

# APPLICATION OF THE LURIE INDICATOR TO THE EVALUATION OF THE ABRASIVE CAPABILITIES OF GRINDING WHEELS MADE OF SUBMICROCRYSTALLINE SINTERED CORUNDUM, WITH VARIOUS ABRADANT COMPOSITIONS

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## Summary

This paper presents the results of experimental studies on the correlation between the abrasant composition and the abrasive capabilities of grinding wheels made of submicrocrystalline sintered corundum during finishing grinding of the surfaces of samples made of corrosion-resistant steel. The abrasive capabilities of grinding wheels were determined in accordance with the classical and modified Lurie complex criterion. It was proved that the machining capabilities of the tested grinding wheels are increasing with the power dependence, together with the increase of the volumetric share of the submicrocrystalline sintered corundum in the abrasant's volume.

**Keywords:** surface grinding, abrasive capabilities of grinding wheels, abrasant chemical composition

## Zastosowanie wskaźnika Lurie do oceny zdolności ściernych ściernic z submikrokryształicznego korundu spiekane go o różnym składzie chemicznym ścierniwa

## Streszczenie

W pracy przedstawiono analizę wyników badań doświadczalnych wpływu składu ścierniwa na zdolności ściernic z submikrokryształicznego korundu spiekane go. Prowadzono wykończeniowe, czołowe szlifowanie płaszczyzn próbek wykonanych ze stali odpornej na korozję. Zdolności ściernic ściernic określano według klasycznego i zmodyfikowanego kryterium zespolonego Lurie. Wykazano, że zdolności skrawne badanych ściernic zwiększają się według zależności potęgowej wraz ze wzrostem objętości względnej submikrokryształicznego korundu spiekane go w ścierniwie ściernicy.

**Słowa kluczowe:** szlifowanie czołowe, zdolność ścierna ściernicy, skład chemiczny ścierniwa

## 1. Introduction

Present-day abrasive wheels made of submicrocrystalline sintered corundum are mostly made of mixed abrasants, containing noble

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electrocorundum and submicrocrystalline sintered corundum in various mutual volumetric proportions. Those proportions are reflected in the abrasant markings. For example 3SG means that only 30% of the total abrasant volume is filled by submicrocrystalline sintered corundum SG, while the remaining volume contains white noble electrocorundum 99A. Similarly, abrasant 5TGP means that the material is composed in half of a special variety of submicrocrystalline sintered corundum TG, and in half of pink noble alloy chrome electrocorundum CrA. Such abrasive wheels are mostly made of ceramic binders, and recently with glass-crystalline ones. It is a production and commercial curiosity that the market offers only such a range of abrasive wheels made of submicrocrystalline sintered corundum which represent odd markings of the abrasant composition, or 1SG, 3SG, 5SG, 7SG and 9SG. According to the recommendations relating to the selection of the abrasant composition for the abrasive wheels made of submicrocrystalline sintered corundum, specified by the manufacturers, the following rule applies: "The higher hardness of the top layer of the workpiece the longer machining path with one abrasive grain; the higher main drive engine power, and the higher grinding depth, and the higher relative grinding effectiveness (G-ratio) to be obtained, and the higher CPS durability of grinding wheels the higher the proportion of the submicrocrystalline sintered corundum should be applied in the abrasant volume."

The principle quoted above suggests linear or monotonous dependences between the selected values and the indicators that describe the grinding process, in respect to the change of the composition of abrasants made of submicrocrystalline sintered corundum. However, in case of complex technical systems, which include the grinding processes, linear relationships hardly occur. That conclusion is definitely confirmed by industrial experiences from which we can infer that the principle of selecting the abrasant composition quoted above may only be a general indication in industrial conditions. The grindability of a grinding wheel consists not only of the capability to separate specific quantities of material per time unit in specific grinding conditions, but also the capability to maintain concurrently the quality properties of the surface, with possibly lowest expenditures [1-4]. The grindability of a grinding wheel obviously depends on such groups of factors as grinding parameters, CPS conditioning parameters, workpiece material properties, grinder rigidity, selected grinding cycle, and the grinding wheel characteristics. In the operating conditions of the grinding wheels made of submicrocrystalline sintered corundum, we are dealing with the synergy phenomenon when the abrasive grain blades of hard noble electrocorundum, with slightly softer submicrocrystalline sintered corundum, act on the surface being machined. The former grains are worn out in the finishing grinding conditions mainly by blunting, while the latter ones display the capability of self-sharpening. In that situation, they differ not only in abrasive potential, but also in diverse capability of adhesion of the material being machined to the grain surface. Therefore, we

