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# SCIENTIFIC PAPERS

ACTA FACULTATIS TECHNICAE XXVII
ZVOLEN – SLOVAKIA 2022

# RESEARCH OF THE RESISTANCE OF SELECTED HARDFACING MATERIALS TO ABRASIVE WEAR ACCORDING TO ASTM G133-95

# VÝSKUM ODOLNOSTI VYBRANÝCH NÁVAROVÝCH MATERIÁLOV VOČI ABRAZÍVNEMU OPOTREBENIU PODĽA ASTM G133-95

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**ABSTRACT:** Tools for crushing unwanted growths operate in a heterogeneous environment. They come into contact not only with the wood, but also with the soil, which contains various minerals and rocks. This working environment causes rapid tool wear. The article focuses on the possibility of increasing the lifetime of these tools by welding additional materials and testing their resistance to abrasive wear. The tool body is made of 16MnCr5 material. Furthermore, 2 types of additive materials were selected, namely OK Weartrode 62 and UTP 690 electrode. Subsequently, Rockwell hardness measurements and abrasive wear resistance testing were performed in accordance with ASTM G133-95. The UTP 690 hardfacing material achieved the lowest volume loss among the tested materials, namely 0.350mm3. The appropriate choice of the additive material is expected to increase the lifetime of the tools for crushing unwanted growths.

**Key words:** tool for crushing unwanted growths, hardfacing by welding, hardness, wear resistance

**ABSTRAKT:** Nástroje na drvenie nežiadúcich nárastov pracujú v heterogénnom prostredí. Prichádzajú do styku nie len s drevom, ale aj s pôdou, v ktorej sú rôzne minerály a horniny. Toto pracovné prostredie spôsobuje rýchle opotrebenie nástrojov. Článok je zameraný na možnosť zvýšenia životnosti týchto nástrojov naváraním prídavných materiálov a ich skúšanie odolnosti voči abrazívnemu opotrebeniu. Telo nástroja je vyrobené z materálu 16MnCr5. Ďalej boli vybraté 2 druhy prídavných materiálov, a to elektróda OK Weartrode 62 a UTP 690. Následne bolo vykonané meranie tvrdosti podľa Rockwella a skúška odolnosti voči abrazívnemu opotrebeniu podľa ASTM G133-95. Návar UTP 690 dosiahol spomedzi skúšaných materiálov najmenší úbytok objemu, a to 0,350mm3. Vhodnou voľbou prídavného materiálu je predpoklad zvýšenia životnosti nástrojov na drvenie nežiadúcich nárastov.

**Kľúčové slová:** nástroj na drvenie nežiadúcich nárastov, naváranie, tvrdosť, oteruvzdornosť

## INTRODUCTION

The work of environmental conditioning tools in forest cultivation is characterized by high loads in a heterogeneous working environment. This environment is mainly processed wood of uneven composition, hardness and diameter. The second important component of this environment is the soil. On its surface there are rocks and minerals of different sizes, hardness and origin, unpredictably and irregularly distributed. Due to the heterogeneity of the environment, the tool wears out very quickly and needs to be replaced.

Wear is the process of gradual loss of material from the surface of a material (Sabet et al. 2011). There are several types of wear, namely adhesive, abrasive, erosive, corrosive, fatigue wear, etc. (Findik 2014). The most dominant type of wear is abrasive (Singh et al. 2020a; Singh et al. 2020b). Abrasive wear is thought to be responsible for up to 50% of failures or replacement of parts, components and tools (Blau & Dehoff 2013). The wear mechanism is a complex process in the context of many factors. The intensity of these factors depends on the operating conditions of the environment in which these components and tools operate. Next are the operating parameters of the machines and the material properties of the contact surfaces (Suchánek et al. 2009). Wear caused by the impact and abrasion of hard abrasive particles is a major problem in many industries, especially in the fields of forestry, mining, mineral processing, etc. (Zdravecká et al. 2014; Ťavodová et al. 2020).

One very effective measure to increase wear resistance is to cover functional surfaces with a suitable covering material (Müller & Hrabě 2013). Hardfacing is a commonly used method to improve the surface properties of agricultural tools, mining components, soil preparation equipment and others (Buchely et al. 2005). The alloy is ap-plied to the surface of the base material (usually on low carbon or medium carbon steels) by hardfacing in order to increase the hardness and wear resistance without significant loss of ductility and toughness of the base material (Buchely et al. 2005; Müller & Hrabě 2013).

Rapid wear and frequent replacement of tools cause technical and economic problems for forestry companies. That is why it is necessary to pay attention to the possibilities of increasing the durability of these tools.

## MATERIAL AND METHODS

Mulching is a mechanised type of work in which the above-ground parts of vegetation are destroyed and shredded. Mulchers are used as adapters that are clamped behind the forest wheel tractor. The main part of the construction of the adapter is a rotating cylinder with a speed of $n = 1\ 000\ min^{-1}$, which is attached to the base machine. Tools are placed around the perimeter of the rotating cylinder (Fig. 1a) (Ťavodová et al. 2018a). In Fig. 1b we can see the tool with its individual parts.


*a* *b*

Fig. 1 Mulcher adapter and tool (Ťavodová et al. 2018b)
*a - adapter with tools, b - tool with individual parts*
Obr. 1 Mulčovací stroj a nástroj
*a - adaptér s nástrojmi, b - nástroj s jednotlivými časťami*

***Materials of research samples***

According to the results of previous research at the Faculty of Engineering of the Technical University of Zvolen in the field of increasing the lifetime of tools for crushing unwanted growths, the body of these tools is made of 16MnCr5 (14 220) (Ťavodová et al. 2018a). It is a stainless structural manganese-chromium steel for cementing. The steel is well malleable when hot, after soft annealing and when cold, it is well machinable and weldable. It is suitable for hardening machine components up to 35 mm diameter, for cementing with high core strength, e.g., shafts, gears, camshafts, valve lifters, piston pins and gear couplings. The chemical composition of 16MnCr5 steel is in Table 1 (www.jkz.cz).

The method of manual arc welding was chosen for the hardfacing. 2 types of electrodes were selected as additional material. The OK WearTrode 62 electrode is a welding electrode giving a weld metal with a high volume fraction of fine carbides in a martensitic matrix. It is designed to protect components subject to intense abrasive wear. Typical applications are on drilling equipment, hammers, scrapers and knives, shovel teeth, etc. Achievable hardness of the hardfacing material is 62 HRC. The chemical composition of the OK WearTrode 62 electrode is in Table 1 (www.esab.com). UTP 690 electrode is used for the repair and production of cutting tools, especially for the restoration of cutting edges and working surfaces. The coating is highly resistant to friction, compression and impact even at elevated temperatures up to 550°C. With this electrode it is also possible to produce new tools by hardfacing by welding on unalloyed and low-alloy basic steels. After hardfacing by welding, it forms a martensitic structure. The achieved hardness of the hardfacing material is 62 HRC. The chemical composition of the UTP 690 electrode is in Table 1 (Müller & Hrabě 2013; www.zvarcentrum.sk).

Table 1 Chemical composition of 16MnCr5, OK WearTrode 62 and UTP 690 materials
Tabuľka 1 Chemické zloženie materiálov 16MNCr5, OK WearTrode 62 a UTP 690

| Element | C | Si | Mn | Cr | Mo | P | S | V | W | Ti | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **16MnCr5 wt. (%)** | 0.14 - 0.19 | 0.17 - 0.37 | 1.10 - 1.40 | 0.80 - 1.10 | - | max. 0.035 | max. 0.035 | - | - | - | rest |
| **OK WearTrode 62 wt. (%)** | 2.9 | 1.9 | 0.4 | 6.2 | - | - | - | 5.2 | - | 4.90 | rest |
| **UTP 690 wt. (%)** | 0.90 | 0.80 | 0.50 | 4.50 | 8.00 | - | - | 1.20 | 2.00 | - | rest |

***Testing methods***

The abrasive wear resistance test was conducted in accordance with standard ASTM G133-95. This test method describes laboratory procedures for determining the sliding wear of ceramics, metals, and other candidate wear-resistant materials using a linear, reciprocating ball-on-flat plane geometry. The direction of the relative motion between sliding surfaces reverses in a periodic fashion such that the sliding occurs back and forth and in a straight line. The principal quantities of interest are the wear volumes of the contacting ball and flat specimen materials. This test method encompasses both unlubricated and lubricated testing procedures (ASTM G133-95: 2002).

This test method involves two specimens—a flat specimen and a spherically ended specimen (herein called the "ball" specimen) which slides against the flat specimen. These specimens move relative to one another in a linear, back and forth sliding motion, under a prescribed set of conditions. In this test method, the load is applied vertically downward through the ball specimen against the horizontally mounted flat specimen. The normal load, stroke length, frequency and type of oscillation, test temperature, lubricant (if any), test duration, and atmospheric environment (including relative humidity range) are selected from one of two procedures. Dimensional changes for both ball and flat specimens are used to calculate wear volumes and wear rates (ASTM G133-95: 2002).

Fig. 2 shows the arrangement for the reciprocating ball-on-flat wear test available on a commercial machine. A lubricant in which a flat sample is immersed can be used for testing. The tangential force can be measured continuously during oscillating contact and used to obtain friction coefficient data (ASTM G133-95: 2002).

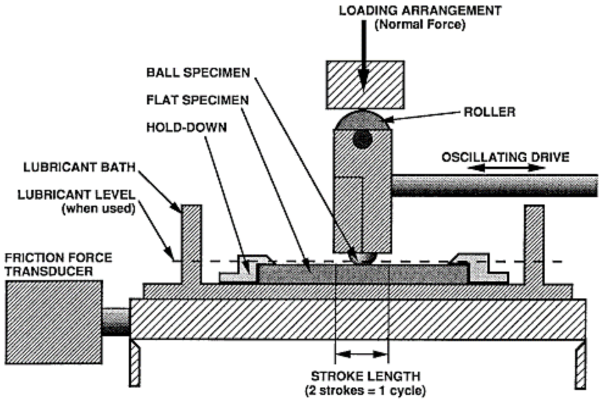



Fig. 2 Schematic diagram of the abrasion resistance test device

Obr. 2 Schéma zariadenia pre test odolnosti voči abrazívnemu opotrebeniu

Ball wear - the wear volume ($V_p$) for a flat ball wear scar of effective diameter $D$ from relation (1) (ASTM G133-95: 2002):

$$V_p = \left(\frac{\pi . h}{6}\right) . \left[\frac{3 . D^2}{4} + h^2\right] \tag{1}$$

where: $h$ – height of material removed [mm] (2) (ASTM G133-95: 2002):

$$h = R - \left[R^2 - \left(\frac{D^2}{4}\right)\right]^{\frac{1}{2}} \tag{2}$$

where: $R$ – original ball radius [mm].

Flat sample wear - the flat sample wear volume $V_f$ is calculated from the stroke length and the average cross-sectional area of the wear track. The wear volume of the flat specimen is calculated from the relation (3) (ASTM G133-95: 2002):

$$V_f = A . L \tag{3}$$

kde: $A$ – average cross-sectional area of the track (mm$^2$)

$L$ – length of the stroke (mm).

### *Evaluation methods*

The measurement of resistance to abrasive wear was evaluated with a 3D profilometer TalySurf CLI 1000 with a confocal and touch induction sensor.

