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INFLUENCE OF DIFFERENT MICROCRISTALLINE Al_2O_3 ON THERMAL DAMAGE AND PROFILE ACCURACY OF THE WORKPIECE IN CYLINDRICAL PLUNGE GRINDING

Walter Lindolfo Weingaertner, wlw@emc.ufsc.br
Universidade Federal de Santa Catarina (UFSC) - Departamento de Engenharia Mecânica - Laboratório de Mecânica de Precisão, Caixa Postal 476 – EMC, Florianópolis – SC Brasil, CEP:88.010-970

Eckart Uhlmann, uhlmann@ipk.fhg.de
Gregor Hasper, Gregor.hasper@iwf.tu-berlin.de
Technische Universität Berlin (TU-Berlin) – Institut für Werkzeugmaschinem und Fabrikbetrieb – Produktionstechnisches Zentrum, Sekretariat PTZ 1, Pascalstraße 8-9, D-10587 Berlin

Lucas Benini, lucasbenini@gmail.com
Universidade Federal de Santa Catarina (UFSC) - Departamento de Engenharia Mecânica - Laboratório de Mecânica de Precisão, Caixa Postal 476 – EMC, Florianópolis – SC Brasil, CEP:88.010-970

Abstract. *Higher material removal rates and process capabilities are continuously expected from conventional grinding tools due to the technological developments regarding innovative machine tools. Thus the grinding tools are often utilized at the limit of their physical properties and capabilities. This leads to the effect that small variations of the grinding wheel characteristics can have a significant impact on the grinding behavior and consequently on the accuracy of the workpiece. The aim of this paper is to present the preliminary experimental results of the influence of different microcrystalline Al_2O_3 grits in conventional grinding wheels on thermal damage and profile accuracy of the workpiece in external profile grinding. Workpieces with grinding wheels of different microcrystalline grits were machined and the profile accuracy of the workpiece was monitored by significant parameters. The thermal damage values were measured by the Barkhausen Noise Method. Generally, this method is based on the physical phenomenon occurring in ferromagnetic materials during magnetization. The correspondent values measured were analyzed and demonstrate how thermal damage and accuracy of the workpiece are influenced by different microcrystalline grits of conventional grinding wheels.*

Keywords*: conventional grinding wheels; thermal damage; profile accuracy*

1. INTRODUCTION

The current scenario on world economy demands more flexible manufacturing systems. In the grinding process, this tendency can be perceived on the grinding wheels applications. Although the superabrasive grinding wheels are more durable, because of their mechanical properties, and are able to be profiled, they are not as suitable for the current low-size inventories, just-in-time minded industries, as the conventional grinding wheels, since they cannot be easily reprofiled. Thus, the former are most commonly employed for large lots of the same product, while the latter are appropriate for small-lot flexible manufacturing.

There are many conventional grinding wheels from different manufacturers on the market. It is important to note that the grinding process control is affected to a considerable degree by the grinding tool properties. At the same time, these are affected by a large number of variables during production:

- phase proportion of grits, bond and pores,
- type of grit, grit geometry, type of bond,
- type and amount of fillers and additives,
- mixing,
- sintering temperature, sintering pressure, sintering time.

Unintended changes of the influencing factors lead to uncontrolled changes of the grinding wheel characteristics and to an altered grinding behavior. The process behavior of the grinding wheels has direct influence on the surface roughness, profile deviation and thermal damage of the workpiece. The surface roughness and profile deviation are easy to measure, even with profiled grinding wheels. That is because those parameters don’t require complex equipments and can be measured in short time tests.

In contrary, the thermal damage suffered by the workpiece is difficult to evaluate, since it requires most of the time expensive and time consuming tests. At the present time, the most common methods to evaluate the thermal damage are:

- hardness,
- residual stress,
- nital etch.

Nital etch is basically a qualitative test, hence it is difficult to compare it with quantitative tests. Although this method may be suitable for sample inspection it is not appropriated for the evaluation of whole batches of production. This method is time consuming, difficult to automate and requires a subjective evaluation of the surface quality. In addition, inspected surfaces attacked by acid etch have to be additionally treated and often require further heat treatment to avoid hydrogen embrittlement.

The current nital etch techniques are routine methods for finding burns, but can be misleading if the burns have been 'removed' by a finishing grinding process, since some damage can still remain even though the etch does not reveal this. Resolution is too low for appraisal of the influence of different grinding wheel types (Wojtas *et al.* 1998).