should expect that properly understood grindability of grinding wheels made of submicrocrystalline sintered corundum will not increase linearly with the proportion of the submicro-crystalline sintered corundum in the wheel's abradant volume, especially in the finishing grinding conditions.

## 2. Experiment description

The experimental system of surface grinding, using a SIC- 330 CNC micro-grinder with a rectangle table, with the evaluation of the influence of the abradant composition on the grindability of grinding wheels made of submicrocrystalline sintered corundum and ceramic binder, is presented in Fig. 1.

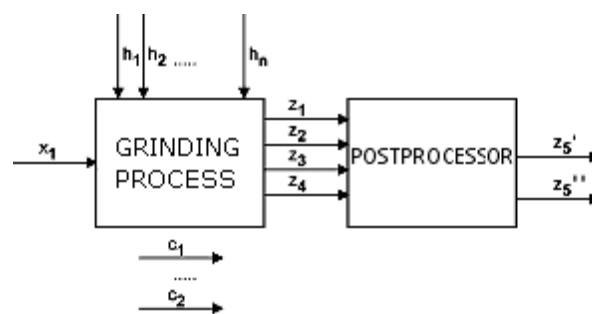


Fig.1. Diagram of experimental studies

Description of parameters:

X – input variables

$x_1$  – percentage proportion of submicrocrystalline sintered corundum in abradant (CB+99A),

Z – output variables

$z_1$  – volume of grinded material in time  $t = 20$  s –  $V_{gr}$ ,  $\text{mm}^3$ ,

$z_2$  – normal component of the grinding force  $F_p$ , N,

$z_3$  – tangential component of the grinding force  $F_v$ , N (for checking the application conditions of the Lurie criterion),

$z_4$  – average arithmetical deviation of the machined surface coordinates  $Sa$ ,  $\mu\text{m}$  (ISO 25178:2010),

$z_5'$  – grindability of the grinding wheel  $K_1$ ,  $1/\text{N}$ , calculated according to the classical complex Lurie indicator,

$z_5''$  – grindability of the grinding wheel  $K_2$ ,  $1/\text{N} \cdot \mu\text{m}$ , calculated according to the modified complex Lurie-Nizankowski indicator

$$K_1 = \frac{V_{mt}}{F_p} \quad (1)$$

$$K_2 = \frac{V_{mt}}{F_p \cdot Sa} \quad (2)$$

#### C – constant values

- c<sub>1</sub> – mini-grinder SIC 330 CNC manufactured by Knuth GmbH,
- c<sub>2</sub> – description of grinding wheels 5216 30 x 30 x 6 XX60L7V, where XX are variables according to x<sub>1</sub>,
- c<sub>3</sub> – grinding parameters:  
velocity  $v_s = 28.3$  m/s,  
feed-in  $a_e = 0.002$  mm,  
longitudinal feed velocity  $v_f = 1$  m/min,
- c<sub>4</sub> – grinding method: finishing, surface, longitudinal grinding of surfaces, using a grinder with a rectangle table,
- c<sub>5</sub> – machining medium, dry grinding,
- c<sub>6</sub> – workpiece: X8CrNiTi 18-10 steel, resistant to corrosion, with the austenitic structure, in the form of prisms, with the 24 x 24 mm square base, finish milled ( $Ra = 2 \pm 0.1 \mu\text{m}$ ), with cylindrical-end cutter,
- c<sub>7</sub> – grinding cycle: standard, 3-phase, without sparking out,
- c<sub>8</sub> – dressing method: diamond system, using a M1020 dresser, with a 0.16 Kr diamond, dressing depth:  $a_d = 0.01$  mm and cover coefficient  $k = 3$ ,
- c<sub>9</sub> – output value measurement methods,

#### H – interfering values

- h<sub>1</sub> – dispersion of physical and mechanical grinding wheel's properties,
- h<sub>2</sub> – dispersion of physical and mechanical workpiece properties,
- h<sub>3</sub> – inaccuracy of assumed grinding, dressing and other parameters.