## RESULTS AND DISCUSSION

In order to perform the abrasive wear test, it was necessary to prepare samples. 2 types of hardfacing material (OK WearTrode 62 and UTP 690) were made on the base material. The hardfacing by welding was carried out by certified welders in ŽOS, a. s. Zvolen. Before welding, the OK WearTrode 62 electrode had to be dried at 200°C for 2 hours and the UTP 690 electrode at 300°C for 2 hours. Both types of electrodes were dried in a ZEPACOMP drying chamber. The base material was preheated to a temperature of 180°C for hardfacing OK WearTrode 62 and 230°C for hardfacing UTP 690. The set welding current was I=105 A. During hardfacing by welding, the temperature of the sample was controlled to prevent it from overheating or cooling down. In Fig. 3 we can see a sample with an OK WearTrode 62 hardfacing material (Fig. 3a) and a sample with a UTP 690 hardfacing material (Fig. 3b).

*a* *b*

Fig. 3 Samples with hardfacing materials
*a - OK WearTrode 62, b - UTP 690*
Obr. 3 Vzorky s návarovými materiálmi
*a - OK WearTrode 62, b - UTP 690*

All samples for further tests were prepared by abrasive water jet machining technology (AWJM), machined by milling and ground on a magnetic plane grinder to a surface roughness of 0.4 µm. The dimensions of the samples were 30mm x 30mm x 5mm.

First, a Rockwell hardness measurement was performed according to ISO 6508-1:2016. The measured hardness values are in Tab. 2.

Table 2. Values from Rockwell hardness measurement
Tabuľka 2. Hodnoty z merania tvrdosti podľa Rockwella

| | 16MnCr5 | OK WearTrode 62 | UTP 690 |
|---|---|---|---|
| Hardness HRC | 20 | 63 | 62 |

The test for resistance to abrasive wear was performed by the Ball-on-Flat method according to the G133-95 standard. The test was carried out in the test laboratory of the University of Defense in Brno, Faculty of Military Technology, on the Bruker TriboLab test equipment. The prepared sample was inserted into the device, the time, loading force and path of movement of the ball along the flat sample were set. After the set time, a trace of the ball was observed on the sample. The samples after the test are shown in Fig. 4.

*a* *b* *c*

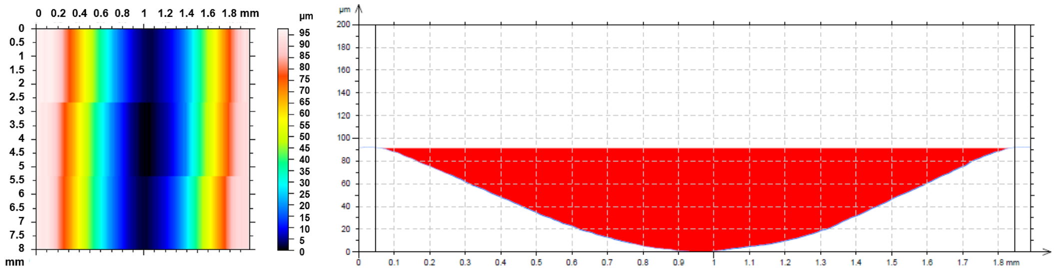
Fig. 4 Samples after test
*a - 16MnCr5, b - OK WearTrode 62, c - UTP 690*
Obr. 4 Vzorky po teste
*a - 16MnCr5, b - OK WearTrode 62, c - UTP 690*

Test conditions for resistance to abrasive wear according to ASTM G133-95 are listed in Tab. 3.

Table 3. Test conditions
Tabuľka 3. Podmienky skúšky

| Parameter | Value |
|---|---|
| **A burdensome force F** | 120 N |
| **Frequency f** | 5 Hz |
| **Test duration t** | 15 000 s |
| **Track length A** | 10 mm |
| **Ball material** | sintered carbide (94% WC + 6% Co) |
| **Ball hardness** | 1 800 HV10 (56 HRC) |

In Fig. 5 we can see the width and depth of the trace after the abrasive wear test (Fig. 5a) at its beginning, middle and end. In Fig. 5b is the average cross-sectional area of the track for the material 16MnCr5.




*a* *b*

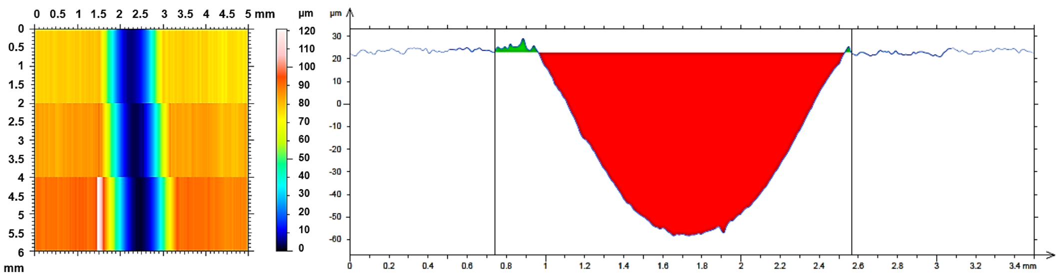
Fig. 5 Test results for 16MnCr5 material

*a - width and depth of the trace, b - average cross-sectional area of the track*

Obr. 5 Výsledky testu pre materiál 16MnCr5

*a - šírka a hĺbka stopy, b - priemerná plocha prierezu stopy*

In Fig. 6 we can see the width and depth of the trace after the abrasive wear test (Fig. 6a) at its beginning, middle and end. In Fig. 6b is the average cross-sectional area of the track for the material OK WearTrode 62.




*a* *b*

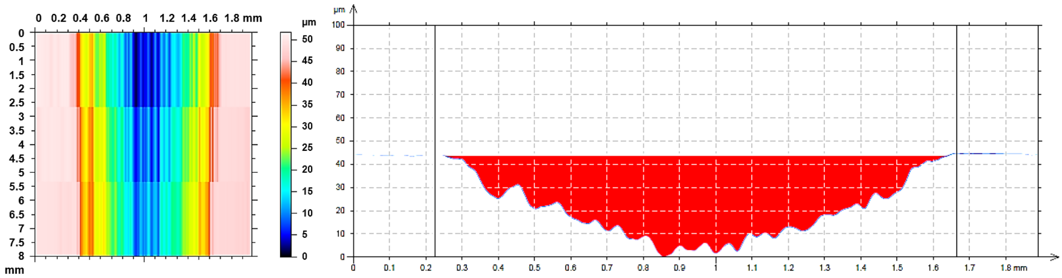
Fig. 6 Test results for OK WearTrode 62 material

*a - width and depth of the trace, b - average cross-sectional area of the track*

Obr. 6 Výsledky testu pre materiál OK WearTrode 62

*a - šírka a hĺbka stopy, b - priemerná plocha prierezu stopy*

In Fig. 7 we can see the width and depth of the trace after the abrasive wear test (Fig. 7a) at its beginning, middle and end. In Fig. 7b is the average cross-sectional area of the track for the material UTP 690.




*a* *b*

*a - width and depth of the trace, b - average cross-sectional area of the track*

Obr. 7 Výsledky testu pre materiál UTP 690

*a - šírka a hĺbka stopy, b - priemerná plocha prierezu stopy*

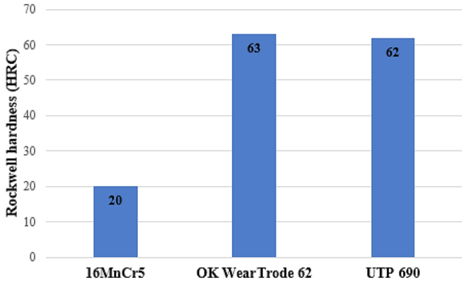
Based on the measured data from individual measurements, the wear volumes of the flat sample were calculated for each material according to relation (3). All measured data are in Tab. 4.

Table 4. Measured values from the abrasion resistance test

Tabuľka 4. Namerané hodnotyzo skúšky oteruvzdornosti

| | Max. track width (mm) | Max. track depth (mm) | Content of the cross-sectional area of the track ($mm^2$) | Flat sample wear volume ($mm^3$) |
|---|---|---|---|---|
| **16MnCr5** | 1.790 | 0.0910 | 0.0968 | **0.968** |
| **OK WearTrode 62** | 1.573 | 0.0803 | 0.0797 | **0.797** |
| **UTP 690** | 1.450 | 0.0441 | 0.0350 | **0.350** |

In Fig. 8a we can see a graph for comparing the hardness of individual materials. The base material of the tool for crushing unwanted growths 16MnCr5 reached a hardness of 20HRC. The OK WearTrode 62 hardfacing material reached a hardness of 63HRC and the UTP 690 hardfacing material 62HRC. Compared to the base material, the hardfacing materials achieved significantly higher hardness. Some authors report that hardness is strongly correlated with resistance to abrasive wear (Slota et al. 2022; Müller & Hrabě 2013; Vargová et al. 2022). In Fig. 8b we can see a graph for the comparison of the wear volume values of the flat sample $V_f$ for each tested material. The hardfacing material OK WearTrode 62 achieved the highest hardness (63HRC) among the tested materials, but its volume loss $V_f$ = 0.797mm$^3$ is more than twice as high as the volume loss of the welding material UTP 690 $V_f$ = 0.350 mm$^3$. It follows that the hardness of the material is not always a decisive factor for resistance to abrasive wear. The base material 16MnCr5 achieved the highest volume loss value, namely $V_f$ = 0.968 mm$^3$.



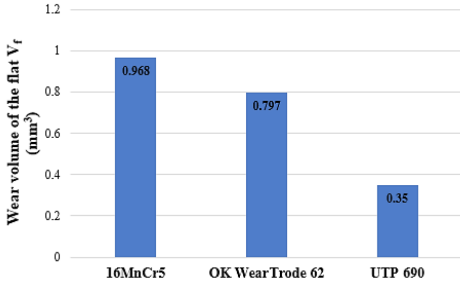




Fig. 8 Graphs for comparison of abrasion resistance test results
*a - Rockwell hardness, b - wear volume of the flat sample*
Fig. 8 Grafy pre porovnanie výsledkov testu oteruvzdornosti
*a - tvrdosť podľa Rockwella, b - objem opotrebenia plochej vzorky*

One of the other factors that affects the resistance to abrasive wear is the microstructure of the material. Based on data from electrode manufacturers, we can say that both hardfacing materials create a similar microstructure after hardfacing by welding (www.esab.com; www.zvarcentrum.com). Nevertheless, these welding materials show different resistance to abrasive wear, which could be influenced by the chemical composition of individual materials.

## CONCLUSION

Tools for crushing unwanted growths operate in a heterogeneous environment. This environment is made up not only of wood, but also of soil, which contains rocks and minerals that vary in size and shape. They are subject to rapid wear as a result of this working environment. This leads to frequent replacement of tools, which causes technical and economic problems for forestry companies. The price of one new tool is around 80€ to 85€, so it is necessary to pay attention to the possibilities of increasing the life of these tools. The article analyzes two ways to modify tools for crushing unwanted growths. Based on the results, it is possible to state:

1. The tool body material 16MnCr5 has reached 20HRC hardness, which is very low. Its volume loss after the test of resistance to abrasive wear was 0.968 $mm^3$.
2. The OK WearTrode 62 hardfacing material had a hardness of 63HRC, which is more than 3 times higher hardness compared to the 16MnCr5 material. The volume loss of this hardfacing electrode was 0.797 $mm^3$. It is almost 18% better result than for the material 16MnCr5.
3. The UTP 690 hardfacing material reached a hardness of 62HRC, which is significantly higher than the 16MnCr5 material, but the hardness of this material is almost the same as the hardness of the OK WearTrode 62 hardfacing material. The volume loss of the hardfacing material UTP 690 reached the smallest value among the examined materials, namely 0.350 $mm^3$. This is a 64% better result compared to the tool body material and a 56% better result compared to the OK WearTrode 62 hardfacing material.

