Albin Matavž[1], Jurij Krope[2], Darko Goričanec[2], Danijela Urbancl[2], Aleksandar Sedmak[3], Ivan Anžel[4]

EXTERNAL ATMOSPHERIC INFLUENCES ON THE MECHANICAL PROPERTIES OF RESIN-BONDED GRINDING WHEELS WITH ALUMINIUM OXIDE AND SILICON CARBIDE GRAINS

SPOLJNI ATMOSFERSKI UTICAJI NA MEHANIČKE OSOBINE SMOLNO VEZANIH BRUSNIH TOCILA SA ZRNIMA ALUMINIJUM OKSIDA I SILICIJUM KARBIDA

Originalni naučni rad / Original scientific paper
UDK /UDC:

Rad primljen / Paper received: 6.12.2020

Adresa autora / Author's address:
[1] MAMUT TIM, Ltd., Zreče, Slovenia
email: albin@mamut-tim.com
[2] University of Maribor, Faculty of Chemistry and Chemical Engineering, Maribor, Slovenia
[3] University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
[4] University of Maribor, Faculty of Mechanical Engineering, Maribor, Slovenia

Keywords
- resin-bonded grinding wheels
- mechanical properties
- ageing
- microstructure

Abstract

Ageing effects on resin-bonded grinding wheel properties are presented, including aluminium oxide and silicon carbide influence. Furthermore, humidity is examined as the most likely cause of significant downgrade in mechanical properties. Toward this aim a new system of accelerated ageing of grinding wheels (additional humidification) is used under special atmospheric conditions. The mechanisms for microstructural changes during ageing are analysed, based on the microstructure exposure to thermo-mechanical impacts.

INTRODUCTION

It is a well known fact that the quality of grinding and the cutting performance of grinding wheels with aluminium oxide or silicon carbide grains reduces during time, /1/, through the process called ageing.

Typically, this means that mechanical properties degrade over the period of two or three months from the date of production, especially because of atmospheric conditions (humidity), changing the microstructure.

Following activities have been carried out:

– samples taken from production are tested to evaluate the influence of humidity on mechanical properties;
– research of cutting abilities to evaluate effects of hygroscopic moisture from the atmosphere, pores and cracks in grinding wheels;
– cutting ability factors are identified and values determined;
– influence of ageing is determined on the rotational speed in disintegration of grinding wheels during ageing;
– microstructural analysis is performed and used to create the model of the course of ageing in the polymeric matrix of the grinding wheel.

Finally, the obtained data and findings are used to improve production procedures and structural integrity and life of resin-bonded grinding wheels.

Ključne reči
- brusna tocila vezana smolom
- mehaničke osobine
- starenje
- mikrostruktura

Izvod

U ovom radu je predstavljen uticaj starenja na osobine brusnih tocila vezanih smolom, uključujući i uticaj oksida aluminijuma i silicijum karbida. Štaviše, vlažnost je ispitana kao najverovatniji uzrok značajne degradacije mehaničkih osobina. U tom cilju je korišćen novi sistem za rad brusnih tocila u posebnim atmosferskim uslovima, kako bi se njihovo starenje ubrzalo (pomoću povećane vlažnosti). Analizirani su mehanizmi promene mikrostrukture tokom starenja, na osnovu izlaganja iste termomehaničkim udarima.

GRINDING WHEELS

Abrasive grains

The grains are of inorganic origin, and their property is high strength and adequate toughness.

The primary purpose of the grains is grinding the treated material (workpiece).

Abrasive grains are usually composed of aluminium oxide (Al_2O_3) and silicon carbide (SiC), which is produced synthetically, has a high hardness and is brittle.

Therefore, such grain quality is used for fine and final grinding, different types of phenolic resin are used as a binder /2/, the bond is more flexible, and resistance to higher temperatures is not so important. For intensive, coarse grinding, grains with lower hardness and also higher toughness are used, and the grains themselves are not as brittle.

Appropriate choice of grain size, which depends on the processed material and grinding conditions, is also very important.

Figure 1 shows the curve of dependence of the size of grains and the roughness of the processed material. As a rule, larger grains are used for coarser grinding and smaller grains are used for finer grinding of workpieces.