Another way to evaluate the thermal damage is by the Barkhausen Noise method. This technique is appliable to ferromagnetic materials, which are composed of small ordered magnetic regions called magnetic domains. The Barkhausen Noise method is based on inductively detecting a noise like signal generated by ferromagnetic materials submitted to an alternating external magnetic field. Magnetic domains walls forced to move back and forth by the exciting magnetic field, will pin to crystal lattice defects and dislocations only to jump further once forced by sufficient excessive energy of the magnetizing field. Each jump will generate a pulse in a coil placed near the surface of the sample. Pulses generated in a finite volume of material close to the coil will add to a noise like signal called Magnetic Barkhausen Noise. The intensity of this signal, BNA, is further used to characterize the integrity of the stress state and the microstructure of the ground surface (Garstka 2008, Gür *et al.* 2009, Kesavan *et al.* 2005, Silva Jr. *et al.* 2000, Ting *et al*. 2006, Wojtas *et al.* 1998).

The effective voltage (RMS) of the generated signal, also referred to as MP (Magnetoelastic Parameter), is a strong function of the microstructure and residual stress state of a material, making the Barkhausen Noise method ideal for detecting grinding abuse. Wojtas *et al.* (1998) found in his work a increasing behavior of the Barkhausen Noise as a consequence of the incresing grinding damage, though performing experiments in special conditions. The increase in the Barkhausen Noise was most likely due to an increasing residual stress and a decreasing hardness on the workpiece.

The Barkhausen Noise method has already been endorsed by the American Society of Automotive Engineers and the Federal Administration of Aviation. In a short period of time since its endorsement many companies in the automotive and aerospace industry have introduced it and many have already included it in their specifications and quality assurance standards. Its sensitivity to both stresses and hardness, combined with its significant penetration depth, enables it to detect grinding burns that may have been partially 'removed' in finish grinding. Also, it allows measurements through coatings, e.g. chromium plating (Wojtas *et al.* 1998).

Currently, there is no known correlation between residual stress and hardness with the measured Barkhausen Noise, because of complex overlapping of these parameters. The Barkhausen Noise method is not extensively tested and the influences of different characteristics are not well known.

2. EXPERIMENTAL SETUP

Experiments in external cylindrical profile grinding were carried out to appraise the potential of the Barkhausen noise measurement (Fig. 1) for a quick-test method of thermal damage at the workpiece. For this purpose a universal cylindrical grinder Schaudt Pf 51 came in operation. The test machine is equipped with a rotating cutting force dynamometer and offers high stiffness and accuracy as well as a powerful spindle drive.

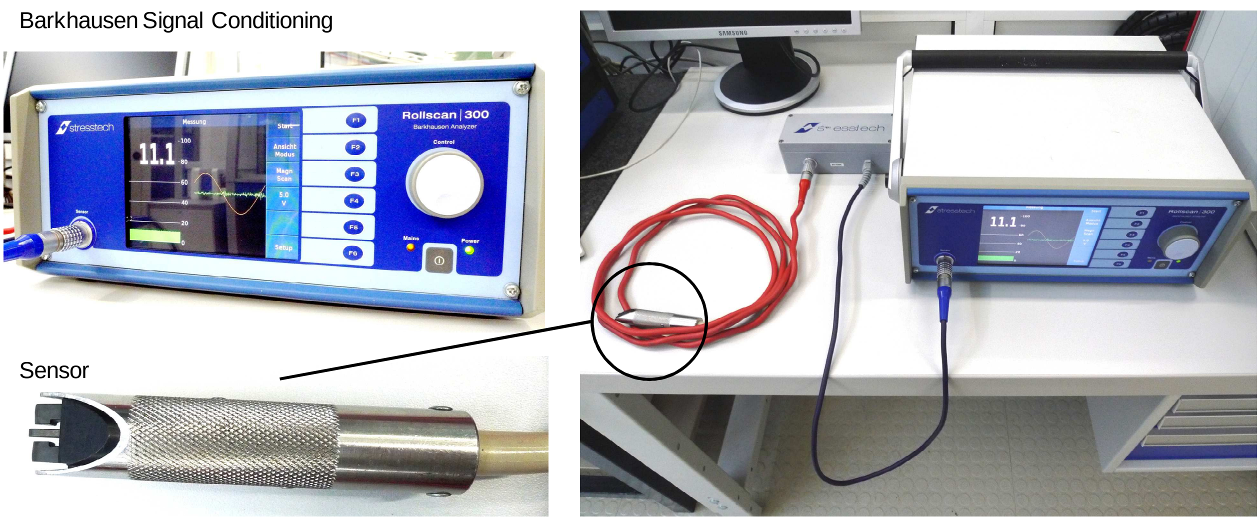

Figure 1. A view of equipments for BN method

Three different vitrified grinding wheel specifications were tested in the experiments, which are showed in Tab. 1. The grinding wheels were conditioned with a stationary MKD dressing plate before each test series. Water mixable solution in a concentration of 5% was used as cooling lubricant. Hardened steel rings were used as workpieces (Fig. 2).