Experiments were conducted in accordance with a static, determined, complete PS/DK plan, treating the surface finishing grinding process as an elementary object. No replication was used. The following dependence was a function of the object of experiment: dependence  $K = f(XX)$ , where XX is an optional abrasant composition. Function approximation was made taking into account both power function and polynomials of the first and second degree, using MS Excel software. For particular functions, the values of multi-dimensional correlation  $R^2$  coefficients were calculated. Measurements of the height of the grinded sample were taken with a KOYONCE laser detector, with the accuracy of  $\pm 0.1 \mu\text{m}$ . Grinding force components were measured by a Kistler

piezoelectric force gauge. Workpiece surface coarseness was measured with a Taylor Hobson Talysurf Form-50 profilograph. The pictures of the SIC 330 mini-grinder, grinding zone, force gauge, monitor recoding of the grinding force components, profilograph, grinding wheels, and workpiece are presented in Fig. 2-7.



Fig. 2. SIC- 330 CNC mini-grinder – general view

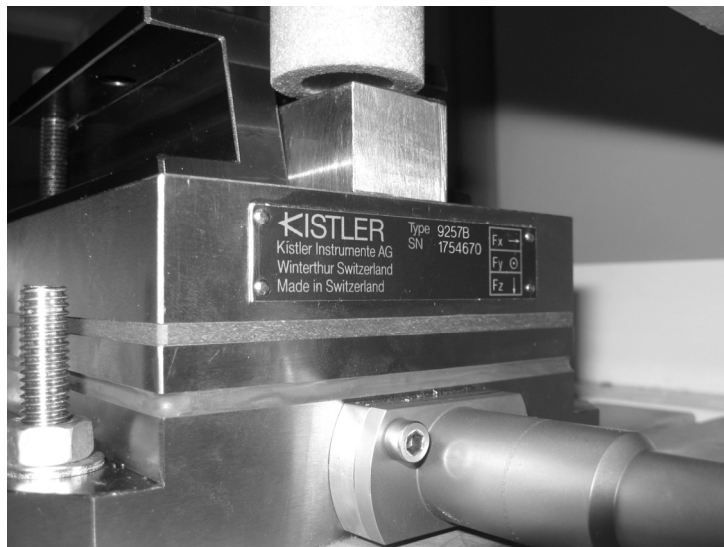


Fig. 3. Grinding zone and workpiece mounting method in the force gauge

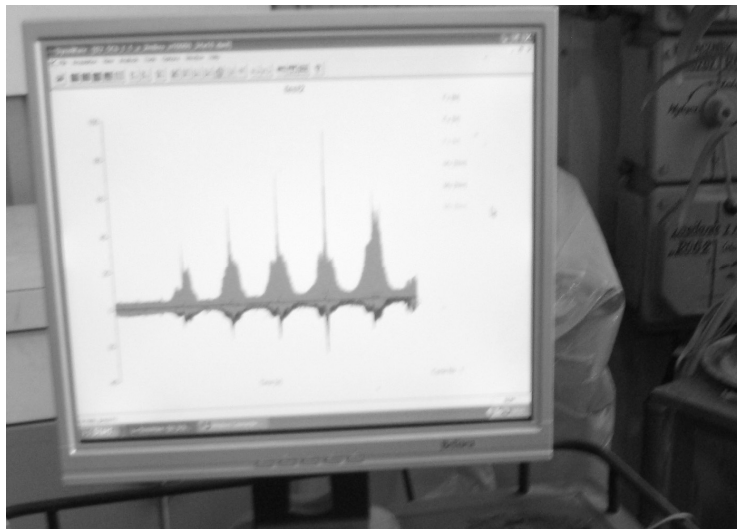


Fig. 4. Display of the monitor recording the force components and grinding moment