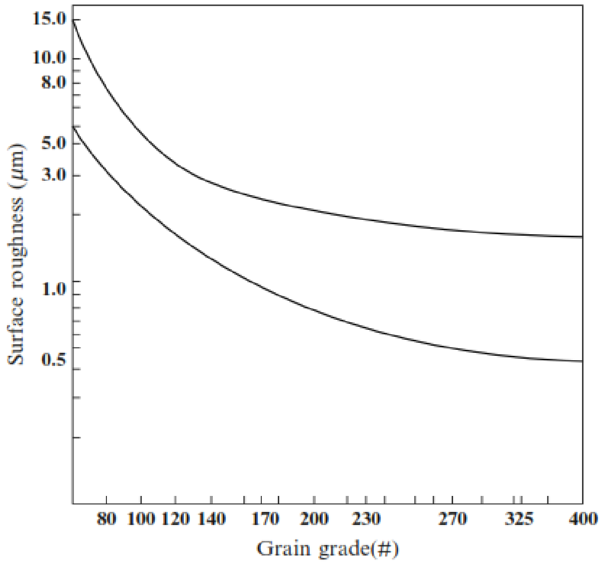


Figure 1. Correlation between grain size and roughness of processed surface, /3/.

Fillers

Fillers have been used in the manufacture of grinding wheels for many years. The use of these has shown that the addition of various, mostly inorganic fillers in the form of powder or fibers, can improve and add new properties to the basic composition of the polymer or grinding wheel.

Fillers in themselves can affect the density of the grinding wheel itself, the optical properties, colour and changes in surface properties. They actually help maintain the shape of the product during the drying process (shrinkage), reduce bending, reduce thermal conductivity, change the magnetic properties and thus actually help improve and achieve the targeted mechanical properties of the grinding wheels /4/.

Microstructure of resin-bonded grinding wheels

Primarily, abrasive disc is made up of grains, binders, fillers, pores and fractures and networks of glass fibres, which give the wheel additional reinforcement. The grains are basically intended for grinding workpieces, the binder holds grains together and pores are responsible for removing chips, /5/. Abrasive grains can self-renew and new grains appear at places where used grain falls out of the structure. This is a very important feature of resin bonded abrasive discs. If the resin holds the grains too tightly, the restoration of the working surface of the grinding wheel is slow and the pores become clogged, which reduces the efficiency of the grinding wheel. Also, the grinding wheel wears out too quickly if the grains fall out too quickly because the resin as a binder does not hold the grains together well enough, /6/.

EXPERIMENTAL PART

Due to the experimental analysis of the results of the influence of aging on mechanical and functional properties in a certain period and for easier traceability in production, different samples (six) are prepared, separated by appropriate codes (TYPE 0X), which are presented in more detail in Table 1, where PL260 PL340 and PL380 suggest a different grammage of impregnated glass cloth as reinforcement of the grinding wheel.

Table 1. Basic types of grinding wheel samples.

Sample No.	Samples code:	Product composition (type and quality of reinforcement):
01	TYPE 01	No reinforcement, non-reinforced product
02	TYPE 02	2 pieces PL 340
03	TYPE 03	1 piece PL 340 and 1 piece PL 380
04	TYPE 04	2 pieces PL 380
05	TYPE 05	2 pieces PL 260
06	TYPE 06	2 pieces PL 380, grinding wheel heat processed again at 190°C, 6 hours

Disintegration

The moment of collapse of the grinding wheel determines the rotational speed at which the grinding wheel tears due to large centrifugal forces. A dedicated machine was used for testing, which constantly increases the speed of rotation of the attached wheel to the value at which the disk explodes. Measurements of the maximum speed of rotation of the grinding wheels were performed for the prepared samples of grinding wheels (T01, T02, etc.). In all cases the same type of grinding wheel was used, F41 of 230 x 3 (3.1) x 22 A30S. The average result values of the rotational speed of the grinding wheels, where the decomposition occurred, are given in Table 2.

Table 2. Average values of rotational speed (min^{-1}) of wheel disintegration.

Type	Day 1:	Day 15:	Day 60:
TYPE 03	13 690	13 650	14 020
TYPE 02	13 600	13 460	13 630
TYPE 04	13 380	13 450	13 840
TYPE 05	13 340	12 930	13 230
TYPE 01	9 860	9 610	9 693

The results of measurements of rotational speed of disintegration show that the lowest values of rotational speed and, consequently, of disintegration are around the 15th day of wheel ageing. Then, by day 60, the values again start to increase.

Based on the comparison of test results of different types of samples (different grammar composition of the glass cloth), the collapse trend was found to be constant until day 45, after which a multiple increase was present in all types of grinding wheels.