Table 1. Grinding wheel specifications.

Grinding wheel	Microcrystalline Al_2O_3	White fused Al_2O_3
Reference (ref.)	0%	100%
A	30% type A	70%
B	30% type B	70%

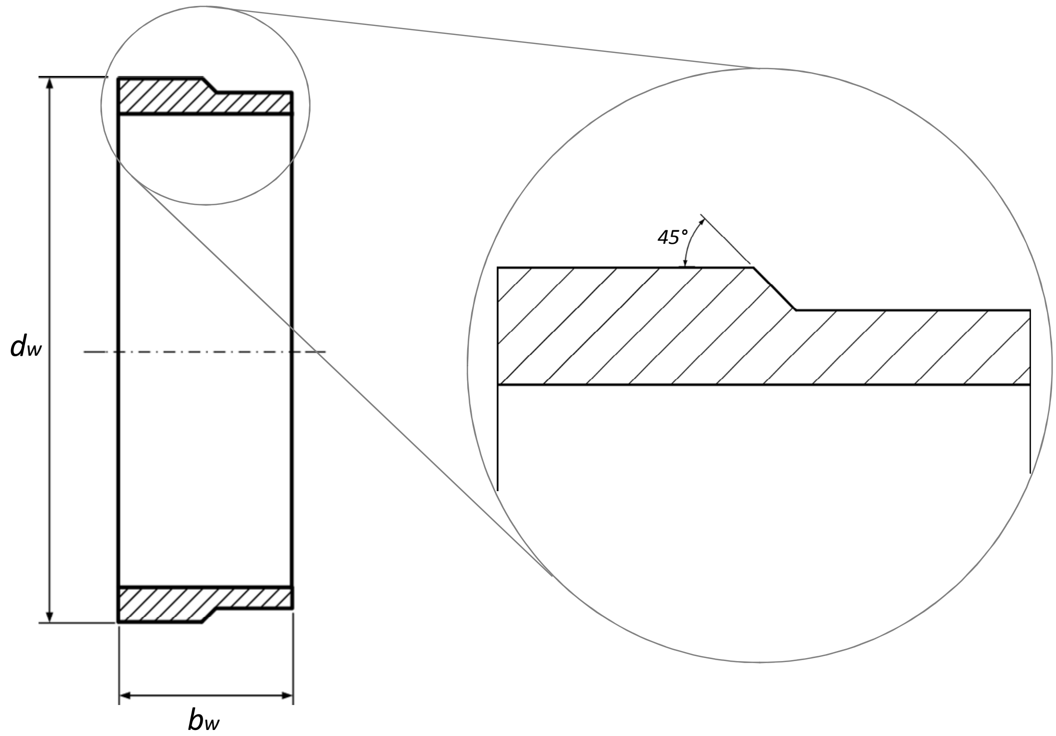

Figure 2. Representative workpiece

The experiments were executed in a three-stage plunge grinding process. In the roughing phase the bulk of the material stock was ground with a high removal rate. After the elastic deformations were reduced in a transition phase, the smoothing process ground the surface with a low material removal rate. No dressing took place neither before the finishing process nor between rings, so the impact of the increasing material removal could be evaluated. To analyze the impact of the different grain types the grinding forces of the roughing steps, the surface roughness and the profile deviations after finishing were measured. The grinding conditions are specified in Tab. 2.

Table 2. Grinding conditions.

grinding parameters	
cutting speed v_c	35 m/s
specific material removal rate roughing Q'_w	12 mm^3/mms
specific material removal rate finishing Q'_{w*}	0,5 mm^3/mms
speed ratio roughing q	-60
speed ratio finishing q_*	-120
grinding wheels	
geometry	500 x 30 x 203,2 mm^3
grit size d_g	F 80

Norton hardness / structure	Jot 6
bond type	vitrified
workpiece	
material	100Cr6
hardness	60±2 HRC
diameter d_w	87,5 mm
width b_w	25 mm

2.1. Technological investigations

Several mechanical and thermal properties are demanded from the abrasive grains used in grinding processes. High values of tenacity and hardness facilitate the chip formation and provide a better condition of the cutting edges. Because of the high temperatures at the grinding processes, as well as the fast temperature changes, a high thermal resistance is also necessary on the abrasive grains. Likewise, a good chemical resistance is required to avoid grit-weakening reactions, since the grinding wheel operates with high temperatures while in contact with components from the workpiece material, air and cooling lubricant.