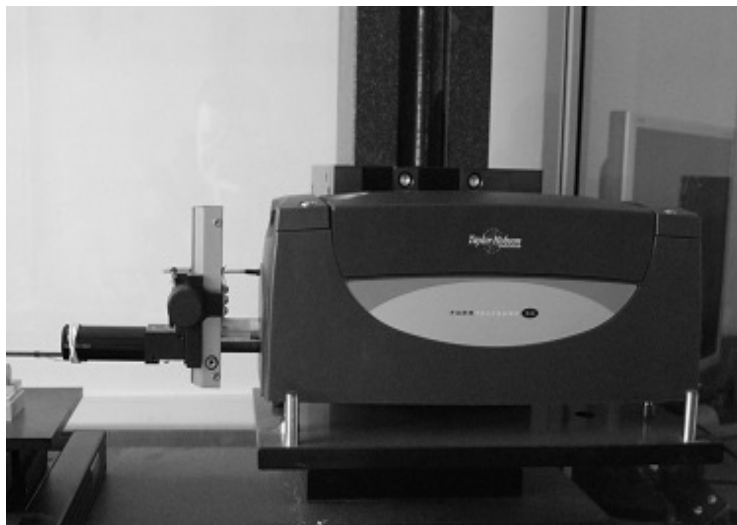


Fig. 5. TALYSURF FORM-50 profilograph

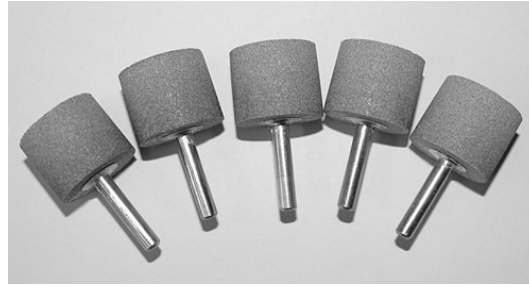


Fig. 6. Grinding wheels used in tests

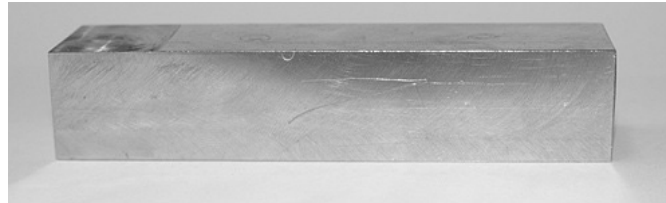


Fig. 7. Sample shape with surface after grinding

### 3. Results and analysis

The results of the experiments on the grindability of grinding wheels made of submicrocrystalline sintered corundum and with diverse abrasant composition are listed in Table 1. The grindability values presented in Table 1 are represented graphically in Fig. 8 and 9, with abrasant composition, connecting the measurement points by the spline method. In addition, the figure shows the approximating function graphs, with their analytical forms, and the values of  $R^2$  coefficients.

Table. 1. Results of the measurements of selected physical properties and grinding wheels' grindability calculations

Abrasant composition	Drawn sample number	Volume $V_{m^3}$ , $\text{mm}^3$	Force $F_v$ , N	Force $F_p$ , N	Parameter $S_a$ , $\mu\text{m}$	Coefficient $K_1$ , $\frac{\text{mm}^3}{\text{N}}$	Coefficient $K_2$ , $\frac{\text{mm}^3}{\text{N} \cdot \mu\text{m}}$
1CB	4	0.720	0.23613	40	1.75	0.0180	0.0103
3CB	5	0.720	0.23619	46	0.0546	0.0157	0.0285
5CB	2	0.720	0.1575	15	1.06	0.0480	0.0453
7CB	6	0.720	0.0797	18	0.878	0.0400	0.0455
9CB	7	0.720	0.0796	16	0.608	0.0450	0.0738

