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GRINDIG OF NI-BASED ALLOYS WITH GRINDING WHEELS OF HIGH POROSITY

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Abstract:
This paper deals with application of Vortex grinding wheel in surface grinding of nickel alloy EI 698VD. There is strong adhesion of machined material when grinding this material. Vortex grinding wheels are progressive wheels of very high porosity. Vortex special technology enables to produce grinding wheels with porosity from 17 to 29. There is the next significant phenomenon of Vortex porosity. It is uniformity of pores in the wheel. These wheels enable reduce adhesion when grinding nickel alloys. The paper presents comparison of conventional wheel with Vortex wheel through the measurement grinding forces, temperature in the cutting zone, wheel wear and surface quality. Application of Vortex grinding wheel enables to reach more stable cutting process, with lower heat load of ground surface together with higher *G* ratios and more suitable residual stresses under the ground surface in comparison with conventional wheels.

Key Words: Stability, G ratio, Temperature, Residual Stresses, Adhesion

1. INTRODUCTION

Nickel and its alloys are attractive materials due to their unique high strength that is maintained at elevated temperatures and their exceptional corrosion resistance. Nickel alloys are classified as difficult-to-machine materials. Machined parts made of nickel alloys are usually exposed to fatigue load because the major application of nickel has been in the aerospace and chemical industry. Gentle machining operations usually result in a high cyclic fatigue strength that is much higher (up to nearly 5 times) than that of the corresponding abusive cutting conditions. The surface of nickel alloys is easily damaged during machining operations, especially during grinding [1, 2]. Even properly processed grinding practice using conventional parameters result in appreciably lower fatigue strength due to surface damage.

There is a strong adhesion of nickel alloy on grinding wheel during the grinding process. Intensity of this adhesion correlates with such aspects of grinding process as grinding forces, temperature, tool wear and quality of ground surface. The high intensity of adhesion causes low G ratios high tensile stresses and low accuracy of ground parts because of unstable process [1]. The damage of a workpiece when grinding is usually thermally induced and comes not just from the heat generated in the cutting zone, but also by the temperature on the surface of a ground part, its gradient and Rw coefficient – partition ratio (the ratio of the heat entering the workpiece to the total heat). Residual tensile stresses, which are primarily thermal may be unacceptable.

Investigation has found that preferred compressive stresses are more likely to be achieved with CBN and diamond grinding wheels. Results of investigations indicate an advantage of CBN and diamond grinding is a smaller proportion of the energy entering the workpiece. On the other hand, these wheels are very expensive and so their economy effectiveness could be low (low *G* ratios in comparison with grinding conventional hardened steels [3]).

Application of conventional wheels is conditioned with application of wheels of high porosity and grinding grain dimensions. Maximum porosity of conventional wheels is 13 and grinding wheels of higher porosity (16) are relatively new product for special application as grinding difficult-to-grind materials (titanium and nickel alloys, austenite stainless steels, soft steels). Higher porosity (than 16) is limited because of decreasing strength of grinding wheels and risk of grinding wheel destruction during the grinding process [4].

Production of grinding wheels with higher porosity (more than 16) is conditioned by special kind of bond and special process of porosity generation. NORTON company produces special product named Vortex. This product is primary applied for creep-feed grinding. Porosity of Vortex grinding wheel is in the range 17 to 29 (Figures 1 and 2). The next, porosity of this grinding wheels homogenous that that for conventional products. This paper deals with analysis of cutting abilities of Vortex grinding wheel in comparison with conventional products. The comparison id carried out through measurement grinding forces, temperatures in the contact of grinding wheel and workpiece, measurement of G ratios, residual stresses and surface roughness.

2. EXPERIMENTAL PART

Experiments were carried out on the heat–proof nickel alloy EI 698 VD (similar to Nimonic 90). Chemical composition of this material is in Table I. Mechanical properties: Rm = 1100 MPa at 500 °C, Rm= 1050 MPa at 700 °C, Rm= 700 MPa at 800 °C, Rp = 720 MPa at 500 °C, A = 26 % at 500 °C, Z = 35% at 500 °C, 363 HB, workpieces 50x25x10 mm.