In order to satisfy all those conditions, many natural and synthetic materials, and different combinations of them as well, are used for different grinding processes. However, the influence of different grain mixtures on the external cylindrical grinding process is not well known. The large number of tests that are needed to precisely measure the profile accuracy and thermal damage on the workpiece, makes those influences hard to evaluate. Besides, in order to get accurate results, the thermal damage demands the process to be followed by a quick test whereas most of current thermal damage tests are long and destructive.

Thus, in this study, the above-mentioned influences will be analyzed with two microcrystalline Al_2O_3 grits on conventional grinding wheels, using Barkhausen Noise and nital etch techniques. The Barkhausen Noise test results can be converted into information about the residual stresses and thermal damage, since they are closely related. However, in this study, only the direct RMS values were used to evaluate the correlation between the Barkhausen results and the different thermally affected areas.

Since the Barkhausen Noise is a quick non-destructive test, an evaluation of its potential for a in-process application was also made. The nital etch method was applied in the same samples with the purpose of qualitatively comparing both methods of thermal damage evaluation.

3. RESULTS

Since no dressing took part before the grinding of a new ring, the specific material removal V'_w increased with each machined workpiece. The normal forces were measured for each ring. The results are shown in Fig. 3, where the normal forces depend on the specific material removal. Also in Fig. 3 are the used parameters, which remained the same for all the tests.

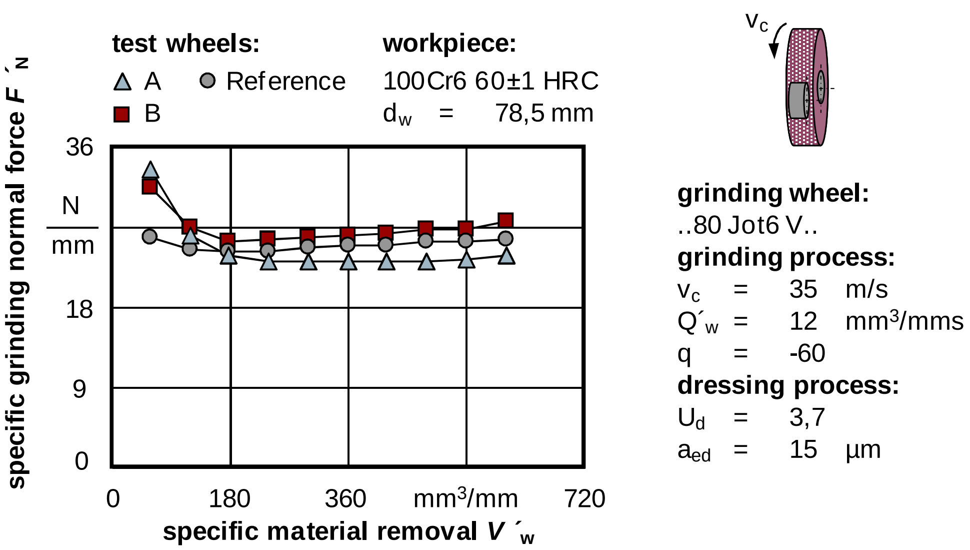

Figure 3. Grinding normal forces versus the material removes rates

A recently dressed grinding wheel presents in the first ring higher normal forces, because of the initial grain wear. However, in the reference grinding wheel this occurrence is barely noticeable, because the grinding wheel maintains an almost constant force behavior throughout the machining of all rings.

It is noticeable that different proportions of grain types cause different forces during the first grinding process. The reference grinding wheel, with 100% white fused Al_2O_3, presented the lowest initial forces, while the grinding wheel A, with 30% microcrystalline Al_2O_3 type A, presented the highest ones. Likewise, the grinding wheel B, with 30% microcrystalline Al_2O_3 type B, presented a very similar behavior, starting with high initial forces, right below grinding wheel A. Therefore, it is shown that the presence of microcrystalline Al_2O_3 demands higher forces for the first grinding process after dressing, with the same process parameters.