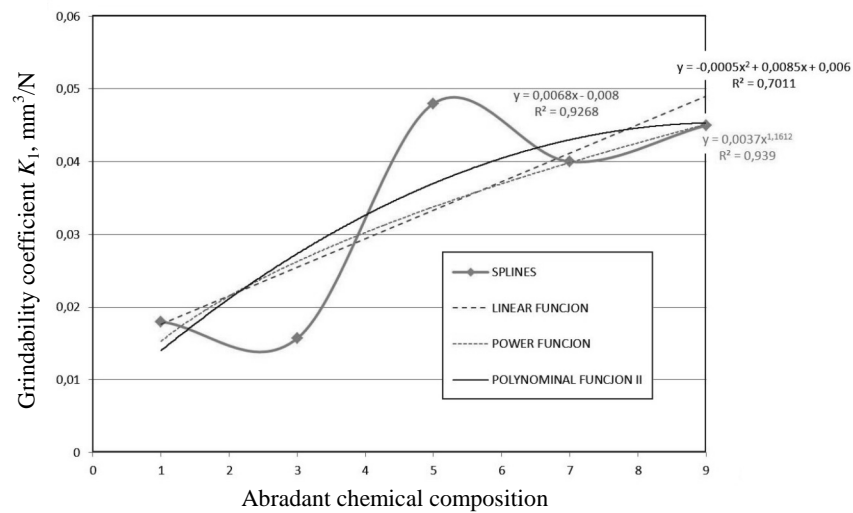


Fig. 8. The functions approximating the results of testing the grindability of wheels made of submicrocrystalline sintered corundum, determined according to the coefficient  $K_1$

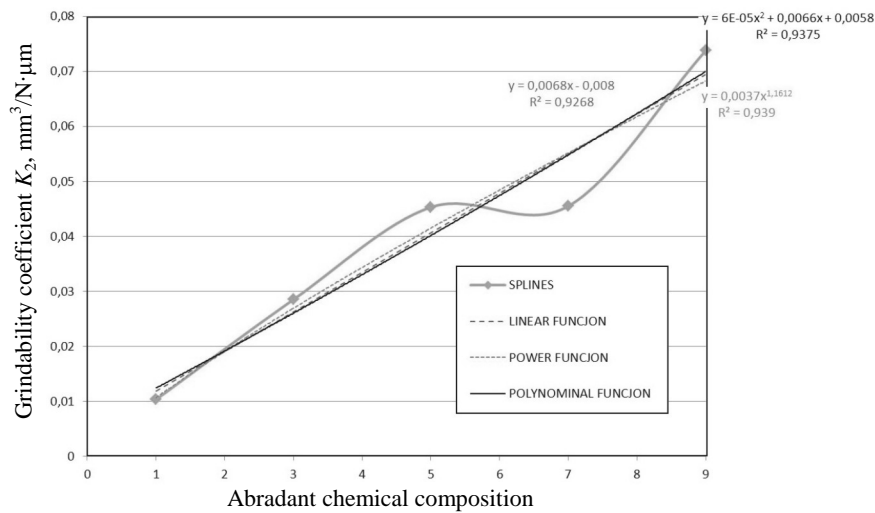
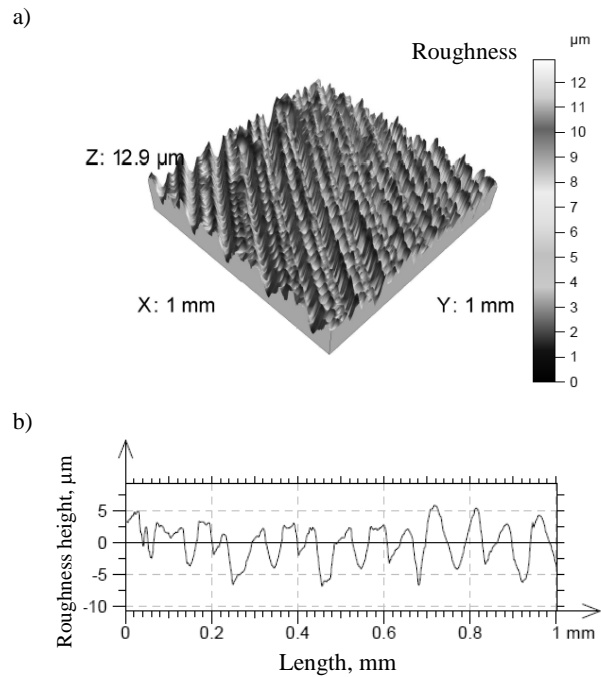


Fig. 9. The functions approximating the results of testing the grindability of wheels made of submicrocrystalline sintered corundum, determined according to the coefficient  $K_2$