Since the tools for crushing unwanted growths are mainly subject to abrasive wear, it is important that the hardfacing material that will be applied to the functional parts of the tool is able to resist this kind of wear as well as possible. The best results were achieved by the UTP 690 hardfacing material, therefore it would be advisable to pay attention to this hardfacing material in further research and to subject it to further laboratory tests. After all observations and tests have been evaluated, the tools will be put into service to determine if the given modifications to the tools can better withstand the effects of the working environment compared to an unmodified tool.


## ACKNOWLEDGMENT

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# EFFECT OF HYDROTHERMAL TREATMENT ON SURFACE QUALITY OF BEECH WOOD AFTER PLANE MILLING

# VPLYV HYDROTERMICKEJ ÚPRAVY A PARAMETROV FRÉZOVANIA NA VÝSLEDNÚ KVALITU POVRCHU BUKOVÉHO DREVA

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**ABSTRACT:** This article deals with issues of influence of selected technical, technological and tools factors during face milling of beech wood which is modified by saturated water steam with emphasis on surface quality. Experiments were conducted on samples which were modified by saturated water steam with temperatures (T=105, 125 and 135 °C) however one of them was in native state, feed rate was (6, 10, 15 $m.min^{-1}$), cutting speed was (20, 40, 60 $m.s^{-1}$) and rake angle was (20, 25, 30°). Experimental measurement of surface quality was conducted via laser device LPM – 4. Effects by parameters were obtained by experiments in this order: rake angle, cutting speed, thermally modification of material, feed rate.

**Key words:** roughness, hydrothermal treatment, cutting speed, feed rate, beech wood, milling

**ABSTRAKT:** Tento článok sa zaoberá problematikou vplyvu vybraných technicko – technologických a nástrojových faktorov v procese rovinného frézovania termicky modifikovaného bukového dreva s využitím sýtej vodnej pary na kvalitu povrchu. Experimentálne meranie sa vykonávalo na vzorkách, ktoré boli termicky modifikované sýtou vodnou parou pri teplotách (T=105, 125 a 135 °C), pričom jedna vzorka bola v natívnom stave, tromi rýchlosťami posuvu (6, 10, 15 $m.min^{-1}$), tromi reznými rýchlosťami (20, 40, 60 $m.s^{-1}$) tromi uhlami čela nástroja (20, 25, 30°). Experimentálne meranie kvality opracovaného povrchu sa vykonávalo prostredníctvom laserového profilometra LPM – 4. Experimentom sa získali vplyvy jednotlivých parametrov v nasledovnom poradí: uhol čela nástroja, rezná rýchlosť, tepelná úprava materiálu, rýchlosť posuvu.

**Kľúčové slová:** drsnosť, hydrotermická úprava, rezná rýchlosť, posuvná rýchlosť, bukové drevo, frézovanie

## INTRODUCTION

Wood and its use is of great importance to humanity, whether it is the use of wood for exterior or interior. Due to outer influences, the mechanical and aesthetic properties of wood can be reduced. (Kokutse et al. 2006, Kaplan et al. 2018). The surface inactivation may also lead to expulsion of oleic extractives on wood surface and hinder the access of hydroxyl groups onto the wood cell wall. For Frybort et al.(2014), some wood extractives (namely fatty acids, terpenes, phenols, and so on) may migrate to outside wood, becoming a resinous layer, leading to increase in surface energy. The inactivated wood surface also presents smaller roughness, reducing losses in planning machine and high quality wood surfaces, which may be important for many wood applications.

Heat-treated wood has been extensively manufactured for more than 10 years, and its production has been introduced to many Western European countries in response to the changing chemical wood treatment legislation. Finland pioneered the production of thermally modified wood with ThermoWood® in 1990. Later, ThermoWood® began to be produced in the Netherlands, Germany, Austria, and France (Koleda et al. 2020). ThermoWood® is one of the most common methods of the material treatment, which achieves better physical and mechanical properties. This is a method of heat treatment of the material (Černecký et al. 2017), which is conducted by two standard treatments, Thermo – S a Thermo – D. Thermo – S is a process that conducts at lower temperatures and the main use is indoors and with the designation S is defined shape and dimensional stability. Thermo – D is a process which is conducted at higher temperatures, which increases the durability of the material (Rajko et al. 2021).

TM is a newer type of wood modification. There are currently several types of TM, the principle of which is different depending on the medium and temperature used (Navi and Sandberg 2012). The most well-known types of TM are ThermoWood in Finland, Plato Wood in the Netherlands, oil-heat treatment (OHT) in Germany, and Les Bois Perdure and retification process (Retiwood) in France (Esteves et al. 2011; Sandberg and Kutnar 2016). In addition to these common TMs, there are also lesser known TM processes that use superheated steam, such as Wood Treatment Technology (WTT) in Denmark and Firmolin technology in the Netherlands, or a partial vacuum, like Termovuoto in Italy (Ferrari et al. 2013). In general, TM can be defined as a process in which high temperatures ranging between 150 and 260 °C are applied to wood in an environment with different types of media (steam, nitrogen, oil, etc.) without chemical substances (Sandberg and Kutnar 2016) (Reinprecht and Vidholdová 2008).

Milling is a widespread process in woodworking and especially in the furniture industry which is done by tools – cutters with a rotating motion, where the trajectory that describes their teeth is cycloid. This process is used to produce flat and profiled surfaces, for making grooves, rebates, tenons, etc. The obtained details are with sufficiently high quality of processing, certain accuracy and roughness of the surfaces. (Gochev et al. 2018). The precision of surface roughness is a result of repetitive cutting edge activity on the workpiece surface, it depends mainly on cutting speed, depth of cut, feed rate and geometry of cutting tool. The precision of surface roughness of the milled parts requires increased attention for the following surface technological treatment. Suitable cutting conditions can achieve an improved surface quality during woodworking (Prokeš 1982; Kačíková and

Kačík 2011, Budakçı et al. 2013) and optimization of energy consumption (Kubš et al. 2017; Koleda et al. 2018).

The aim of the study was to determine the influence of the heat treatment temperatures of beech wood and the subsequent plane milling parameters on the quality of milled surface. This research is part of a study of the properties of woodworking thermally modified beech wood by saturated water steam that is focused on measuring the quality and energy of the machining process.

## EXPERIMENTAL

### Materials and Methods

The milling blades which were used for experimental milling had dimensions 45 x 35 x 6 mm (h x w x t) (Fig. 1), which were made of tool steel 19 573 (STN 41 9573) and surface induction hardened. The milling blades were coated by the method PVD (Physical Vapor Deposition). The coating process of the blades was carried out in the company WOOD – B s.r.o in Nové Zámky in Slovakia. The chemical composition of the milling blades is shown in Tab. 1.

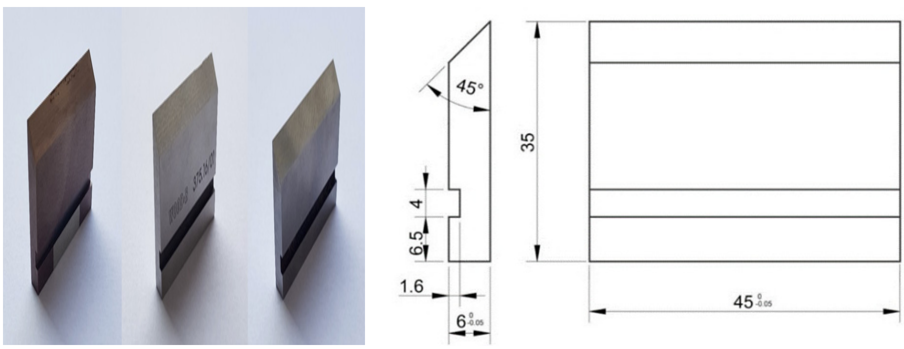


Fig. 1 Changeable milling blade
Obr. 1 Vymeniteľný frézovací nôž

Table 1 Chemical Composition of Used Milling Blades
Tabuľka 1 Chemické zloženie použitých frézovacích nožov

| Blade from the tool steel 19 573 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Co** | **Mn** | **Si** | **P** | **S** | **Cr** | **Mo** | **V** |
| 1,4 ÷ 1,65 | 0,2 ÷ 0,45 | 0,2 ÷ 0,45 | 0,03 | 0,035 | 11 ÷ 12,5 | 0,6 ÷ 0,95 | 0,8 ÷ 1,20 |

The blades were clamped in the milling heads marked FH 45 STATON made in SZT – machines Turany, with parameters mentioned in the table below.

Table 2 Parameters of Milling Head
Tabuľka 2 Parametre frézovacej hlavy

| | |
|---|---|
| Diameter of the Cutter Body | 125 [mm] |
| Diameter of the Cutter Body with Blades | 130 [mm] |
| Thickness of the Cutter Body | 45 [mm] |
| Number of Blades | 2 [ks] |
| Maximum speed | 8000 ($min^{-1}$) |
| Rake Angle | $\gamma$ = 20°, 25°, 30° |

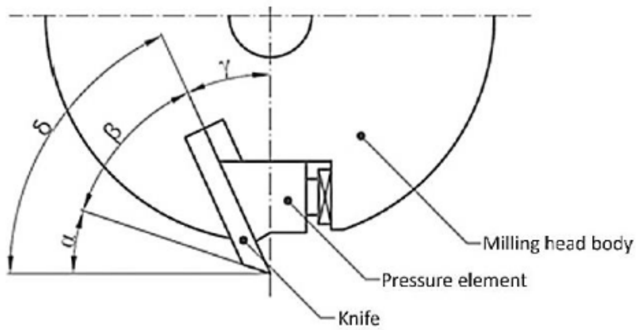


Fig. 2 Milling heads used
Obr. 2 Schéma použitých frézovacích hláv

Beech wood (Fagus sylvatica) was used as a material for the samples. From the logs, the boards of the radial medial timber with a thickness of 25 mm were first manipulated on a band saw. Moisture of boards were w > 45%. The boards were dried to 12 % moisture content in a wood drying kiln in KAD 1x6 (KATRES s.r.o.) at the company Sundermann spol. s.r.o (Banská Štiavnica Slovak republic). Subsequent processing of the boards, samples were obtained by circular saw. DMMA 35 (Rema s.a., Reszel, Poland) and wood thickness planer machine F2T80 (TOS Svitavy, Czech Republic). Then, the cuts with a length of 600 mm, width 100 mm and thickness 25 mm and thickness of samples was adjusted by thickness machine F2T80 with thickness 20 mm. Part of the cuts were not treated and remained in a native state. Other cuts were thermally modified at a specified temperature. Samples of 600 mm 100 mm 20 mm were heat – treated in an APDZ 240 autoclave at a higher saturated water steam pressure than atmospheric pressure (Dzurenda 2022). The process of thermal treatment of the material was carried out at the company Sundermann spol. s.r.o (Banská Štiavnica Slovak republic). Fig. 3 shows the course of heat treatment of samples.