After the first process, the grinding wheel A normal forces quickly decrease, becoming the lowest ones, before entering a constant behavior. The grinding wheels B and reference presented a similar, linear but increasing tendency after the first rings, with grinding wheel B showing the highest normal forces.

In Fig. 4 are shown the profile deviation results and the process parameters. The upper graph shows the correlation between surface roughness *Rz* and the material removal.

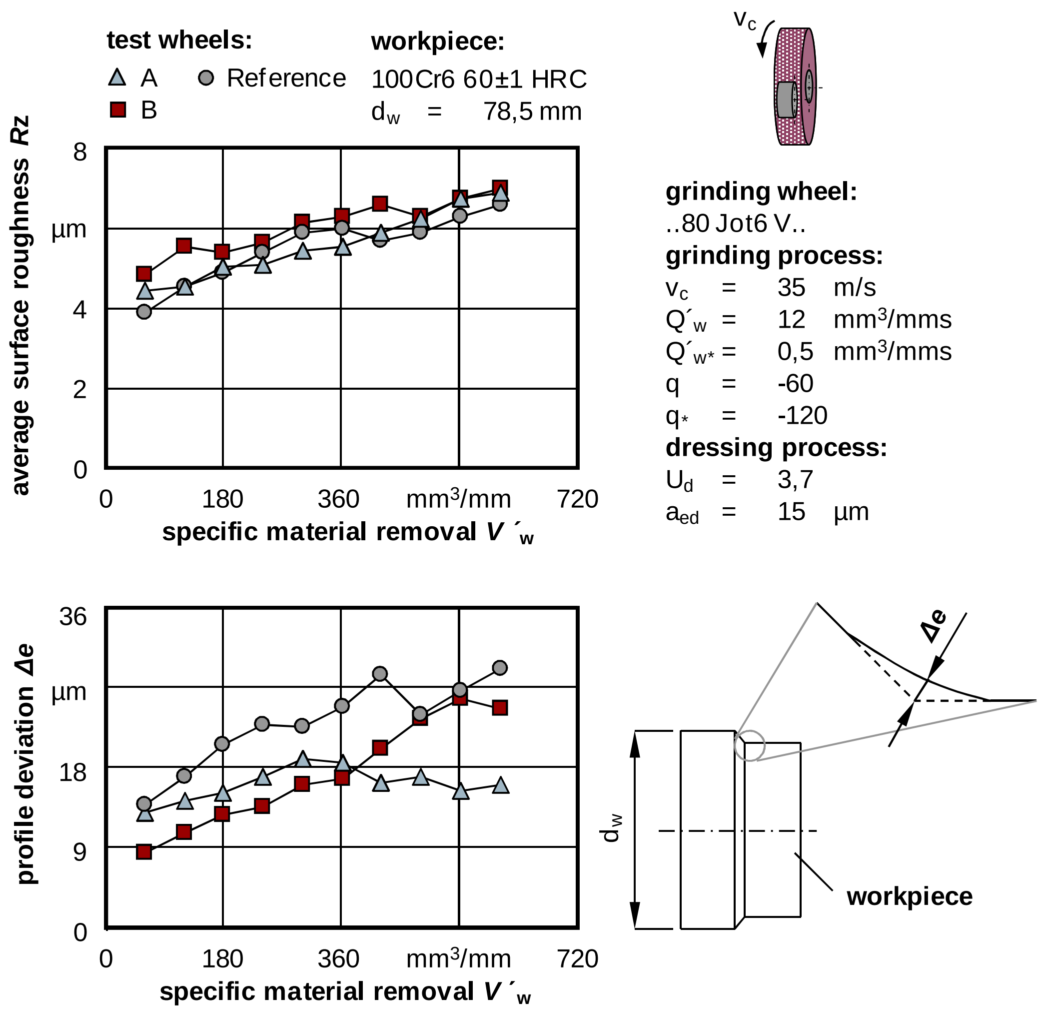

Figure 4. Profile deviation versus the material removes rates

As shown in the graph, grinding wheel B produced the highest values of surface roughness for every material removal. It is also shown that though the surface roughness values are quite different from one grinding wheel to another in the first rings, they are very similar at the end, with a high material removal. Finally, the difference between different grain types is clear, since the grain type A produced a better surface roughness than the grain type B. The microcrystalline splitting and topography changes are the main reason for the nearly linear behavior of the surface roughness produced on the workpiece by each grinding wheel.