Figures 10 and 11 show a comparison of the change of the geometric structure of the surface layers of the workpieces made of corrosion-resistant



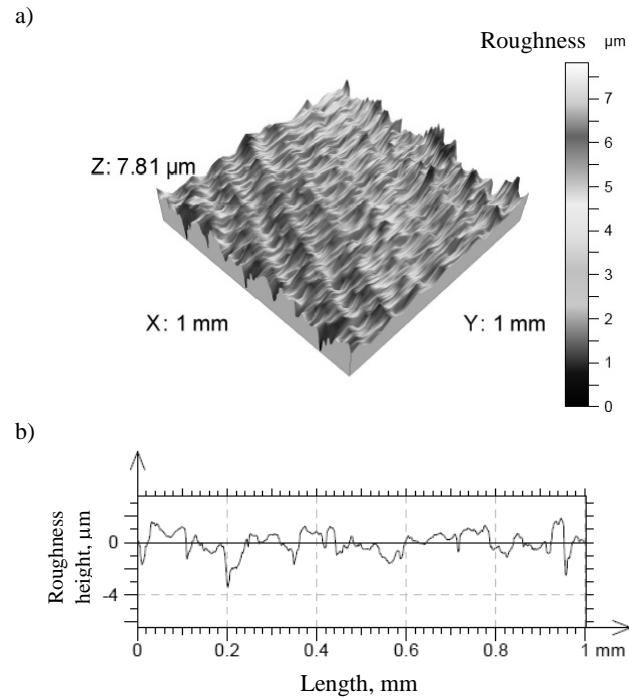
steel, grinded with the 1CB (Figs. 10a and 10b) and 9CB (Figs. 11a and 11b) abrasant wheels. In addition, Fig. 12 presents a sample filtered record of grinding forces and moments for 5CB abrasant grinding process.



ISO 4287		
AMPLITUDE PARAMETERS PROFILE		
<b>Rp</b>	5.89	$\mu\text{m}$
<b>Rv</b>	6.85	$\mu\text{m}$
<b>Rz</b>	12.7	$\mu\text{m}$
<b>Rc</b>	7.47	$\mu\text{m}$
<b>Rt</b>	12.7	$\mu\text{m}$
<b>Ra</b>	2.47	$\mu\text{m}$
<b>Rq</b>	2.94	$\mu\text{m}$
<b>Rsk</b>	-0.332	
<b>Rku</b>	2.32	

ISO 25178		
HEIGH PARAMETERS		
<b>Sq</b>	2.18	$\mu\text{m}$
<b>Ssk</b>	-0.334	
<b>Sku</b>	2.66	
<b>Sp</b>	6.03	$\mu\text{m}$
<b>Sv</b>	6.87	$\mu\text{m}$
<b>Sz</b>	12.9	$\mu\text{m}$
<b>Sa</b>	1.75	$\mu\text{m}$
FUNCJON PARAMETERS (GENERAL)		
<b>Smr</b>	0.259	%
<b>Smc</b>	3.39	$\mu\text{m}$
<b>Sxp</b>	4.74	$\mu\text{m}$

Fig. 10. Surface coarseness after grinding, using 1CB abrasant, in a 3D system (levelled profiles) (a) and the profile and the grinded surface coarseness measurement results, using 1CB abrasant, in a 2D system (b)



ISO 4287		
AMPLITUDE PARAMETERS PROFILE		
<b>Rp</b>	1.86	$\mu\text{m}$
<b>Rv</b>	3.42	$\mu\text{m}$
<b>Rz</b>	5.28	$\mu\text{m}$
<b>Rc</b>	2.2	$\mu\text{m}$
<b>Rt</b>	5.28	$\mu\text{m}$
<b>Ra</b>	0.66	$\mu\text{m}$
<b>Rq</b>	0.834	$\mu\text{m}$
<b>Rsk</b>	-0.593	
<b>Rku</b>	3.77	

ISO 25178		
HEIGH PARAMETERS		
<b>Sq</b>	0.799	$\mu\text{m}$
<b>Ssk</b>	-0.129	
<b>Sku</b>	4.65	
<b>Sp</b>	3.73	$\mu\text{m}$
<b>Sv</b>	4.08	$\mu\text{m}$
<b>Sz</b>	7.81	$\mu\text{m}$
<b>Sa</b>	0.608	$\mu\text{m}$