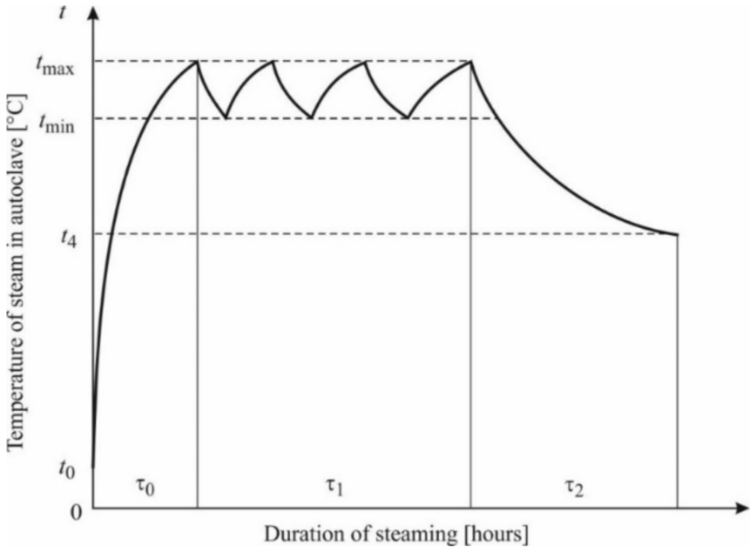


Fig. 3 Time course of heat-treatment
Obr. 3 Grafické zobrazenie tepelnej úpravy vzoriek

Table 3 Modes of thermal treatment of beech wood with saturated steam
Tabuľka 3 Režimy termickej modifikácie bukového dreva sýtou vodnou parou

| Modes | Temperature of saturated steam [°C] | | | Steaming time in hours [hours] | | | |
|---|---|---|---|---|---|---|---|
| | $t_{max}$ | $t_{min}$ | $t_4$ | $\tau_0$ - heating | $\tau_1$ - phase I | $\tau_2$ - phase II | Total time |
| Steaming mode I. | 107.5 | 102.5 | 100 | | 3.5 | 1.0 | ≈ 6.0 |
| Steaming mode II. | 130.0 | 125.0 | 100 | ≈1.5 | 4.0 | 1.0 | ≈ 6.5 |
| Steaming mode III. | 140.0 | 135.0 | 100 | | 4.5 | 1.0 | ≈ 7.0 |


Fig. 4 Samples for experimental measurement
Obr. 4 Pripravené vzorky na experimentálne meranie

The milling process was performed on the lower spindle miller ZDS-2 (Liptovské strojárne, Slovakia). The feeding was ensured by the feeding device Frommia ZMD 252/137 (Maschinenfabrik Ferdinand Fromm, Fellbach, Germany). The cutting conditions were as follow: cutting speed: 20, 40 a 60 $m.s^{-1}$, feed rate: 6, 10 a 15 $m.min^{-1}$, rake angle: 20°, 25° a 30°.


Fig. 5 Lower spindle milling machine FVS and feeder mechanism Frommia ZMD 252/137
Obr. 5 Spodná vretenová frézka FVS s podávacím zariadením Frommia ZMD 252/137

Table 4 Technical Parameters of the Lower Spindle Miller FVS and feeding device Frommia
Tabuľka 4 Technické parameter spodnej vretenovej frézky FVS a podávacieho zariadenia Frommia

| **Lower spindle miller FVS** | | **Feeder Frommia ZMD 252/137** | |
|---|---|---|---|
| Input [kW] | 4 | Feed Range [$m.min^{-1}$] | 2,5;10;15;20;30 |
| Current System [V] | 360/220 | Engine [$m.min^{-1}$] | 380 V; 2800 |
| Year of Production | 1976 | Year of Production | 1972 |

## Determination of density

In order to successful evaluation of the experiment, was necessary accurately determine the material density of the experimental samples. The volumetric mass density of the experimental samples was conducted according to the STN 49 0108 standard. All samples were weight by laboratory scale with a measuring accuracy of 0,01 g and subsequent measurement by a calliper with an accuracy 0,01 mm. The resulting values of dimensions and weights of the samples were processed and the measured values of the density was calculated according to $\rho_w = m_w/V_{w.}$ The average density values which are calculated from obtained values and percentage change compared to native wood are shown in the table 4. The density of wood decreased with increasing hydrothermal treatment temperature , however density of untreated wood had value of density between samples with modification by temperature 105 and 125 °C.

Table 5 Measured Values of the Bulk Density of Beech Wood
Tabuľka 5 Namerané hodnoty hustoty vzoriek Bukového dreva

| Thermal Treatment [°C] | Density m/v [$kg.m^{-3}$] | Percentage change [%] |
|---|---|---|
| **Native Wood** | 683,5 | - |
| **105 °C** | 671,8 | -1,74% |
| **125 °C** | 691,9 | 1,21% |
| **135 °C** | 705,1 | 3,05% |

The measurement of the surface quality was conducted after the milling of experimental samples by laser device LPM – 4 (Fig. 6). A digital camera captured images of the laser line at an angle and, based on the scanned image, the object profile in the cross-section was evaluated. The roughness measurement was made on three points of the sample; on the entrance of the sample into the cut, on the center of sample, and on the output of sample of the cut to monitor the changing of surface roughness on the input of the tool. This was measured after stabilization and on the output of tool of the cut, as well as in three wide zones on the edges and in the middle of sample thickness. The technical parameters of the laser device LPM – 4 are shown in the table 6. The bottom spindle milling machine which is equipped by a three phase asynchronous engine was controlled via a frequency changer UNIFREM 400 007M (Vonsch s.r.o., Brezno, Slovak Republic). Frequency changer was connected to computer via USB serial converter USB (Fig. 7). The technical parameters of the frequency changer are shown in the table 7. The program LPM - View was used to graphically display of the resulting values and then this values were saved to program Excel to another processing by STATISTICA 12. From the measured data of the experiment were generated the results of the effects of factors via one-factorial analysis and multi-factorial analysis by statistical program.

Table 6 Basic Parameters of Profilometer LPM – 4
Tabuľka 6 Základné parametre profilometra LPM – 4

| | |
|---|---|
| **Measuring range in the z axis (vertical)** | 420 - 470 mm |
| **Measuring range in the z axis** | ± 0,15 mm |
| **Measuring range in the x axis (transverse)** | 200 mm |
| **Number of samples in x axis** | 1350 |
| **Processing speed** | 25 prof./s |
| **Type of laser diode** | 660 nm /25 mW |
| **Laser scatter angle** | 30° |
| **Roughness parameters** | Rp, Rv, Rz, Ra, Rq, Rc |
| **Waviness parameters** | Wp, Wv, Wz, Wa, Wq, Wc |

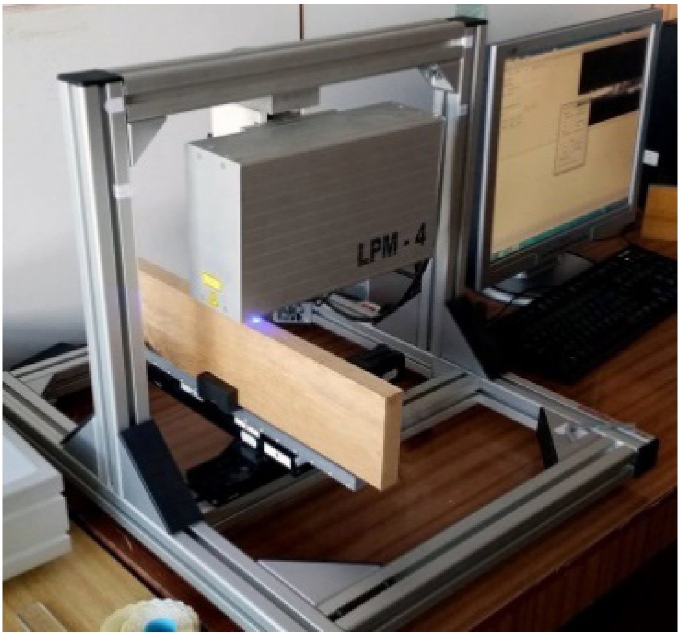


Fig. 6 Laser device LPM – 4
Obr. 6 Laserový profilometer LPM – 4

Fig. 7 Cutting power control apparatus
Obr. 7 Zapojená meracia sústava pre riadenie asynchrónneho motora

Table 7 Technical Parameters of the Frequency Changer
Tabuľka 7 Technické parametre frekvenčného meniča

| Type of Frequency Changer | M – Quadratic Load | | M – Constant Load | | | | Nominal Output Current of Changer $I_{nIN}$ [A] |
|---|---|---|---|---|---|---|---|
| | Engine Power $P_{nom}$ [kW] | Nominal Output Current $I_{NQ}$ [A] | Engine Power $P_{nom}$ [kW] | Nominal Output Current $I_{NK}$ [A] | Max. Output Current $I_{NK60}$ [A] | Max. Output Current $I_{NK2}$ [A] | |
| UNI-FREM 400 007M | 7,5 | 18,1 | 5,5 | 13,2 | 19,8 | 26,4 | 18,1 |

## RESULTS AND DISCUSSION

### Effect of Thermal Treatment on Surface Roughness

From the Fig. 8 it is clear that the highest surface roughness depending on the temperature of thermal modification was achieved during heat treatment of the sample on 125 °C. The subsequent decrease of surface roughness was occurred with thermally treated samples to 135 °C and by samples without thermally modification and so in native state. According to the graph, it can be claimed that the lowest achieved value of surface roughness was in the heat treatment to 105 °C.

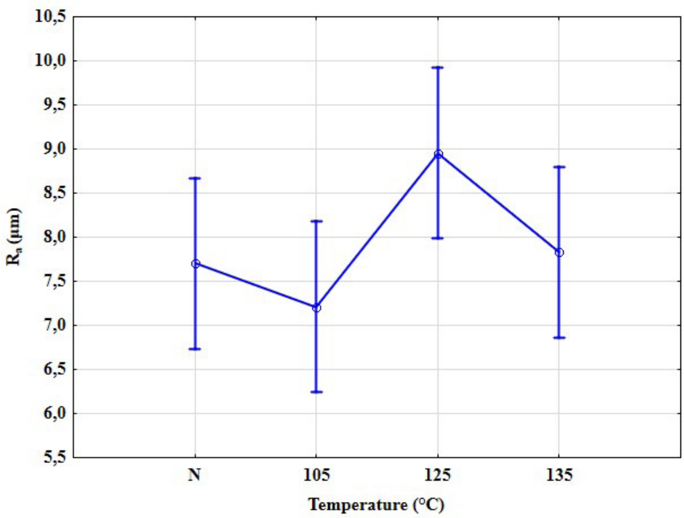


Fig. 8 Effect of thermal treatment on the surface quality
Obr. 8 Vplyv teploty termickej úpravy na kvalitu povrchu

**Effect of Feed rate on Surface Roughness**

A multi-factorial analysis of the variance of dependence surface roughness on feed rate in shown in Fig. 9. From the chart is clear that the value of surface roughness increases when feed rate is increased but the opposite phenomenon is by temperature on 125 °C . According to multi-factorial analysis is cleared that the highest achieved surface roughness was when the samples were treated by temperature 125 °C and milling by feed rate 10 m.min$^{-1}$. The lowest surface roughness was achieved during heat treatment of the sample on 135 °C by feed rate 6 m.min$^{-1}$. From the Fig. 9 is cleared that the modification of the samples to 125 °C causes the surface roughness at a feed rate of 6 and 10 m.min$^{-1}$ is almost the same. Almost the same surface roughness was for thermally treated samples on 105 °C by feed rate 6 m.min$^{-1}$ and 10 m.min$^{-1}$. The best surface roughness by samples without temperature modification is by feed rate 10 m.min$^{-1}$.