The obtained results for profile deviation were plotted on the lower graph, above shown. In contrary to the surface roughness, the profile deviation presented very different behaviors for each grinding wheel. It is clear that the reference grinding wheel produced the highest values of profile deviation, since it is made completely from white fused Al_2O_3, therefore suffering more grain wear. In comparison to grinding wheel B, the reference grinding wheel had, most of the time, a 50% higher profile deviation. The grinding wheel A presented a completely different behavior, increasing its value until a material removal of about 300 mm³/mm, then slowly decreasing with higher removals.

In light of the above-mentioned results, it is ascertainable that the grinding wheel A is more suitable to the process since it demands lower machining forces, produces a better surface roughness and a profile deviation similar or lower than grinding wheel B.

Figure 5 shows the thermal damage evaluated by the Barkhausen Noise in two locations: the perimeter and the profile of the workpiece.

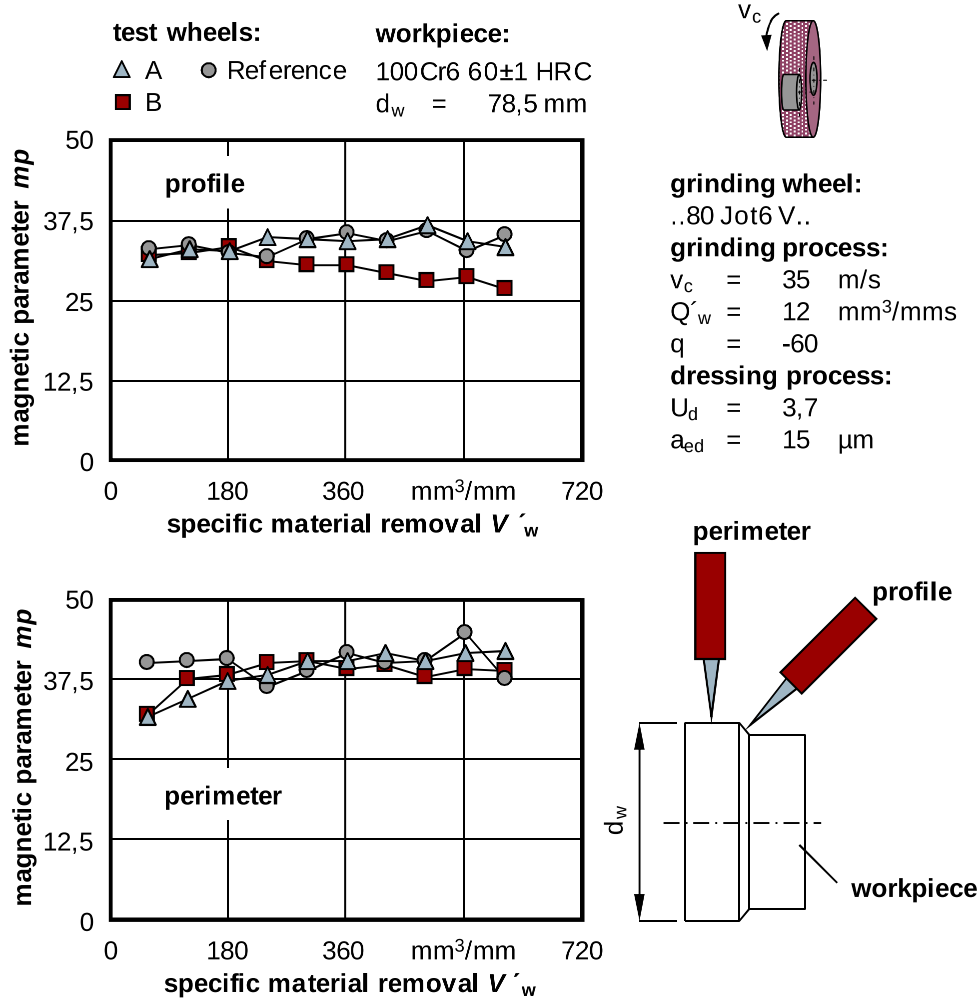

Figure 5. Magnetic parameters versus material remove rates

The results of the Barkhausen Noise tests were surprising. The magnetic parameter values on the perimeter were higher than in the profile, indicating a more severe thermal damage at the former. Usually, the thermal damage is supposed to be higher on the profile, since bigger mechanical and thermal loads are applied to this location because of the workpiece geometry.

These results are shown in Fig. 5. In addition, it is shown in the upper graph that the rings machined by the grinding wheel B presented the lowest magnetic parameter values, contradicting the normal force measurements. In most cases, higher machining forces can produce higher residual stresses and a worse thermal damage. Hence, the thermal magnetic parameter values were supposed to be higher as well.

