
Rough feed-rate (mm/min)		6.6	10.0	13.2
Star finishing position 1 (mm)	11.7	0.03	0.03	0.03
Finishing feed-rate 1 (mm/min)		0.8	0.8	0.8
Star finishing position 2 (mm)	7.5	0.016	0.016	0.016
Finishing feed-rate 2 (mm/min)		0.3	0.3	0.3
Star finishing position 3 (mm)	2.5	0.007	0.007	0.007
Finishing feed-rate 3 (mm/min)		0.12	0.12	0.12
Star fine finishing position (mm)	3.3	0.004	0.004	0.004
Fine finishing feed-rate (mm/min)		0.06	0.06	0.06
Workpiece rotation (1/min)	Up grinding	980	980	980
Final diameter (mm)	-	4.700±0.002	4.700±0.002	4.700±0.002
Workpiece length (mm)		15	15	15
Peripheral speed (m/s)		60/70/80	60/70/80	60/70/80

Table 4. Dressing parameters.

Description	Data
Supplier (spindle)	Dr.Kaiser
Supplier (tool)	Dr. Kaiser
Dressing tool type	Galvanic disc
Grain type and size(µm)	D91
Dressing tool diameter (mm)	120
Dressing tool width (mm)	0.8
Feed-rate (mm/min)	65
Dressing tool rotation (1/min) Up direction	4600
Rough increment (mm)	0.002
Fine increment (mm)	0.001

Before starting machining process, the grinding parameters were adjusted as Tab. 5. The process sequence was: 1- dressing; 2- 50 cicles; 3- dressing; 4- 50 cicles; 5- change grinding parameters to next experiment. The value on the axis “x” of the CNC screen were recorded before the first part and after 50^{th} was grinded, analysis the grinding wheel wear was made through these information.

A batch of 1800 parts were made, 540 of those were separated to laboratory analysis. In each experiment with two intervals with 15 parts each. Geometric errors were measured with a MFU100 equipament (Fig. 4). It was used a probe with diameter 0,5 mm, polar filter 50 UPR and Gauss 50%, linear filter 0,8 and Gauss 50%, polar interval 0.1, linear interval 0.005 mm and the avaliation method used were polar MZC and Linear MZS.

Table 5. Parameters used in the experiments.

Experimental number	Sequence	Peripheral speed (m/s)	Q'_w (mm^3/mm.min)	Grinding wheel	Quantity of parts	Dressing interval (parts)
1	1	60	100	CBN	100	50
2	4	60	150	CBN	100	50
3	7	60	200	CBN	100	50
4	2	70	100	CBN	100	50
5	5	70	150	CBN	100	50
6	8	70	200	CBN	100	50
7	3	80	100	CBN	100	50
8	6	80	150	CBN	100	50
9	9	80	200	CBN	100	50
10	10	60	100	Seeded-gel	100	50
11	13	60	150	Seeded-gel	100	50
12	16	60	200	Seeded-gel	100	50
13	11	70	100	Seeded-gel	100	50
14	14	70	150	Seeded-gel	100	50
15	17	70	200	Seeded-gel	100	50
16	12	80	100	Seeded-gel	100	50
17	15	80	150	Seeded-gel	100	50
18	18	80	200	Seeded-gel	100	50

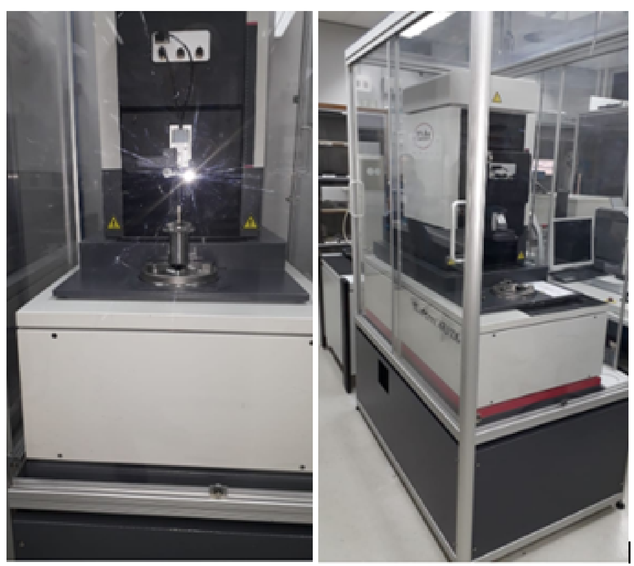

Figure 4. Mahr MFU100 equipament.