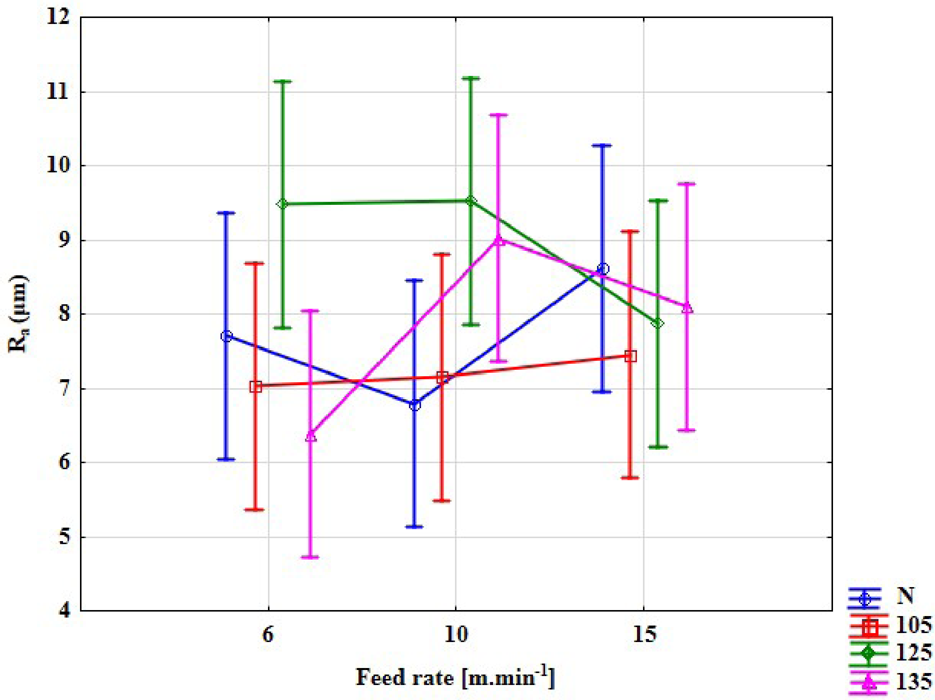


Fig. 9 Multifactor analysis of variance for the dependence of surface roughness on feed rate
Obr. 9 Viacfaktorová analýza rozptylu závislosti drsnosti povrchu od posuvnej rýchlosti

**Effect of Cutting Speed on Surface Roughness**

A multi-factorial analysis of variance of influence the surface roughness on cutting speed is shown in Fig.11. It can be stated from the chart that as cutting speed is increased, the surface roughness is decreased in direct proportion. The highest surface roughness was with a thermally treated samples at temperature 125 °C at a cutting speed 20 m.s$^{-1}$.

The best quality of surface was reached with a heat-treated sample at 105 °C and a cutting speed 60 m.s$^{-1}$. It is further obviously from the graph that almost all thermally treated samples have the best quality of surface at the highest cutting speed 60 m.s$^{-1}$ excluding native samples where the best quality of surface was with using cutting speed 40 m.s$^{-1}$. At a cutting speed 60 m.s$^{-1}$, the thermally modified samples at 135 °C and native samples have almost surface roughness as well as with using cutting speed 40 m.s$^{-1}$ with temperatures 105 °C and 135 °C.

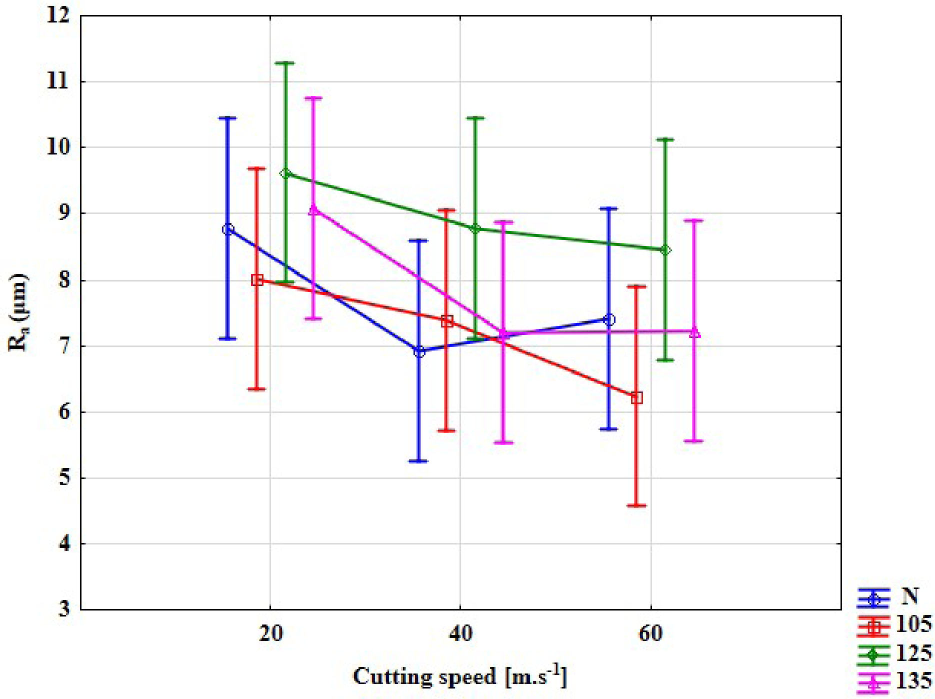


Fig. 10 Multifactor analysis of variance for the dependence of surface roughness on cutting speed
Obr. 10 Viacfaktorová analýza rozptylu závislosti drsnosti povrchu od reznej rýchlosti

### Effect of Rake Angle on Surface Roughness

At the rake angle of 30° the best surface roughness was on all of the samples of thermally-treated excluding of natural samples because there was the best quality of surface by rake angle 20°. The best quality was on the sample with a thermal treatment of material at 135 °C. In terms of angle positions, the best quality was in the sample with a thermal treatment at 135 °C, with the rake angle of 30°. The worst quality of machined surface was the sample with thermal treatment at 125 °C and the rake angle of 20°. According to graph is clear that the bigger rake angle is the best quality of surface is.

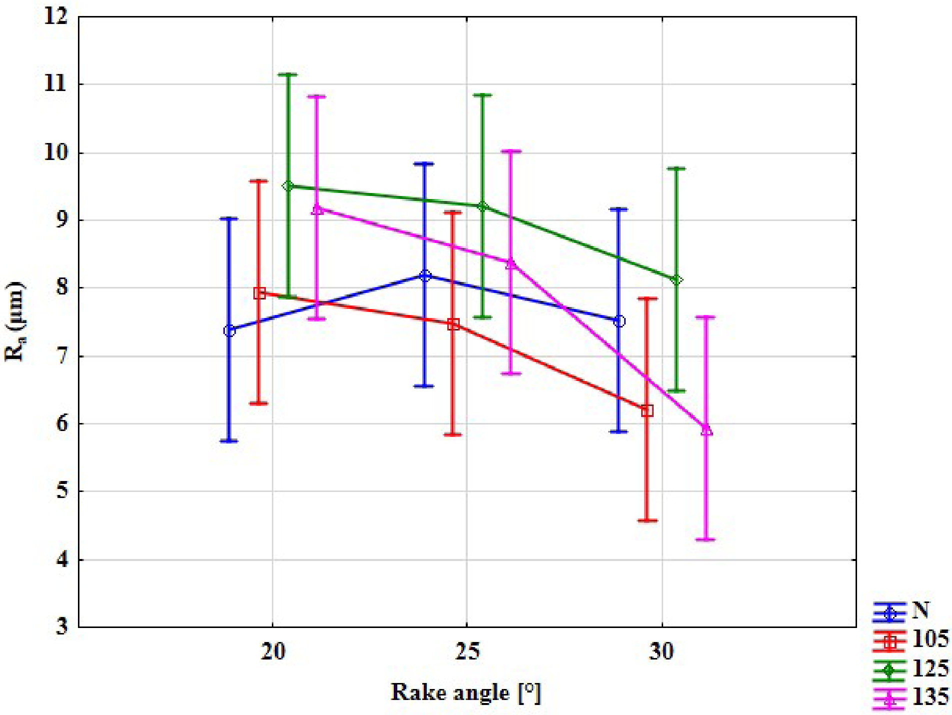


Fig. 11 Multifactor analysis of variance for the dependence of surface roughness on rake angle
Obr. 11 Viacfaktorová analýza rozptylu závislosti drsnosti povrchu od uhla čela

Table 7 The order of the effects of various factors on surface roughness
Tabuľka 7 Poradie vplyvov sledovaných parametrov na drsnosť povrchu

| Impact on Surface Roughness | Variance F | Significance Level P |
|---|---|---|
| **Rake angle [°]** | 4,137 | 0,02 |
| **Cutting Speed $v_c$ [m.s$^{-1}$]** | 3,925 | 0,02 |
| **Temperature T [°C]** | 2,313 | 0,08 |
| **Feed Rate $v_f$ [m.min$^{-1}$]** | 0,346 | 0,7 |

The published article deals with an experimental study on the influence of selected technical and technological factors on surface roughness. The measurement was conducted on samples of beech wood. This paper is not be reliable compare with others research because in this age is not a lot of papers which were published with the same hydrothermal modification in accordance with investigating of technical and technological parameters during plane milling. Despite the results of the experiment can be compared with ThermoWood technology which is similar with PlatoWood so this paper can be compared with that. Regarding research on the roughness of heat-treated wood, it is possible to compare this work with Barcík et al. (2014, 2015), Korčok et al. (2018) and Kvietková et al. (2015a, b), who studied pine, beech, oak, and birch wood. For the roughness evaluation in their experiments, the contact method was used for the surface roughness measurement. Considering these results, it was justified in stating that it is possible to draw on the knowledge and laws of the work to understand the issue.

According to Kaplan et al. (2018) who examined oak wood, proclaimed that thermal modification of wood does not affect the average roughness values after machining. Based on results was discovered that the difference between the measured roughness values of treated and untreated wood was negligible. Also he concludes that the lowest surface roughness values after machining were found at a rake angle of 25°. There was found out also that the best quality of surface after plane milling when 40 $m.s^{-1}$ cutting speed was used. The best results in terms of the quality of the machined surface were measured at a feed rate of 4 $m.min^{-1}$.

## CONCLUSIONS

The value of surface roughness during machining depended on the monitored factors in following order: 1) rake angle; 2) cutting speed; 3) thermal treatment; 4) feed rake

The angular geometry had the most significant impact on the quality of surface finish. The most significant change of roughness was at the thermal treatment of material at 105 °C. At this temperature, the surface roughness reached optimal characteristics. With a increased rake angle the surface quality increased. The worst surface quality appeared at the thermal treatment at 125 °C and rake angle of 20°. It could be generally stated that at the temperature 105 °C, the quality indicators were the best in all of the studied factors.

Cutting speed was the second parameter that affected the quality of the surface. With increased cutting speed the surface quality was improved, but this was not clear in all of the samples. With samples without thermal treatment were found a reverse course of increasing the roughness depended on the cutting speed. This phenomenon could have been caused by the transition from spring wood to summer wood.

Thermal modification by water saturated steam affected the surface quality; the best quality was achieved for the sample treated by 105 °C. By increasing the temperature the surface roughness was increased, and the worst results were at the thermal treatment at 125 °C. Thermal treatment at 135 °C caused an increase in the surface roughness compared to the natural material.

Feed rate had the least influence on the quality of the surface, with increased feed rate the surface quality decreased but by temperatures at 125 °C was effect opposite and it could have been caused also by the transition from spring wood to summer wood. Based on the thermal treatment of the wood, the best quality was the sample thermally modified at 135 °C and the worst quality was the sample modified at 125 °C with using of feed rate 10 $m \cdot min^{-1}$.

From the summary is recommended that the best conditions for milling of heattreated beech sample at 105 °C are: rake angle 30°; feed rate 10 m.min-1 and cutting speed 60 m.s-1.

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# RESEARCH OF ETHICAL ENVIRONMENT OF MANUFACTURING COMPANIES IN SLOVAKIA

# VÝSKUM ETICKÉHO PROSTREDIA VÝROBNÝCH PODNIKOV NA SLOVENSKU

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**ABSTRACT:** The aim of article is to identify the ethical environment of selected manufacturing companies in Slovakia and based on the analysis, to propose a model of improving ethical credibility. In the introduction of the article, the issue of the ethical environment is briefly described, which includes ethics, business ethics, ethical credibility and risks. The material and methods chapter describes the research sample and the complete procedure for developing an analysis of the ethical environment of selected manufacturing companies, the number of which was 43. The research was carried out in the form of an online questionnaire, which contained 7 questions. In the results, the responses of the manufacturing companies were analysed and evaluated. The results showed that the ethical environment in selected manufacturing companies is not ideal, and therefore a model for improving ethical credibility was proposed. The model contains principles that companies should follow to improve their current market situation. These principles included process risks identification, relationship building, problems solving ethical principles and motivation.