Cutting efficiency - f

The cutting factor is the ratio between a chip (ΔM_{ml}) in grams of grounded workpiece and grinding wheel wear (ΔM_{gw}) in grams of wheel wear, Eq.(1):

$$f = \frac{\Delta M_{ml}(g)}{\Delta M_{gw}(g)} . \qquad (1)$$

The same type of F41 230 x 3 (3.1) x 22 A30S abrasive grinding wheel is used each time (ten samples). Cutting efficiency (*f*) was calculated on the basis of data with the test method of 30 cuts with a wheel.

The cutting efficiency (*f*) is tested on the automatic machine KB 230, 50 Hz: 6600 rpm; 2.3 kW, following the 223001R method; the test material is stainless steel (5480), dimensions 60 mm × 5 mm. Each testing of an individual sample contains 30 cuts. Tests are performed with 10 repetitions of cutting. The cutting ability check procedures are defined in the internal standards of the manufacturer and are used for regular testing of grinding wheels in production (monitoring and ensuring the stability of grinding wheels' quality).

To understand the concept better and to assess changes, more frequent measurements (from 1 to 83 days) are initially performed on the sample TYPE 04 and a time diagram of factor dependence is drawn, Fig. 2.

As shown in Fig. 2, there is a large dispersion of values by individual days. In order to facilitate the interpretation of the results themselves and to monitor the time dependence, diagrams of the dependence of the cutting factor for the 1st, 2nd, 15th, 45th and 60th day were made for all samples and are presented in Fig. 3.

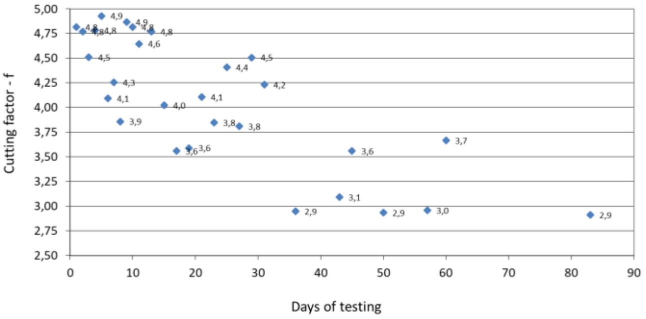


Figure 2. Cutting factor by days for sample TYPE 04, initial graph.

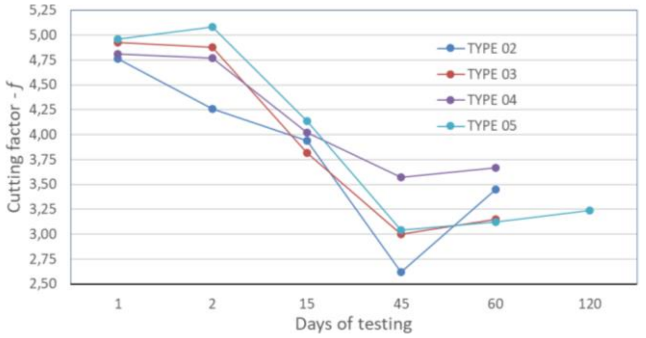


Figure 3. Cutting factor by days for sample TYPE 02, TYPE 03, TYPE 04, and TYPE 05.

Measured results shown in Figs. 2 and 3 actually show the following:

- the measured results confirm the actual impact of aging in the measured period of time and prove a direct impact on the mechanical properties of grinding wheels, i.e. cutting efficiency of grinding wheels,
- cutting efficiency reaches the lowest value for all types of grinding discs in the measured period of 45 days and is in fact 40% lower than originally measured for freshly made sanding discs,
- after a period of 45 days, the aging process itself stops and stabilizes, and cutting efficiency improves markedly,
- re-heat treatment of grinding wheels at a process temperature of 190 °C causes mechanical properties (cutting ability) to be reversibly restored to their original values, Fig. 4,
- we, therefore, conclude that atmospheric storage conditions (humidity and temperature) certainly have a key influence on the decline in the mechanical properties of grinding wheels during storage,
- the reliability of the measurement results themselves is confirmed using the Weibull statistical method, /7/.