At the perimeter measurements, there was an overlapping of results, which makes difficult to get a concrete conclusion about the thermal damages with different grain types. It is hard to observe any relation of the magnetic parameter values with different thermal damages and residual stresses caused by different grinding wheels. Thus, the Barkhausen Noise method was not conclusive by itself and therefore, other methods like nital etch or hardness tests were required to reach an adequate conclusion.

In this study, the nital etch technique was applied to the samples, in order to find an improvement on the understanding of thermal damage behavior. To do so, a sample machined with V'_w =32 mm³/mm was submitted to the nital etch procedure. The nital etch method is able to identify the most thermally affected areas, highlighting them with different colors. The magnetic parameter values of the workpiece were then measured, in different colored areas of the sample, to find a correlation between them.

Figure 7 (a) shows the sample after the nital etch procedures (Reichenbach 1999, Bauch 1982). According to this method, the orange areas indicate the most thermally affected parts, while the gray color represents the lowest affected areas. As shown, the profile and outermost areas presented the highest thermal damages, according to the method.

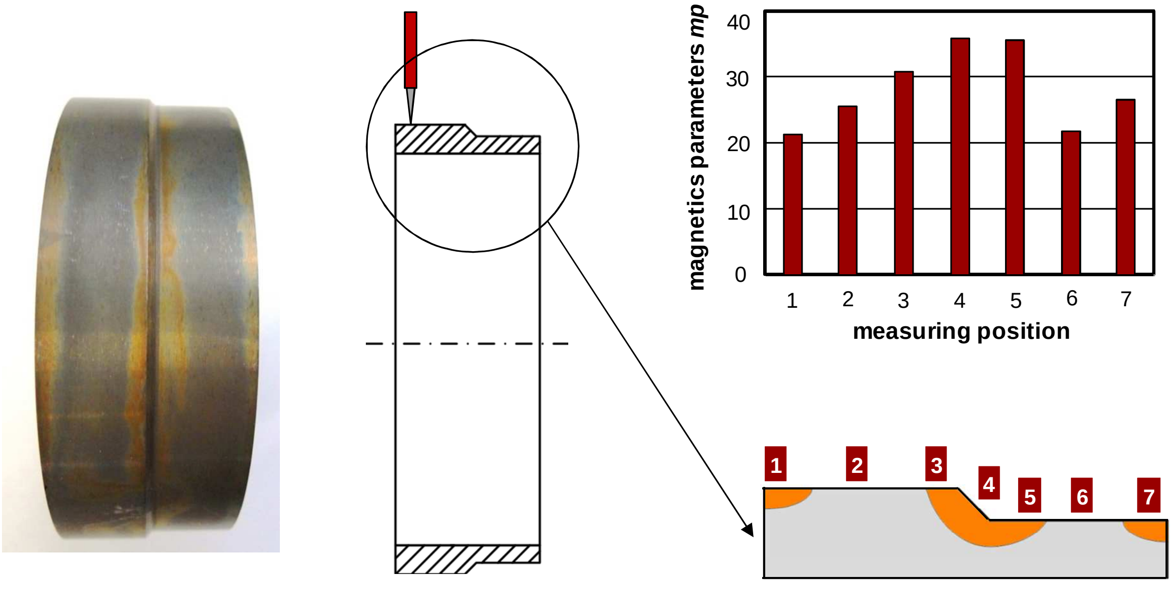

Figure 5. Nital echt measurements

Seven different regions were then chosen to have its thermal damage measured by the Barkhausen method. Each region had its magnetic parameter values measured in three different spots, in order to get an average value. Figure 7 (b) points, in a simple sketch of the workpiece, where each measurement took place, and shows its magnetic parameter results.

An increase of about 50% can be observed on the first three columns. The highest magnetic parameter values were obtained at the regions 4 and 5. It becomes clear that the magnetic parameter values present much fluctuation, which may explain the overlapping of results on Fig. 5.

Another likely reason to the overlapping of results, are the measurements conditions. The later tests were made in laboratory conditions, gathering more data for a single sample, and already showed a considerable fluctuation of the magnetic parameter values. The earlier tests were performed at workplace conditions, right after machining, with much less measuring points. Thus, the former results may have even more fluctuation, being unacceptably inaccurate. Finally, some other possible reasons are the angle of the Barkhausen measurements, and the chemical procedure carried out on the workpiece.