Table I: Chemical Composition of Ni Alloy EI 698 VD.

element	Fe	S	P	Nb	Ni	C	Si	Cr	Ti	Mo
content (%)	max. 2	max. 0,007	max. 0,015	1,9 ÷2,2	rest	max. 0,03	max. 0,5	13 ÷16	2,35 ÷2,75	2,8 ÷3,2

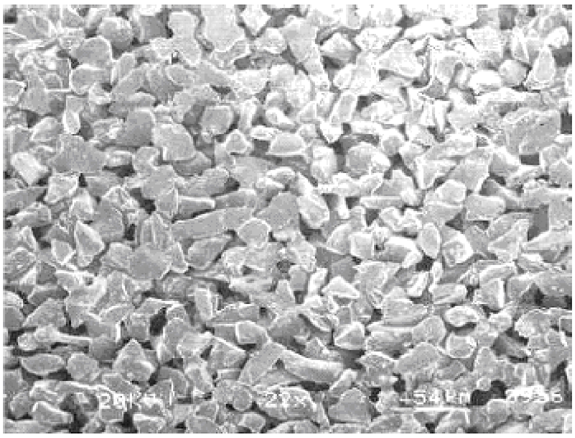

Figure 1: Conventional wheel grains 48%, bond 17%, porosity 35% [5].

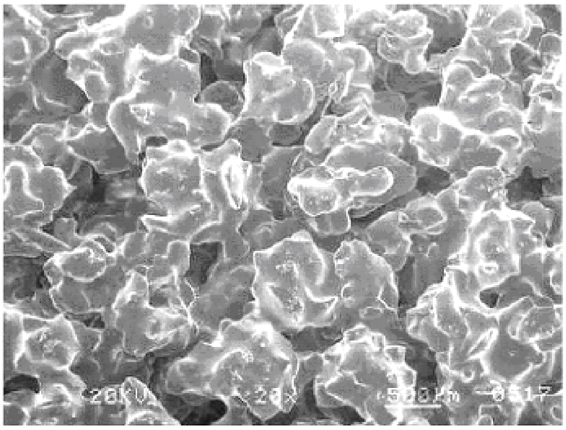

Figure 2: Vortex grinding wheel grains 30%, bond 17%, porosity 53% [5].

Grinding wheels: 01 250x20x76 A99 60 J9V, 01 250x20x76 A99 60 J16V, Vortex 01 250x20x76 60 J17 V

Cutting conditions:

- - surface plunge grinding (machine BPH20).
- - cutting fluid Emulzín H (2% concentration),
- - single crystal diamond dresser (a_d = 10 μm, f_d = 40 μm)

a_p = 0,01 - 0,04 mm, v_c = 34 m.s^{-1}, v_f = 4 m.min^{-1},

The measurement of F_c and F_p was made with a piezoelectric KISTLER dynamometer together with the measurement of temperature. The temperature was measured by the thermocouple technique introduced by Peklenik [6] (both quantities measured through an A/D card to a PC).

A personal computer collects information from the dynamometer in the predetermined points of the grinding cycle. Analysis of collected information was carried out in the software DasyLab 3.5. Surface topography was analyzed through its *Ra* value (applied device Mitutoyo 301). Mechanical method was applied for measurement residual stresses.

3. RESULTS OF EXPERIMENTS

Grinding forces, temperatures and *Ra* values were measured at regular intervals in relation to material removal V_w' This way the long term interaction between grinding wheel and workpiece were monitored in relation to the grinding wheel (respective grinding grains) wear. Typical records of grinding forces are illustrated on Figures 3, 4 and 5.

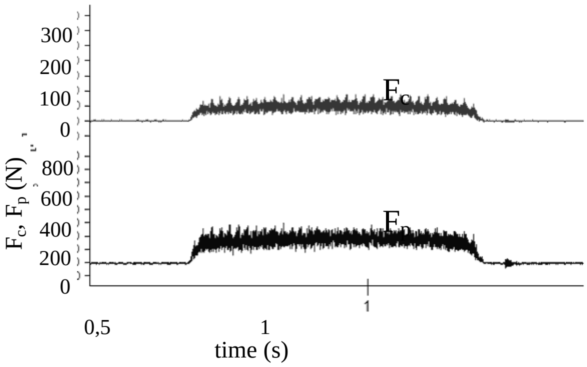

Figure 3: Record of grinding forces for ap = 0,03 mm, Vw' = 10 mm3.mm-1, A99 60 J9VS.