Fig. 11. Surface coarseness after grinding, using 9CB abrasant, in a 3D system (levelled profiles) (a) and the profile and the grinded surface coarseness measurement results, using 9CB abrasant, in a 2D system (b)

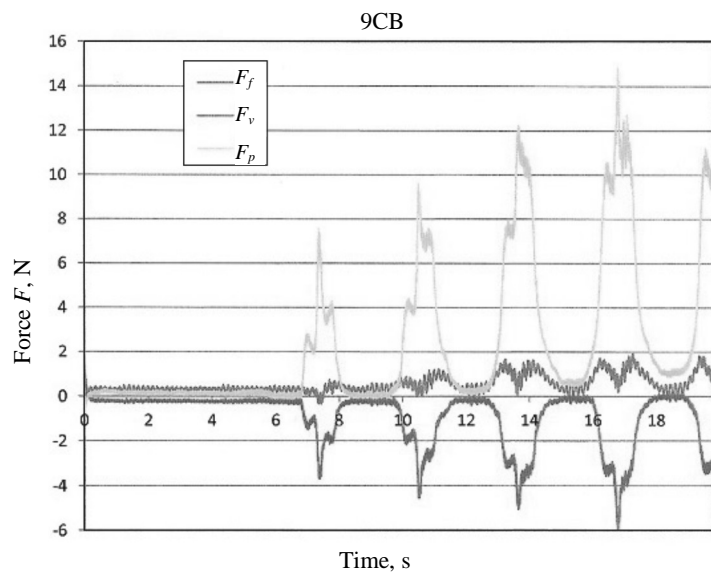


Fig. 12. Selected changes of grinding force components and of the component moments acting on the sample, in the grinding time function

#### 4. Conclusion

The analysis of the results of experimental studies on the influence of the abrasant composition on the abrasive capabilities of grinding wheels made of submicrocrystalline sintered corundum during finishing grinding of sample made of corrosion-resistant steel allows us to conclude as follows:

- For all abrasant compositions, the tangential force components  $F_v$  have the values which are significantly lower than the normal force components  $F_p$ .
- Together with the increase of the proportional share of submicrocrystalline sintered corundum in the abrasant volume, the grindability is increasing as a result of the reduction of the normal grinding force and of the grinded surface coarseness.
- The increase of grindability determined according to the coefficient  $K_1$ , together with the increase of the proportional share of submicrocrystalline sintered corundum in the abrasant volume, occurs according to the following power dependence:

$$K_1 = 0.0037x^{1.1612} \quad (3)$$

with the multi-dimensional correlation coefficient of  $R^2 \approx 0.94$ .

• The increase of grindability determined according to the coefficient  $K_2$ , together with the increase of the proportional share of submicrocrystalline sintered corundum in the abrasant volume, occurs according to the following power dependence:

$$K_2 = 0.0106x^{0.8471} \quad (4)$$

with the multi-dimensional correlation coefficient of  $R^2 \approx 0.98$ .

• The principle of abrasant composition selection, depending on the grinding conditions, applied in industry and quoted in the paper, is partly unfortunate, because the increase of the normal grinding force occurs only with the increase of the grinding parameters when we use a wheel with a specific abrasant composition and when the wheel is getting worn out. However, in case of constant grinding parameters, the normal grinding force of a specific abrasant composition is decreasing with the increase of the proportional share of submicrocrystalline sintered corundum in the abrasant volume.

### References

- [1] CZ. NIŻANKOWSKI: Wpływ struktury ścierniw z korundu spiekaneego na zdolność ścierną ściernic ze szklanokrystalicznym spoiwem ceramicznym. *Obróbka ścierna – współczesne problemy*, red. A. Barylski, Politechnika Gdańska, Gdańsk 2011, 81-90.
- [2] Instruction materials of Saint Gobain Abrasives.
- [3] Catalogues of Andre Abrasives Articles.
- [4] C. STARK: Potentials of abrasive tools with microcrystalline sintered aluminium oxide. *VDI-Z Integrierte Produktion*, Issue II/97, Düsseldorf 1997.

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