4. CONCLUSIONS

Three grinding wheels were used in the experiments, varying only the proportion of different microcrystalline grains with the white fused Al_2O_3. With the experiments results, it is ascertained:

- The type of microcrystalline Al_2O_3 grit has influence over the machining forces. Type B grains demand higher forces than the type A grains.
- The type of microcrystalline grit has little influence over the surface roughness *Rz*, since the results presented similar values of surface roughness. Also, all the grinding wheels presented a nearly linear increasing behavior as V'_w increased.
- Regarding profile deviation, the reference grinding wheel showed the highest values. Thus, the addition of microcrystalline grains type A and B decreases this deviation, by reducing the grinding wheel wear.
- Examining the forces and profile deviations on the process, the grinding wheel A is the most useful, since it requires lesser forces, produces a smaller profile deviation and obtains a better surface roughness.
- The thermal damage results obtained by the Barkhausen method showed a complex overlapping of different factor, like stress residual and hardness, which must be accounted. It is necessary to optimize the measurement procedure as well as gather more data from complementary methods, in order to achieve better conclusions.

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- A complementary experiment showed that fluctuations were also present at laboratory conditions. Thus, it was not possible to achieve a good picture of the thermal damage behavior on the workpiece during the experiments.
- It is necessary to optimize the current thermal damage tests, the measurement procedures or even to find new more reliable tests in order to be able to implement thermal damage evaluation in the industry.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Bausch, T., 1982, “Nitalätzung zum Nachweis von Schleifbrand”, Antriebstecknik 21, No. 3, pp. 89 - 91.

Garstka, T., 2008, “The influence of product thickness on the measurements by Barkhausen Noise method”, Journal of Achievements in materials and Manufacturing Engineering, Vol. 27, No. 1, pp. 47 - 50.

Gür, C.H., Yelbay, H. I, Cam, I., “Prediction of surface Residual streeses in Butt - Wellded steel plates by magnetic Barkhausen Noise Analysis”, The Open Access NDT Database. 27 Jan. 2009 < http://www.ndt.net/>.

ISO 4287:1997 + Cor 1:1998 + Cor 2:2005 + Amd 1:2009, “Geometrical Product Specifications (GPS) Surface texture: Profile method Terms, definitions and surface texture parameters”, 25 p.

Kesavan, K., Ravisankar, K., Parivallal, S., Sreeshylam, P., 2005, “Non destructive Evaluation of Residual stresses in Welded Plates Using the Barkhausen Noise Technique”, Vol. 29, No. 5, pp. 17 - 21.

Liu, Z. L., Miao, Q., Zuyi, L.Y., 2000, “Theoretical analysis of the influence of different microstructure on Barkhausen noise”, Proceedings of the 15th World Conference on Nondestructive Testing, Roma.

Marinescu, I. D., Hitchiner, M., Uhlmann, E., Rowe, W. B., Inasaki, I., 2006, “Handbook of Machining with Grinding Wheels”, Ed. CRC Press, Taylor & Francis, Boca Raton, New York, 596 p.

Reichenbach, M., 1999, “Schleifbrandprüfung an Zahnrädern als Service der Härterei”, Anttriebstechnik 38, No. 12.

Silva, S., Mansur, T., 2000, “Determining residual stresses in Ferromagnetic materials by Barkhausen noise measurement”, Proceedings of 15th World Conference on Nondestructive Testing, Roma.

Tönshoff, H.-K., Westkämper, E., 1997, “Jahrbuch schleifen, Honen, Läppen und Polieren Verfahren und Maschinen”, Ed. Vulkan - Verlag Essen, Germany, 685 p.

Uhlmann, E., Stark, C. 1997, “Potentiale von Schleifwerkzeugen mit mikrokristalliner Aluminiumoxidkörnung” Jahrbuch Schleifen, Honen, Läppen und Polieren Verfahren und Maschinen, Band 58, Essen, Vulcan, pp. 281 - 309.

Wojtas, A.S, Suominen, L.; Shaw, B.A, Evans, J.T., 1998, “Detection of Thermal Damage IN Steel Components After Grinding Using the Magnetic Barkhausen Noise Method”, The Open Access NDT Database. 27 Jan. 2011 < http://www.ndt.net/>.

Ting, M. L., Wah, H., Wong, S., 2006, “Inspection of Aircraft Landing Geat Componentes by Barkhausen Noise Measurement”, NCATMC - New Challenges in Aerospace Technology & Maintenance Conference, Singapore.

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