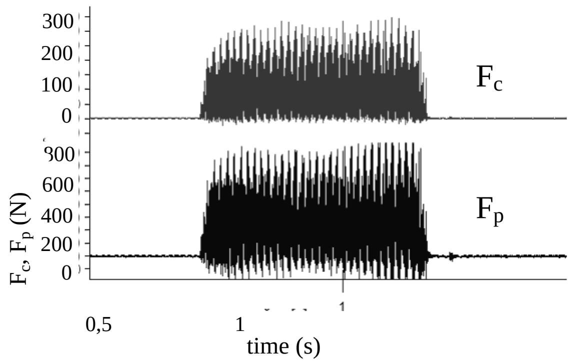

Figure 4: Record of grinding forces for ap = 0,03 mm, Vw' = 51 mm3.mm-1, A99 60 J9VS.

The record in Figure 3 represents the stage of a redressed grinding wheel. The following records represent the stage of a worn grinding wheel. There is a visible difference in the amplitude of vibration among the conventional and Vortex wheels. The negative values in Figure 4 are caused by persistence of grinding system.

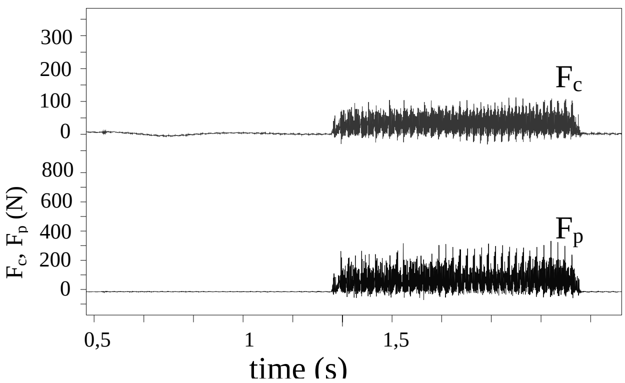

Figure 5: Record of grinding forces for ap = 0,03 mm, Vw' = 51 mm3.mm-1, Vortex 60 J 17V.

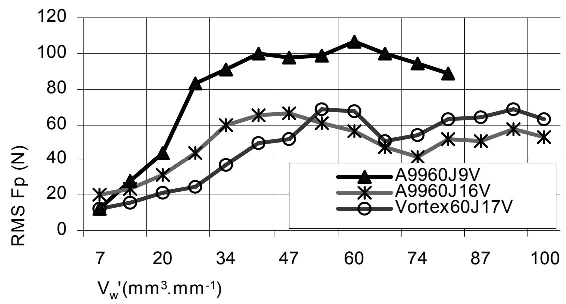

Figure 6: Comparison of RMS values of Fp (ap = 0,03 mm).

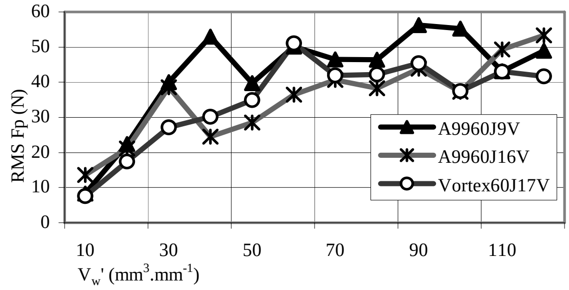

Figure 7: Comparison of RMS values of Fp (ap = 0,01 mm).

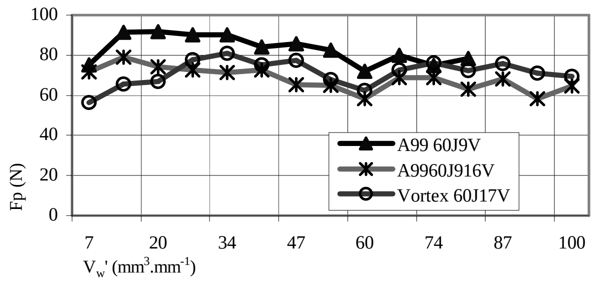

Figure 8: Comparison of static values of Fp (ap = 0,03 mm).