**Key words:** ethical environment, ethical credibility, risks, manufacturing company

**ABSTRAKT:** Cieľom článku je identifikovať etické prostredie vybraných výrobných podnikov na Slovensku a na základe analýzy navrhnúť model zlepšenia etickej kredibility. V úvode článku je stručne popísaná problematika etického prostredia, do ktorej patrí etika, podnikateľská etika, etická kredibilita a riziká. V kapitole materiál a metódy je popísaná výskumná vzorka a kompletný postup pre vypracovanie analýzy etického prostredia vybraných výrobných podnikov, ktorých počet bol 43. Výskum bol realizovaný vo forme online dotazníka, ktorý obsahoval 7 otázok. Vo výsledkoch sa analyzovali a vyhodnotili odpovede výrobných podnikov. Výsledky ukázali, že etické prostredie vo vybraných výrobných podnikoch nie je ideálne a preto bol navrhnutý model zlepšenia etickej kredibility. Model obsahuje zásady, ktoré by mali podniky dodržiavať, aby zlepšili svoju súčasnú situáciu na trhu. Do týchto zásad boli zahrnuté identifikovanie rizík, budovanie vzťahov, riešenie problémov, etické princípy a motivácia.

**Kľúčové slová:** etické prostredie, etická kredibilita, riziká, výrobný podnik

## INTRODUCTION

The exclusion of oneself from a privileged position is also extremely important in ethical thinking. Ethical thinking is normative, meaning that when we make an ethical choice, we are not guided by what is good for me, but by what is good for everyone. It is difficult in ethics to avoid prejudice, to justify our ethical judgments and to support them with sufficient argumentation. The process of ethical argumentation is essentially ambiguous. We can never be sure that our courts are without prejudice and that their reasoning is quite correct. The need of tolerance is a necessity in this regard. Ethics is a social discipline that is above group interests. Ethical knowledge represents a rational justification of norms and principles for human coexistence that apply universally, not to one or more groups (cultures), but to every human on earth (Waddock 2008; Čierna et al. 2015).

Business ethics deals with the analysis of moral norms and principles in all spheres of the economic system, examining the ethical assumptions for the functional conditions of a modern market economy. Business ethics is a critical reflection of economic activities based on the values of humanism, justice, solidarity, freedom and tolerance. A specific area that business ethics deals with is the relationship between ethics and economics. The main stimuli leading to the creation of business ethics include environmental problems, social problems, unemployment, poverty and wealth, migration, social justice (Treviňo & Nelson 1995; Remišová 2004; Ubrežiová 2008).

The term trustworthiness means credibility or reliability. In the manufacturing companies, reliability and credibility, especially of people, are very important for the proper functioning of the whole company. Creating the credibility of any subject allows you to better assert yourself in a wider social environment. All actors seeking to build credibility are aware that credibility means being accepted, recognized, preferred. It is also a recognition of the customer, the citizen, stakeholders, the public interest and the social good. In principle, it is an activity focused on the social good, the good life, which also fulfills the ethical mission. However, ethical parameters, ethical determination and conviction must also be met (Fobel 2019).

Risk is a term that indicates an uncertain result with a possible adverse condition. Risk means a threat, a potential problem, the risk of damage, the possibility of failure, damage, loss or destruction. Risk expresses a certain degree of uncertainty, therefore the probability of achieving a result that is different from what is expected (Robbins & Coulter 2004; Merna & Al-Thani Faisal 2007). Business risks are divided into production, technological, business, financial, exchange rate, political and social (Gozora 2000).

## MATERIAL AND METHODS

At the beginning, the basic criteria were determined and information about manufacturing companies were obtained.

According to the number of employees, companies are divided into micro-companies (up to 9 employees), small companies (10 to 49 employees), medium-sized companies (50 to 249 employees) and large companies (250 and more employees) (Sujová et al. 2012).

The research analysed primarily medium-sized manufacturing companies in the Banská Bystrica Region. Several small manufacturing companies were also included for comparison. Subsequently, it was determined which companies and with what focus will be part of the ethical environment research. 3 main focuses from the technical field were selected:

- Manufacturing of machinery and equipment,
- Metal manufacturing and processing,
- Wood manufacturing and processing.

After determining the basic parameters, companies were searched according to the required parameters. For this, the internet database of all companies in Slovakia was used. It was found that 43 manufacturing companies comply with the specified requirements. The following table (Tab. 1) shows the number of manufacturing companies from each focus.

Table 1 Number of manufacturing companies by focus
Tabuľka 1 Počet výrobných podnikov podľa zamerania

| Business focus[1)] | Number of companies[2)] |
|---|---|
| Manufacturing of machinery and equipment | 8 |
| Metal manufacturing and processing | 27 |
| Wood manufacturing and processing | 8 |

[1)]Zameranie podniku, [2)]Počet podnikov

The internet application Forms, which is part of Office 365, was used to create the questionnaire. This application enables the creation of questionnaires, quizzes, polls and surveys. The questionnaire contained 7 questions on the given issue. Subsequently, the questionnaire was sent to the manufacturing companies.

Questions of research questionnaire

1. Do you have a code of ethics in your company ?
2. Does your company operate based on ethical principles ? If yes, please specify which of them is recognized in your company.
3. Do you have people in your company who help to solve employee problems ? If yes, please specify who.
4. Do you have people in your company who deal with the opinions and suggestions of employees ?
5. Do you have an integrated management systems in your company ? If yes, please specify which of them.
6. Do you have identified process risks in your company ?
7. How are employees informed about possible risks ?

## RESULTS

The number of responses stopped at 13. The return rate for completing the questionnaire was 30.23%. The lower return of responses could be caused by pandemic situation of Covid-19, where some companies could be closed.

Question 1: Do you have a code of ethics in your company ?

The subject of this question was to find out if the manufacturing companies have established a code of ethics. The responses are represented by a bar chart (Fig. 1).

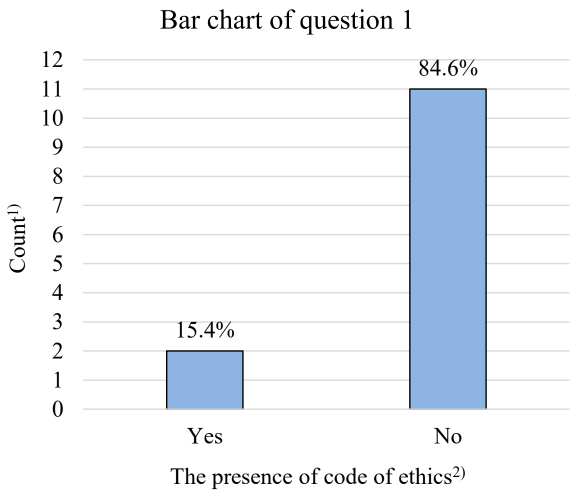


Fig. 1 Bar chart of the presence of code of ethics
Obr.1 Stĺpcový graf prítomnosti etického kódexu

1)Počet, 2)Prítomnosť etického kódexu

Based on the results of the responses to the question 1, it can be stated that 15.4% of manufacturing companies have established a code of ethics and 84.6% of manufacturing companies do not have established code of ethics.

Question 2: Does your company operate based on ethical principles ? If yes, please specify which of them is recognized in your company.

The subject of this question was to find out if the manufacturing companies work on the basis of ethical principles, or with which ones. The responses are represented by a bar chart (Fig. 2).

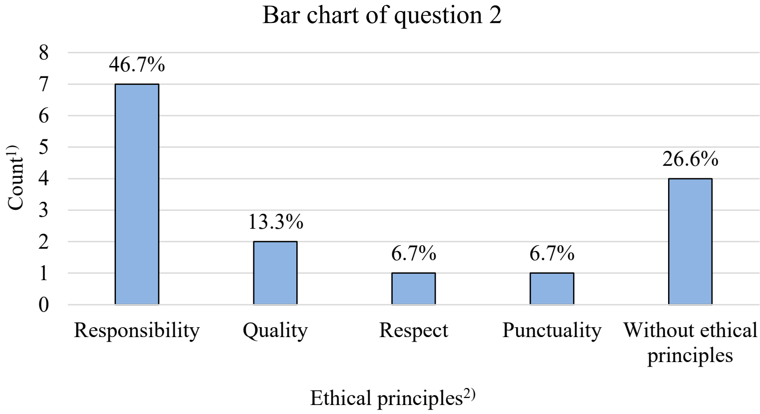


Fig. 2 Bar chart of ethical principles
Obr. 2 Stĺpcový graf etických princípov

1)Počet, 2)Etické princípy

Based on the results of the responses to the question 2, it can be stated that 46.7% of manufacturing companies operate based on responsibility, 13.3% of manufacturing companies operate based on quality, 6.7% of manufacturing companies operate based on respect, 6.7% of manufacturing companies operate based on punctuality and 26.6% of manufacturing companies do not operate based on ethical principles.

<u>Question 3: Do you have people in your company who help to solve employee problems ? If yes, please specify who.</u>

The subject of this question was to find out if the manufacturing companies have someone who deals with employee issues, or with who. The responses are represented by a bar chart (Fig. 3).

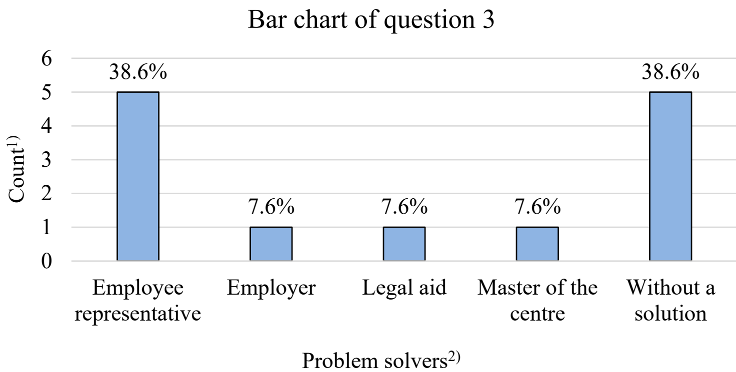


Fig. 3 Bar chart of sphere of people for solving problems
Obr. 3 Stĺpcový graf okruhu ľudí pre riešenie problémov

1)Počet, 2)Riešitelia problémov

Based on the results of the responses to the question 3, it can be stated that 38.6% of manufacturing companies solve problems through employee representative, 7.6% of manufacturing companies solve problems through employer, legal aid or master of the centre and 38.6% of manufacturing companies do not solve employee problems.

Question 4: Do you have people in your company who deal with the opinions and suggestions of employees ?

The subject of this question was to find out if the manufacturing companies have someone who deals with opinions and suggestions of employees. The responses are represented by a bar chart (Fig. 4).

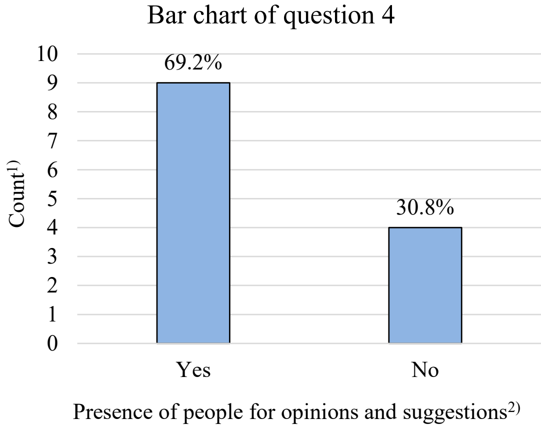


Fig. 4 Bar chart of presence of people for opinions and suggestions
Obr. 4 Stĺpcový graf prítomnosti ľudí pre názory a návrhy

[1)]Počet, [2)]Prítomnosť ľudí pre názory a návrhy

Based on the results of the responses to the question 4, it can be stated that 69.2% of manufacturing companies have people who deal with opinions and suggestions of employees and 30.8% of manufacturing companies do not deal with opinions and suggestions of employees.