3. RESULTS

It is extremely important for the grinding process that the roundness values meet the design specifications. The values obtained in the grinding process are related to the chosen conditions, the machine disturbances and the workpiece fixation (Wang, 2008). Figure 5 shows roundness in function of the peripheral speed for seeded-gel and CBN grinding wheels at different specific material removal rates. Each point in the graphics is represented by the average of 30 workpieces added to three standard deviations. The curves present similar behavior for all the material removal rates.

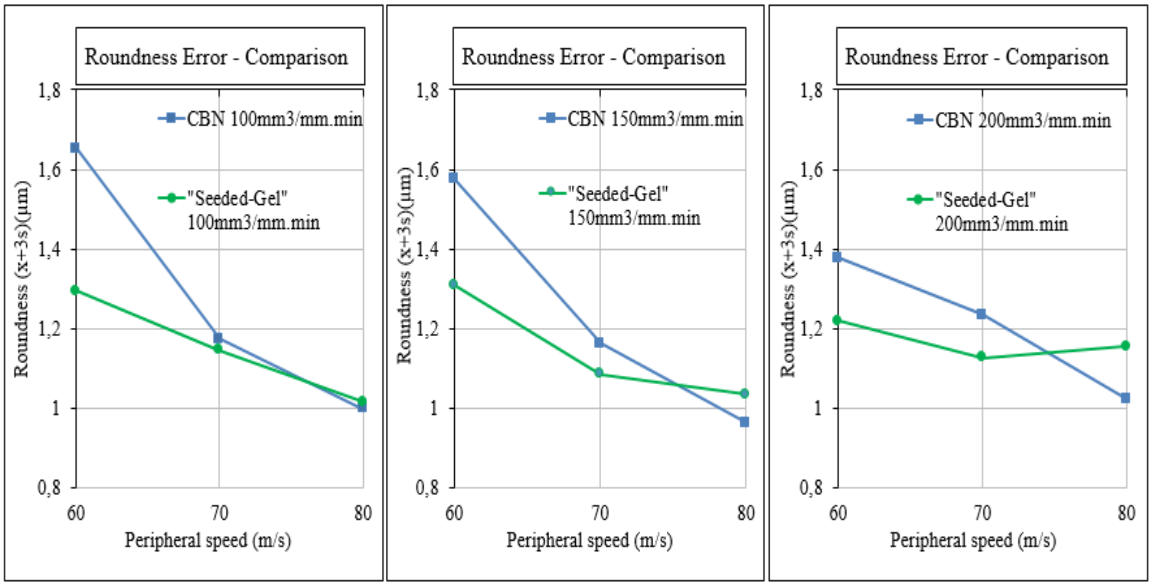

Figure 5. Roundness Error (X+3S) (µm).

It is possible to observe that roundness decreases as the peripheral speed increases, this was due to the smaller undeformed chip thickness. According to Bianchi et al. (2001), when the peripheral speed increases the undeformed chip thickness decreases, making easier for the chips to penetrate into the grinding wheel pores, maintaining the quality of the grinded part and allowing the increase of the dressing interval. At 60 and 70 m/s the seeded-gel grinding wheel performed better than the CBN grinding wheel. However at 80 m/s CBN grinding wheel presented better results especially at higher material removal rates due to the structure and hardness of its abrasive grains. CBN grinding wheel has also high wear resistance at high material removal rates. Singh et al. (2014) found that abrasive grain size is the most significant parameter that influences roundness in cylindrical grinding of AISI 4140 steel. Another important factor is the type of cutting fluid, according to Souza et al. (2004) the use of integral oil allows the reduction of roundness errors and diametrical wear of grinding wheel due to its higher lubricating power, reducing the friction and the heat generation in the grinding zone.