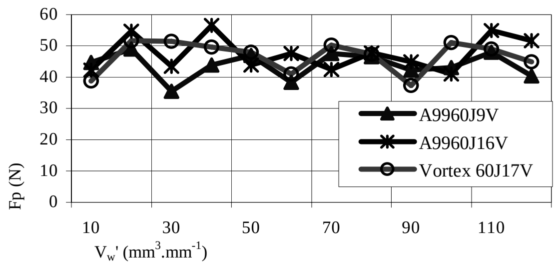

Figure 9: Comparison of static values of Fp (ap = 0,01 mm).

Grinding forces were analyzed as the static and the dynamic components [4]. The static value represents the average value of grinding force during the contact between wheel and workpiece. The dynamic component is related to the oscillation of force. Decomposition of grinding forces was realized through the filtration of the original signals. The static component represents harmonic components up to frequency 10Hz. The dynamic component represents the harmonic components in the frequency range 10 Hz ÷ 5 kHz. The dynamic components of grinding forces were analyzed though the RMS values (the RMS value is the most relevant measure of amplitude because it both takes the time history of the wave into account and gives an amplitude value which is directly related to the energy content, and therefore the destructive abilities of the vibration). From the results in Figures 6 and 7 it can be seen that the RMS values progressively increase the same way with the continued grinding for all wheels.

Figure 7 illustrates that there is no significant difference in the RMS values among the grinding wheels under the low cutting depth. On the other hand, there is a significant difference under the higher cutting depth. When compared with the conventional wheel (Figure 6) RMS values for the conventional wheel of porosity 16 and Vortex wheel are significantly lower that that for conventional wheel of porosity 9. Figure 9 illustrates that there is no such significant difference in the static values among the grinding wheels. Moreover, experiments with application of conventional wheel of porosity 9 had to be stopped at $V_w^{'}$ = 85 $mm^3.mm^{-1}$ because of the ground surface burn. Cutting abilities of conventional wheel of porosity 9 is insufficient under the higher material removal rates.

Application of grinding wheel of high porosity eliminates adhesion of machined material on the grinding wheel and so reduces the area of active contact between wheel and workpiece. On the other hand, application of grinding wheel of higher porosity decreases *G* ratios. This aspect is related to the lower number of grinding grains in the contact between wheel and workpiece and so their higher mechanical and thermal load. On the other hand, *G* ratios are higher for Vortex wheel despite of the higher porosity (Figure 10). This aspect is given by the special character of porosity of Vortex wheel (very homogenous distribution of porosity in the wheel).

Temperature in the contact between wheel and workpiece is increasing with Vẃ (Figures 11, 12, 13 and 14) because of increasing intensity of adhesion. The higher temperatures were obtained with application conventional wheel of porosity 9 in comparison with the wheel of high porosity. The temperature on the surface (Figures 11, 12, 13 and 14) was obtained by putting a smooth curve through the measured trace. Temperature in the contact is about 450 °C after dressing for Vortex wheel (ap = 0,03 mm) and increases with Vẃ on 700 °C. Temperature in the contact is about 600 °C after dressing for conventional wheel of porosity 9 (ap = 0,03 mm) and increases with Vẃ on 950 °C. Temperature in the contact between grinding wheel and workpiece is important from the point of view of thermally induced parameter of ground surface as for example residual stresses.

Figures 15 and 16 illustrate the state of residual stresses after grinding with the conventional wheel of porosity 9 and the Vortex wheel. Fig. 16 illustrates that application the Vortex wheel enable to obtain the compressive residual stresses near the ground surface on the contrary to tensile stresses obtained with application of the conventional wheel.

Figure 18 illustrates that there is no significant difference in the *Ra* values of ground surface under the low cutting depth. On the other hand, the differences are increasing under the higher cutting depth and with increasing V_w'. Conventional wheel of porosity 9 gives the better values of *Ra* at a_p = 0,01 mm (Fig. 18). On the other hand, *Ra* values are the lower for Vortex wheel under the higher cutting depths and increasing V_w'. Moreover, variability of values of repeated measurements is much lower (Fig. 19 and 20). The lower values of *Ra* respectively lower variability for Vortex wheel under the higher cutting depths is given lower intensity of adhesion and so more stable cutting process.