Question 5: Do you have an integrated management systems in your company ? If yes, please specify which of them.

The subject of this question was to find out if the manufacturing companies have an integrated management systems (IMS), or which of them. The responses are represented by a bar chart (Fig. 5).

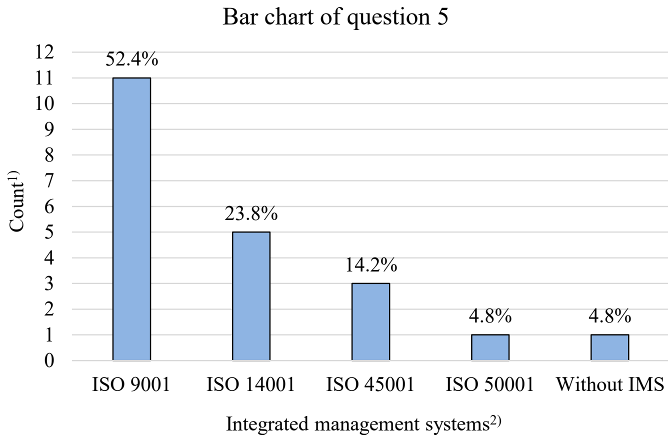


Fig. 5 Bar chart of integrated management systems
Obr. 5 Stĺpcový graf integrovaných manažérskych systémov

[1)]Počet, [2)]Integrované manažérske systémy

Based on the results of the responses to the question 5, it can be stated that 52.4% of manufacturing companies have ISO 9001, 23.8% of manufacturing companies have ISO 14001, 14.2% of manufacturing companies have ISO 45001, 4.8% of manufacturing companies have ISO 50001 and 4.8% of manufacturing companies do not have an integrated management systems.

<u>Question 6: Do you have identified process risks in your company ?</u>

The subject of this question was to find out if the manufacturing companies have identified process risks. The responses are represented by a bar chart (Fig. 6).

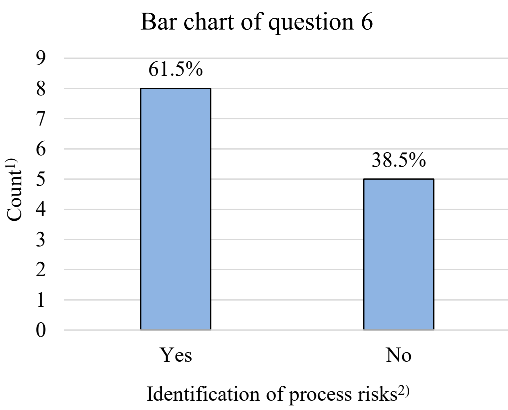


Fig. 6 Bar chart of presence of process risks
Obr. 6 Stĺpcový graf prítomnosti rizík procesov

[1)]Počet, [2)]Identifikácia rizík procesov

Based on the results of the responses to the question 6, it can be stated that 61.5% of manufacturing companies have identified process risks and 38.5% of manufacturing companies do not have identified process risks.

Question 7: How are employees informed about possible risks ?

The subject of this question was to find out how are employees informed about possible risks. The responses are represented by a bar chart (Fig. 7).

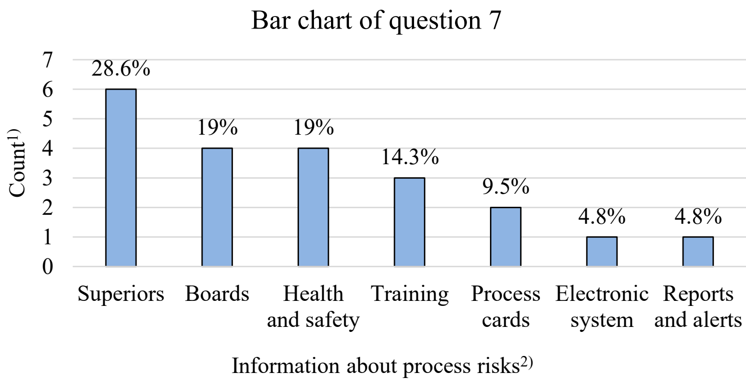


Fig. 7 Bar chart of process risks information

Obr. 7 Stĺpcový graf informovania o rizikách procesov

1)Počet, 2)Informovanie o rizikách procesov

Based on the results of the responses to the question 7, it can be stated that 28.6% of manufacturing companies have identified process risks through superiors, 19% of manufacturing companies have identified process risks through boards or health and safety, 14.3% of manufacturing companies have identified process risks through training, 9.5% of manufacturing companies have identified process risks through process cards and 4.8% of manufacturing companies have identified process risks through electronic system or reports and alerts.

Because of analysis of ethical environment, it can be concluded that the ethical environment in manufacturing companies in Slovakia is not ideal, and therefore a model for improving ethical credibility was proposed (Fig. 8), which consists of two phases, namely phase of the current status and phase of the improvement. Manufacturing companies should follow this model if they want to improve their current market position with respect to credibility.

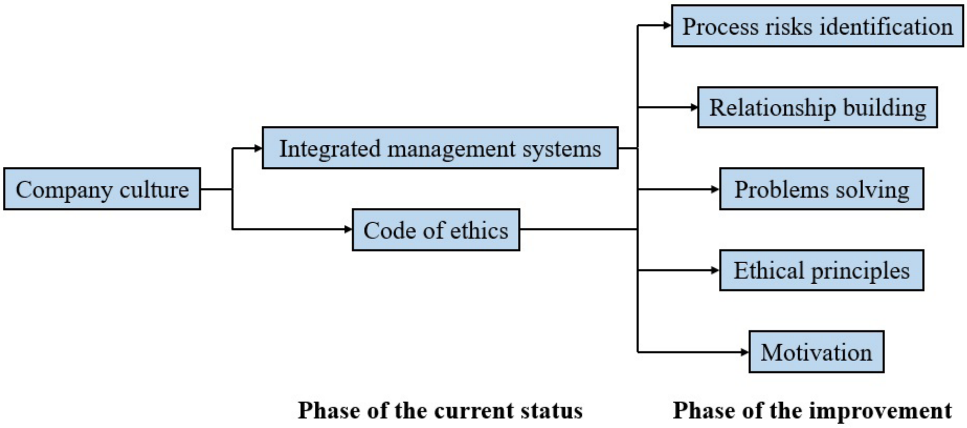


Fig. 8 Model for improving ethical credibility
Obr. 8 Model pre zlepšenie etickej kredibility

## DISCUSSION

A similar issue was dealt by the research which examined general companies around Orava. Research showed that ethical politics in Slovak companies is generally not enough represented (Balúnová 2019). The credibility of businesses based on the credibility of advertising was investigated by Hussain et al. (2020). Research has shown that credibility is the most important factor in the market. The issue about disclosure of social, ethical and environmental performance by corporations and other organisations was investigated by Dando & Swift (2003), where it was confirmed that social, ethical and environmental credibility is the most important thing in the market. Tremblay et al. (2016) evaluated ethical environment, namely ethical risks and its importance. Based on the results, they proposed an ethical governance infrastructure that will guide and regulate interactions between internal and external parties. The improvement of the ethical environment was dealt with in the research by Sujová et al. (2021) and Čierna & Sujová (2020), which were similar to this research. The articles suggested ways to improve ethical credibility. The research results were comparable to this research.

## CONCLUSION

An ethical environment is generally very important in all types of businesses. In this work, research was carried out on the ethical environment of manufacturing companies in Slovakia. The ethical environment was briefly described in the form of ethics, business ethics, ethical credibility and risks. The research methodology consisted in the creation of an online questionnaire, which contained 7 questions on the given issue. The questionnaire was sent to 43 selected manufacturing companies in the Banská Bystrica Region in Slovakia. The return rate of the questionnaires was only 30.23%, probably due to Covid-19 pandemic situation. The results of the responses showed that the ethical environment in the selected manufacturing companies is not ideal, and therefore it was necessary to propose a procedure for its improvement. A model for improving ethical credibility was proposed. This model was composed of two phases, namely phase of the current status and phase of the improvement. Integrated management systems and a code of ethics were included in phase of the current status. Phase of the improvement included process risks identification, relationship building, problem solving, ethical principles and motivation. It is assumed that if companies follow this model, they will significantly improve their competitiveness and credibility on the market.

## ACKNOWLEDGMENT

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# MEASUREMENT OF SEPARATION EFFICIENCY OF FINE FRACTIONS WASTE MATERIAL IN VORTEX SEPARATOR

# MERANIE ÚČINNOSTI ODLUČOVANIA JEMNÝCH FRAKCIÍ ODPADOVÉHO MATERIÁLU VO VÍROVOM ODLUČOVAČI

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**ABSTRACT:** The contribution is focused on the experimental research of the separation efficiency of waste material fine fractions in a new construction type of vortex separator. The aimed of the new construction is to achieve a separation efficiency of more than 95% for fine fractions of waste material. Samples of waste materials from the woodworking, engineering, and building industries are used for the measurement. The samples are subjected to a sieve analysis to determine the grain size of the individual fractions followed by determination of the separation efficiency. The vortex separator achieves a separation efficiency of over 96% for all examined samples of waste material. The maximum separation efficiency of 100% is achieved by the vortex separator for plastic fractions with a size of 2 mm and gravel and sand fractions with a size of 4 mm. In addition, wood fractions with sizes of 4 mm, 1 mm, 0.6 mm, and 0.125 mm, plastic fractions (0.6 mm and 1 mm), rubber fractions (2 mm and 4 mm), gravel and sand fractions from size 2 mm to fractions of 0.125 mm, iron dust fractions (0.6 mm and 0.125 mm), and aluminum dust fractions (2 mm and 1 mm), achieve separation efficiency above 99%. The designed and constructed separator is able to effectively separate not only fractions of larger sizes, but also waste material with low grain size. Therefore, it can be effectively used not only as a pre-separator for larger fractions, but also as a separate unit for the separation of fine fractions.