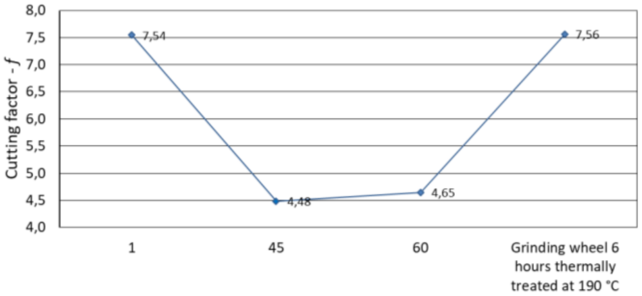


Figure 4. Cutting factor by days for sample TYPE 06 with repeated heat processing.

Microstructure of grinding wheels

Microstructural analysis of the samples themselves is based on imaging of the samples on a scanning electron microscope (Quanta 200 3D) with a tungsten cathode as the source of electrons in a high vacuum. Based on the method of cross-observation, comparison and analysis of microstructures of grinding wheel samples exposed to different thermo-mechanical influences, model mechanisms of microstructural changes in grinding wheels during aging were developed.

The same type of grinding wheel, F41 230 x 3 (3.1) x 22 A30S, was always used. How the samples were made and prepared is shown in Table 3.

Table 3. Preparation of samples for the microstructural analysis.

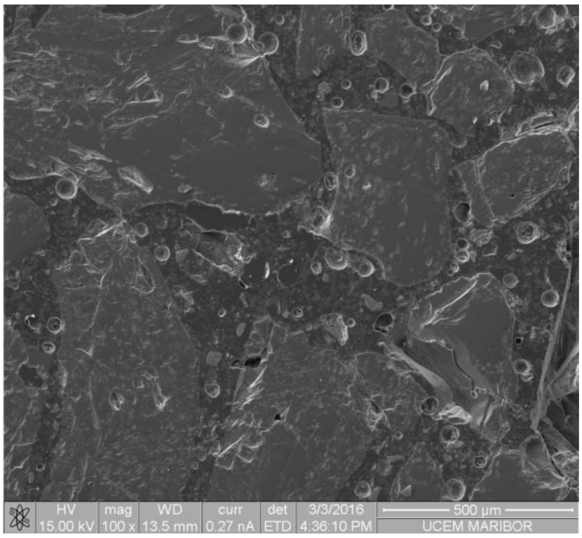
Sample code /measure time	Sample description	Sample processing
Sample A/07.02.	sample analysed 5 days old	wheel not used – measurement standard
Sample B/07.02.	sample analysed 5 days old	5 cuts with grinding wheel
Sample C/03.03.	sample analysed 30 days old	additional force humidification 30 days and 5 cuts – 1% humidity
Sample D/03.03.	sample analysed 140 days old (1% moisture)	Stored under normal conditions (40% humidity and 15°C) and 5 cuts

The microstructure of the grinding wheel sample A is shown in Fig. 5, the grinding wheel was not yet in use and was 5 days old. The images of the microstructure of the grinding wheel served as a comparable measurement standard in observing changes in the microstructure of other samples of grinding wheels that were used for cutting under different conditions.

The microstructure of the grinding wheel sample B is shown in Fig. 6, the grinding wheel was already used for cutting, it was 5 days old.

The microstructure of the 30-day-old grinding wheel sample C is shown in Figs. 7 and 8. The grinding wheel was further aged in the laboratory under special treatment and conditions (1% moisture content in the grinding wheel) and was already used for cutting. The microstructural changes of the sample are shown and documented at various magnifications.

The microstructure of a 140-day-old grinding wheel D sample is shown in Figs. 9 and 10. The grinding wheel was stored under normal storage conditions (~ 40% humidity and ~ 15 °C, the moisture content in the grinding wheel was 1%) and was already used for cutting. The microstructural changes of the sample are shown and documented at various magnifications.



Figures 5. Microstructure of grinding wheel sample A/07.02 – 100× magnification.

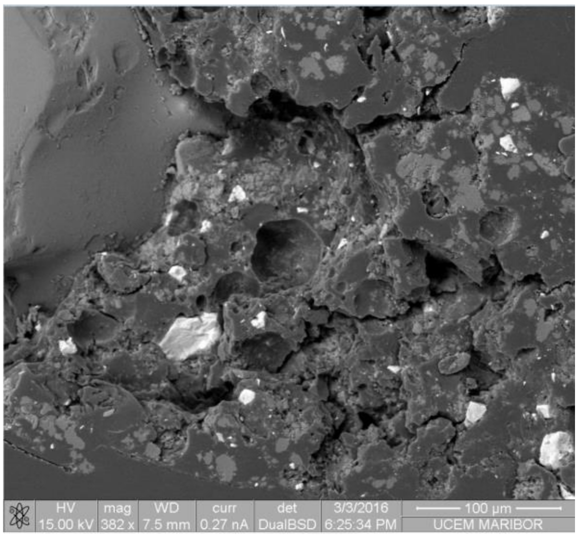


Figure 6. Microstructure of grinding wheel sample B/07.02 – 382× magnification.