The difference in the topography of ground surface illustrates photographs in Figures 21 and 22. There is a visible redeposition of ground material on the machined surface at application conventional wheel of porosity 9. This redeposition indicates the strong adhesion of ground material on the wheel and the high temperature in the contact of grinding wheel and workpiece. The ground surface is without visible redeposition when application Vortex wheel (Figure 21) or conventional wheel of porosity 16. Adhesion of ground material on the grinding wheel surface changes the geometry of the grinding grain and negatively influences process of material removal. More over, there is a more intensive side flow of grinding grain by the ground material. All these aspects negatively influence surface topography and so the *Ra* values too.

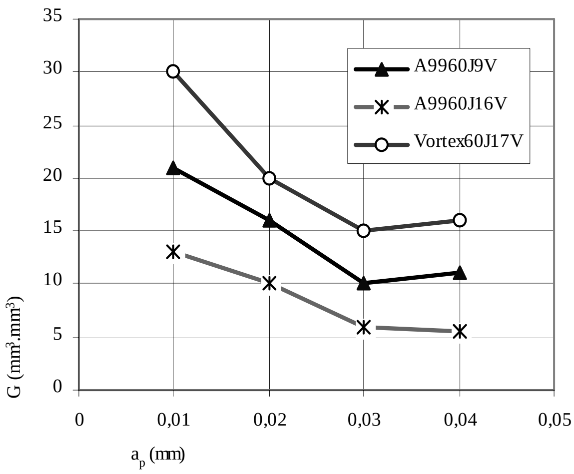

Figure 10: Comparison of G ratios.

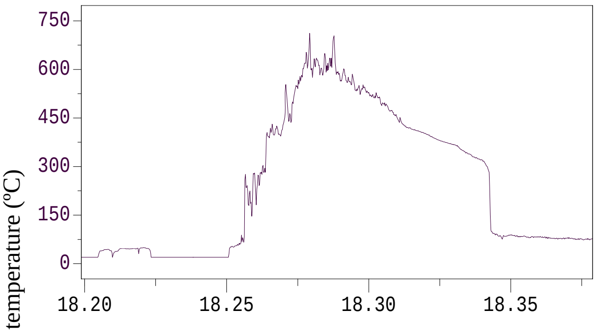

Figure 11: Record of temperature, A9960J9V, ap = 0,03 mm, after dressing.

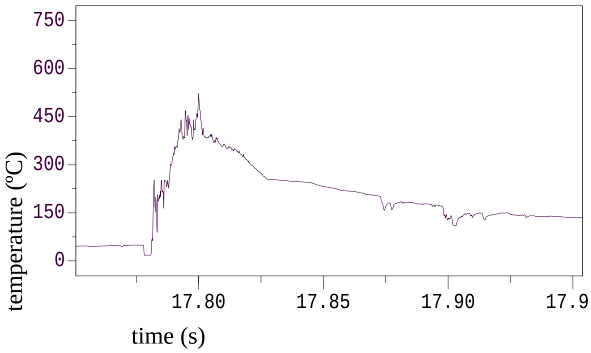

Figure 12: Record of temperature, Vortex, ap = 0,03 mm, after dressing.

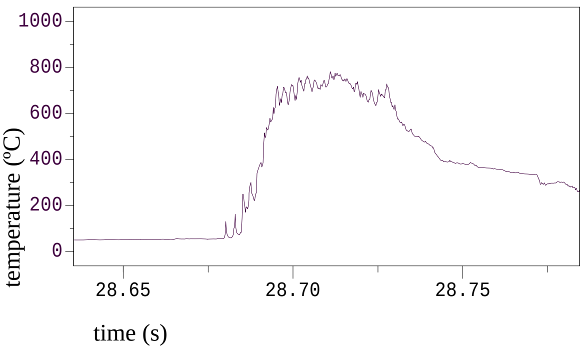

Figure 13: Record of temperature,

Vortex, a_p = 0,03 mm,

V_w' = 51 mm^3.mm^{-1}.