Figure 6 depicts the straightness error in function of the peripheral speed for seeded-gel and CBN grinding wheels at different removal rates.

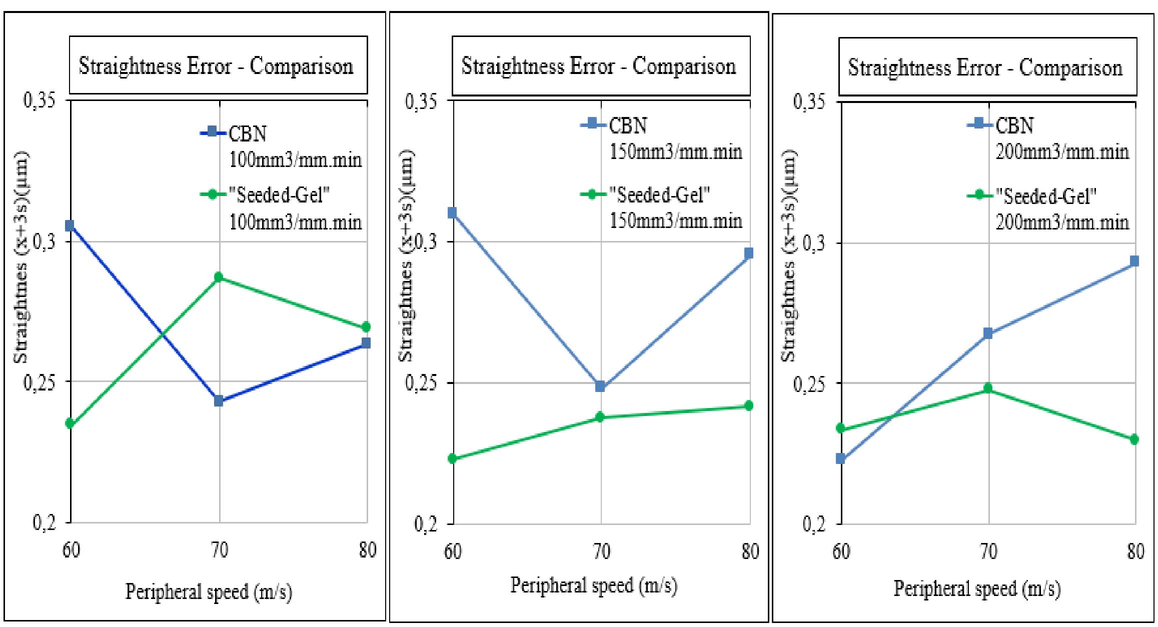

Figure 6. Straightness Error (X+3S) (µm).

The straightness error is much lower than 1 µm for all the cutting conditions, the dressing frequency chosen was very small and because of this the workpieces maintained the profile. CBN grinding wheel presents difficulties when it is being dressed, while seeded-gel has a high-dressing ability. There was little variation of the straightness error in function of the peripheral speed and material removal rate, especially for the seeded-gel grinding wheel.

The results of the present work are in agreement with those found by Souza and Da Silva (2019), who studied grinding of superalloys and found that the seeded-gel grinding wheel presents superior performance when considering the economic indicator, while the CBN grinding wheel shows better performance in relation to the energy indicator and roundness.

4. CONCLUSIONS

Based on the results following the comparison between seeded-gel and CBN grinding wheels in high peripheral speeds in bands where both could be applied, the following significant points can be highlighted:

- The roundness error was lower at higher peripheral speeds for all evaluated material removal rates, due to the smaller undeformed chip thickness.
- At 60 and 70 m/s the seeded-gel grinding wheel performed better than the CBN grinding wheel, however at 80 m/s CBN grinding wheel presented better results especially at higher material removal rates due to the structure and hardness of the abrasive its grains.
- The straightness error was much lower than 1 µm, the dressing frequency chosen was very small and because of this the workpieces maintained the profile.

The results also showed that seeded-gel alumina grinding wheel maintains the grain sharpened and can be a good process alternative due to relative lower price and short delivery time in comparison with CBN grinding wheel.

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7. RESPONSIBILITY NOTICE

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