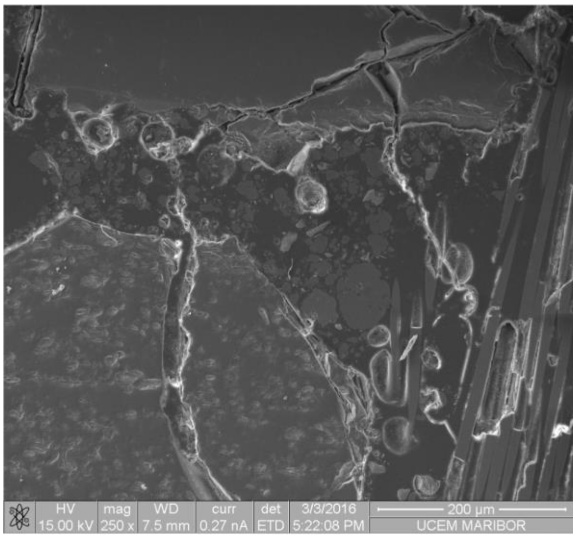


Figure 7. Microstructure of grinding wheel sample C/03.03. – 250× magnification.

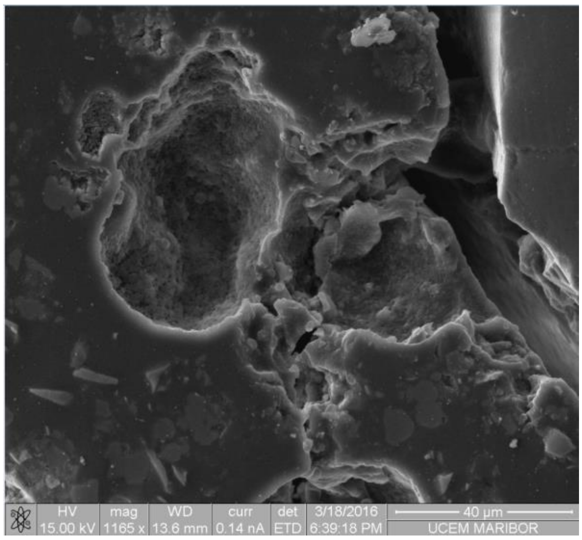


Figure 8. Microstructure of grinding wheel sample C/03.03. – 1165× magnification.

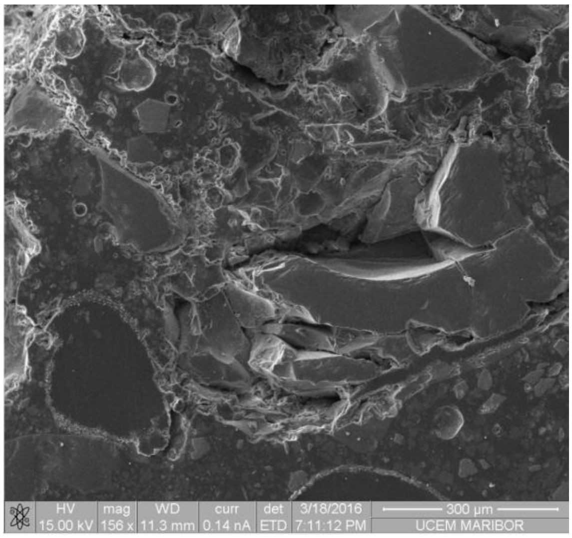


Figure 9. Microstructure of grinding wheel sample D/03.03 – 156× magnification.

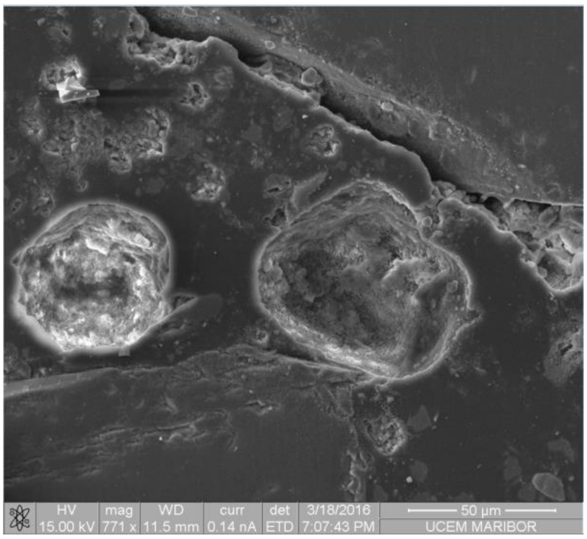


Figure 10. Microstructure of grinding wheel sample D/03.03 – 771× magnification.