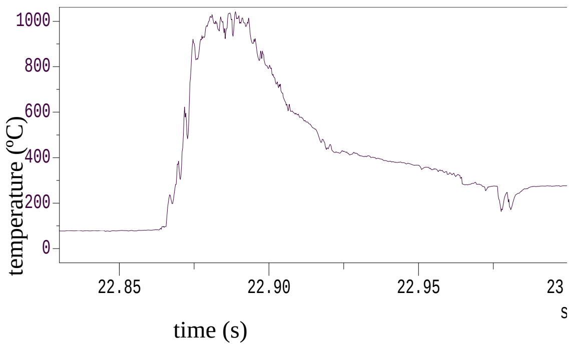

Figure 14: Record of temperature,

A9960J9V, a_p = 0,03 mm,

V_w' = 51 mm^3.mm^{-1}.

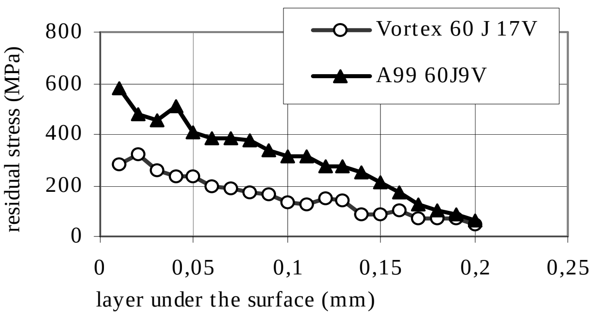

Figure 15: Residual stresses after

dressing

a_p = 0,03 mm.

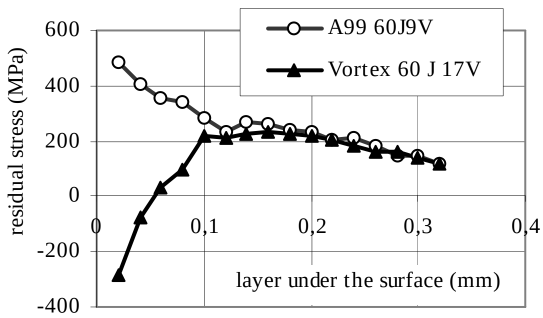

Figure 16: Residual stresses for

V_w' = 34 mm3.mm-1, a_p = 0,03 mm.

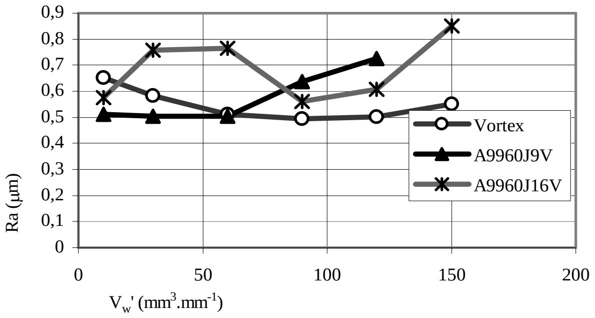

Figure 17: Comparison of R_a for a_p = 0,04mm.

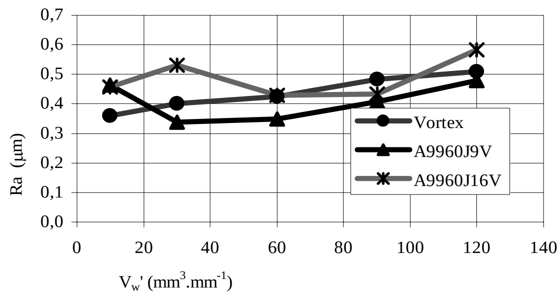

Figure 18: Comparison of R_a for a_p = 0,01mm.

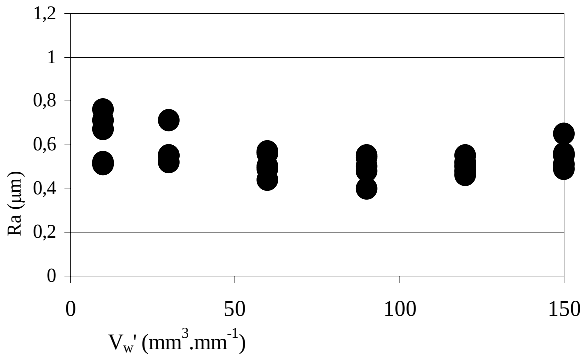

Figure 19: Variability of *Ra* for Vortex a_p = 0,04mm.

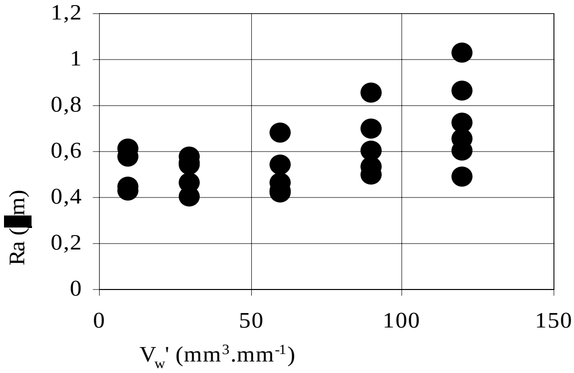

Figure 20: Variability of *Ra* for A9960J9V, a_p = 0,04mm.

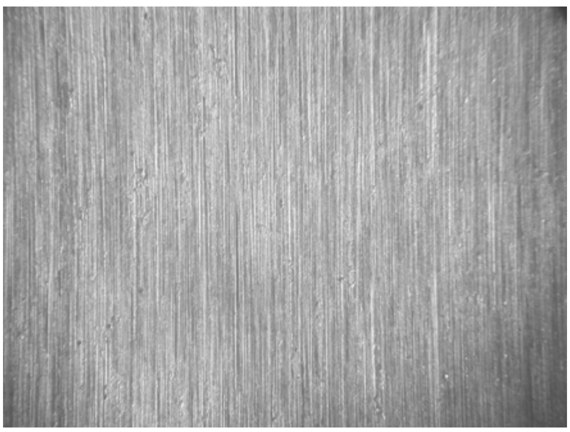

Figure 21: Photo of ground surface for Vortex, V_w'= 74 $mm^3.mm^{-1}$, a_p = 0,03 mm, (real dimensions 2x3 mm).

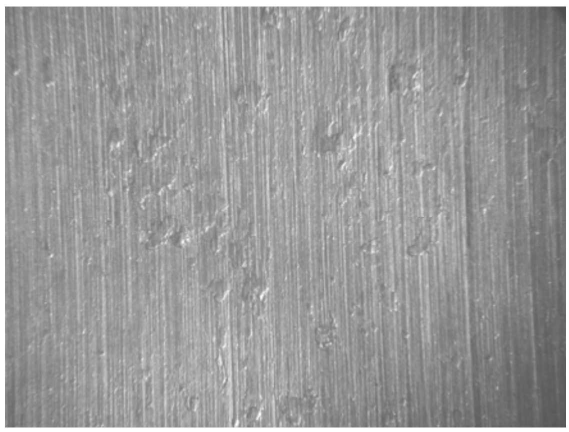

Figure 22: Photo of ground surface for A9960J9V, V_w'= 74 $mm^3.mm^{-1}$, a_p = 0,03 mm, (real dimensions 2x3 mm).

4. CONCLUSION

Results of the mentioned experiments show that application of grinding wheels of high porosity is suitable for grinding such materials as nickel alloys. The high porosity of grinding wheels enables to eliminate adhesion between wheel and workpiece and so gives the more stable grinding process. On the other hand, it is visible that the significant role takes the character of porosity and properties of bond. All these aspects influence the accuracy of ground parts and quality of ground surfaces. The next research could be focused on application of Vortex grinding wheels with higher porosity (20, 26 and 29) than that applied in this research (17).

REFERENCES

[1] Neslušan, M; Czán, A. (2001). Machining of Titanium and Nickel Alloys, EDIS Žilina
[2] Peng, X.L; Niewelt, W; Ősterle, W. (1994). Microstructural Changes Induced by Grinding of Ni-base Superalloy IN 738 LC and their Relationship to Machining Parameters, Zeitschrift für Metallkunde, Vol. 85, p. 20-28
[3] Lipták, J; Mihalčák, P; Panoch, J; Radošínska, K. (1984) Research of Grinding and Application of Ultrasound for Machining Ni and Ti Alloys. Research report n.18/83-30/60, Bratislava
[4] Vasilko, K; Bokučava, G. (1998). Grinding of Metal Materials, ALFA Bratislava
[5] Saint Gobain presentation at conference Strojárska technológia 2004, 29. – 30.9. 2004, Súľov
[6] Peklenik, J. (1957). Ermittlung von geometrischen and physicalischen Kenngrossen fur die Grundlagenforschung des schleifens, PhD. Thesis, Aachen