Based on the method of cross-observation, comparison and analysis of microstructures of grinding wheel samples (Figs. 5 to 10), the following findings are made:

- in fact, the morphology of the microstructure of the unused grinding wheel differs significantly from the grinding wheel already in use,
- with a successful laboratory experiment of rapid aging, where additional moisture (1%) is forcibly penetrated into pores of the grinding wheel, the aging of the grinding wheel in normal storage conditions over a significantly longer period is successfully simulated,
- this process obviously has a negative effect on the internal structure of the polymer matrix (microstructure) of the grinding wheel, which is nicely reflected in the recorded microstructures of the samples,
- the rate and extent of the fall of the cutting efficiency of the grinding wheel is directly related to the number and size of pores in the polymer matrix,
- the heat released during cutting process heats the water (atmospheric moisture) in pores of the grinding wheels to form a gas phase – water vapour, while increasing the hydrostatic pressure of the vapour in the pores, leading to mechanical deformation at the perimeter of the pores and expansion cracks from here on along the polymer matrix,
- water vapour initiates cracks in polymer binders, cracks grow through matrix and stop on grain edge,
- a dilatation crack is formed between the structurally homogenous grain and matrix, reducing hardness and causing fall-off of abrasive grains, resulting finally in a significant reduction of the grinding wheel cutting ability in the first 45 days (up to 40 %),
- phenol-formaldehyde resin (duromer) in grinding wheel cross-binds individual abrasive grains. By nature, duromer is very hard and fragile, so the formation of cracks in the matrix contributes to a much faster reduction of grinding wheel hardness,
- increased presence of water vapours in pores increases internal tensions between the matrix, grain and glass impregnated cloth, strengthening the microstructural matrix of wheel.

CONCLUSIONS

From the results obtained, the experimental data can be assessed as follows:

- disintegration rotation speed measurements show that after the first 15 days the values are the lowest and then increase, and may actually exceed the original values,
- measurements of the cutting factor over time actually confirm the reasons and the effect of the aging process on the mechanical properties of the grinding wheels,
- the cutting factor reaches a minimum after about 45 days for all samples of grinding wheels, after which the aging process stops and stabilizes and the cutting ability improves slightly, but does not reach the original values,
- the method of storage and atmospheric conditions (humidity and temperature) certainly have a decisive influence on aging and the associated decline in the mechanical properties of grinding wheels.

REFERENCES

1. Matavž, A. (2016), The impact of ageing on mechanical characteristics of resin bonded wheels with corundum and SiC grains, Doctoral Thesis, University of Maribor, Faculty of Chemistry and Chemical Engineering, Maribor, Slovenia.
2. Debevc, E., Internal matter: Manufacture of phenolic resins (in Slovenian), 2016. (accessed: 10.03.2016). http://www.fenolit.si/index.php?lang=en&page=4
3. Gardziella, A., Pilato, L.A., Knop, A., Phenolic Resins Chemistry, Reactions, Mechanism, In: Phenolic Resins, Springer-Verlag, Berlin, 2000. doi: 10.1007/978-3-662-04101-7_2
4. Kuniasi, U., Kensakukakou, N.K. (2007), Nikkan Kogyo Shimbun: 64-76.
5. Pilato, L. (ed.), Resin Chemistry, In: Phenolic Resins: A Century of Progress, L. Pilato (ed.), Springer-Verlag Berlin, Heidelberg, 2010. doi: 10.1007/978-3-642-04714-5
6. Matavž, A., Mursics, J., Anžel, I., Žagar, T. (2018), *The influence of external conditions on the mechanical properties of resin-bonded grinding wheels*, Stroj. Vest. - J Mech. Eng. 64(7-8): 453-464. doi: 10.5545/sv-jme.2017.5083
7. Matavž, A., Krope, J., Goričanec, D., Gubeljak, N. (2007), *The impact of ageing on mechanical characteristics of resin bonded wheels*, Strojarstvo, 49(4): 311-316.