**Key words:** waste material, vortex separator, sieve analysis, fraction, separation efficiency

**ABSTRAKT:** Príspevok je zameraný na experimentálny výskum účinnosti odlučovania jemných frakcií odpadového materiálu v novom konštrukčnom type vírového odlučovača. Cieľom novej konštrukcie je dosiahnuť odlučivosť viac ako 95% pre jemné frakcie odpadového materiálu. Pre meranie sú využité vzorky odpadových materiálov z drevárskeho, strojárskeho a stavebného priemyslu. Vzorky sú podrobené sitovej analýze pre určenie zrnitosti jednotlivých frakcií s následným stanovením účinnosti odlučovania. Vírový odlučovač dosahuje odlučivosť nad 96% pre všetky skúmané vzorky odpadového materiálu. Maximálnu odlučivosť 100% dosahuje vírový odlučovač pre plastové frakcie o veľkosti 2 mm a frakcie štrku a piesku o veľkosti 4 mm. Okrem toho, odlučivosť nad 99% dosahujú drevné frakcie o veľkosti 4 mm, 1 mm, 0.6 mm a 0.125 mm, plastové frakcie (0.6 mm a 1 mm), gumené frakcie (2 mm a 4 mm), frakcie štrku a piesku od veľkosti 2 mm po frakcie 0.125 mm, železné prachové frakcie (0.6 mm a 0.125 mm), a hliníkové prachové frakcie (2 mm a 1 mm). Navrhnutý a skonštruovaný odlučovač je schopný efektívne odlúčiť nielen frakcie väčších rozmerov, ale zároveň aj sypký materiál o nízkej zrnitosti. Preto ho možno efektívne využiť nielen ako predodlučovač pre väčšie frakcie, ale aj ako samostatnú jednotku pre odlučovanie jemných frakcií.
Kľúčové slová: odpadový materiál, vírový odlučovač, sitová analýza, frakcia, účinnosť odlučovania

**Kľúčové slová:** etické prostredie, etická kredibilita, riziká, výrobný podnik

## INTRODUCTION

Separation devices for the separation of solid pollutants support limit the leakage of these substances into the air. They are used in various woodworking and engineering industrial operations, where it is necessary to capture the resulting fractions, e.g. from the process of cutting, sawing, grinding, machining the material. In addition to the gravitational force, the difference in the centrifugal force acting on the fractions of the bulk material and on the particles of the carrier gas in the overflow vortex is used to separate the particles of the bulk material from the carrier gas. Vortex separation devices (cyclones) are used to separate coarse and medium coarse fractions of bulk material with fraction sizes of 10 to 100 μm.

For fine fractions with sizes up to 10 μm, the separation efficiency is around 85%, and these cyclones are characterized by a slender shape of an elongated cylinder and cone. For coarser fractions with sizes above 10 μm, the separation efficiency is 90% to 95%, and large-space separators with a diameter of more than 1 m, a smaller height and a more obtuse angle of the cone of the conical part are used for separation (Plandorová & Černecký, 2010). Separation efficiency is a basic parameter used in the design of separation devices. The contribution (Lipnický & Brodnianská, 2021) was focused on the development of a new construction design solution for a cylindrical vortex separator, which would achieve a separation efficiency higher than 95%. This contribution is followed by the currently presented research on the separability of different types of bulk waste material.

Many studies have been carried out to improve the separation efficiency in vortex separators. The author (Alexander, 1949) evaluated the influence of the geometric and operational parameters of the cyclone on its performance. He changed the design and geometry of the cyclone inlet. The authors (Zhao et al., 2004) investigated and compared three cyclone separators with different inlet geometries – tangential single inlet, straight symmetrical spiral inlet and symmetrical spiral inlet. The inlet area is one of the relevant parameters affecting the natural length of the vortex (Cortés & Gil, 2007) and (Avci et al., 2013) comparing the performance of two types of cyclones with conventional single inlets and spiral double inlets. Numerical results show that the cyclone separator using a spiral double inlet can improve the symmetry of the gas flow and increase the particle separation efficiency. The authors (Xiang & Lee, 2008) demonstrated that the tangential velocity increases as the diameter of the overflow pipe decreases, resulting in higher particle collection efficiency, and the pressure drop occurs with increasing pipe diameter. The effect of inlet pipe cross-section was investigated (Qian & Wu, 2009). The authors (Erdal & Shirazi, 2006) also investigated the effect of three different inlet geometries (one inclined inlet, two inclined inlets and a gradually reduced inlet nozzle) on the flow behavior. The effects of cone size on flow pattern and cyclone performance were investigated by (Chuah et al., 2006) and (Xiang et al., 2011). The authors (Qian et al, 2006), (Kaya & Karagoz, 2009) investigated the effect of a cone extended by a vertical tube on the separation performance of the cyclone. The effect of the counter cone at the bottom on the performance of the cyclone was also investigated (Yoshida et al., 2010), (Kepa, 2012). The effect of the shape and diameter of the overflow pipe on the performance of the cyclone has been dealt with by much research. The influence of the dimensions of the inlet opening on the flow and performance of the cyclone was investigated numerically (Elsayed & Lacor, 2011). They found that the effect of changing the width of the inlet is more significant than the height of the inlet, mainly due to the collection efficiency.

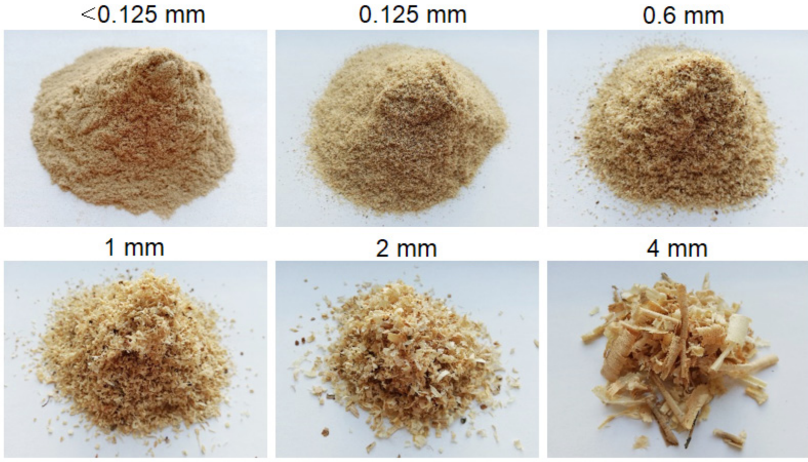
The separation efficiency and pressure drop of a cyclone separator with an exhaust pipe at different depths of its insertion into the cyclone, and different tilt angles, were performed (Chen & Liu, 2010). In addition, other parameters were also considered in the literature. For example, cyclone height was studied by (Hoffman et al., 2001) and (Safikhani et al., 2010). The performance of square-section cyclones was investigated by (Su & Mao, 2006), (Safikhani et al., 2011) and (Su et al., 2011). The researchers also paid attention to the optimization of the dimensions of the conventional cyclone. Optimizing the geometry of the cyclone to minimize the pressure drop using mathematical models and CFD simulations was performed by (Elsayed & Lacor, 2012). A number of different designs of cyclones are described in the literature. One of them is the double cyclone, which was studied by the authors (Zhu et al., 2001), (Lim et al., 2004). The authors (Karagoz et al., 2013) dealt with the design and performance evaluation of a new cyclone separator. Their cyclone design is based on the idea of improving efficiency by increasing the length of the vortex. The new design differs from the classic cyclone by the separation space. Instead of a conical part, the separation space of this separator consists of a cylinder and a swirl limiter. After making a functional model of this new type, the collection efficiency and pressure drop of the cyclone under different operating conditions were monitored. They compared the experimental results with conventional cyclones. They also investigated the effects of vortex restrictor position on cyclone performance. A movable swirl limiter allows the length of the swirls to be adjusted according to the input speed to achieve high efficiency. The effects of the dimensions of the overflow pipe on the natural length of vortices in a new type of vortex separator were investigated by (Tan et al., 2016). They emphasized that the shape and structure of the vortex inside the separator is very important for its efficiency, as it controls the separation process. For research, they used a cylindrical cyclone without a conical bottom. The results showed that the increase in the height of the cyclone, i.e. j. friction surface, leads to a reduction in the vortex length. The diameter and length of the overflow pipe adversely affect the length of the vortices. The authors contribution (Haake et al., 2020) presents experimental and numerical results obtained from a gas-solid vortex separator in which the classic conical shape of the device is replaced by a larger square chamber where the vortex can develop freely. They analyzed both single-phase and multiphase flows. In the second case, very small concentrations of particles, between 100 ÷ 500 mg.m$^{-3}$, were considered. Compared to classic cyclone separators, the new geometry showed advantages in terms of performance, e.g. smaller pressure drop. A vortex restrictor plate was introduced into the precipitator to allow the change of continuous structure and to guarantee the natural length of the eddy flow according to the precipitator inlet velocity. The authors (Fu et al., 2021) dealt with the performance evaluation of an industrial cyclone separator with a new overflow pipe. The overflow pipe was designed with grooves on the wall to improve the performance of the cyclone. The pressure drop was reduced by up to 27.9% compared to the conventional separator and the maximum separation efficiency was increased by 5.45%. Numerical and experimental results indicate that the grooved overflow pipe allows optimization of the separation performance.

The presented contribution is focused on measuring the separation efficiency of fine waste material of the designed and constructed vortex separator. The separation measurement is preceded by the measurement of the grain size of the individual examined samples using the method of sieve analysis. Fractionally sorted samples are subjected to separation with the subsequent determination of separation capacity for individual types of waste material of different fractions. The goal is to achieve the separation efficiency in the new design type of vortex separator higher than 95% for individual fractions of waste material.

## MATERIAL AND METHODS

The separation process in the vortex separator was preceded by a sieve analysis of individual samples of waste material. Fractions from wood waste, plastic car tanks, old tires, gravel and sand, iron dust, and aluminum dust, were used as samples (Fig. 1). Sieve analysis belongs to the group of separation techniques of particle size analysis and is based on the use of a set of sieves with a known hole size. The set of sieves is assembled in the direction of gravitational transport of the analyzed sample with gradually decreasing size of the sieve mesh openings.

The sample with the total weight is laid out on the topmost sieve and is divided into partial weights by gradual shaking. The ground under the sieves is without holes and in our case represents fractions smaller than 0.125 mm. After the end of fractionation, a certain part of the sample remains on each sieve, which contains particles within the limits determined by the hole size of the upper and lower sieve. The sieve retained is weighed and the result evaluated as the weight of fractions with a defined particle size range. For sieve analysis, a vibrating sieve apparatus with a set of analytical metal sieves encased in circular metal frames was used. The ground sieve was placed in the lower part of the sieving device, and sieves with a mesh size of 0.25 mm, 0.5 mm, 1 mm, 2 mm, and 4 mm, were successively placed on it. The top sieve was closed with a lid. The vibrating sieving device was always in operation for 10 minutes in order to properly divide the samples into individual fractions. The samples were weighed with analytical scales SARTORIUS BP 3100 P with an accuracy of ±0.05 g.

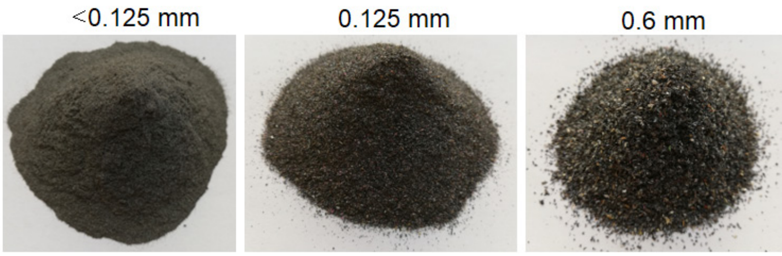



a)

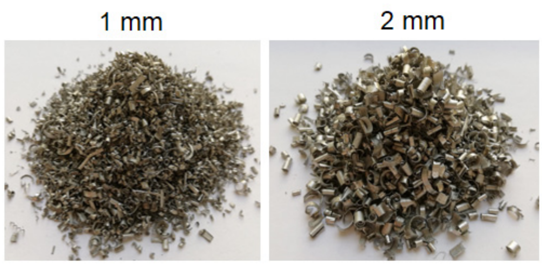

b)


c)


d)




e)




f)

Fig. 1. Fractional distribution of waste material samples
a) wood fractions, b) plastic fractions (automobile tanks), c) rubber fractions (tires),
d) fractions of gravel and sand, e) fractions of iron dust, f) fractions of aluminum dust
Obr. 1. Frakčné rozdelenie vzoriek odpadového materiálu
a) drevné frakcie, b) plastové frakcie (automobilové nádrže), c) gumené frakcie (pneumatiky),
d) frakcie štrku a piesku, e) železné prachové frakcie, f) hliníkové prachové frakcie

The percentage fraction ratio in the sample is expressed using the equation:

$$f_i = \frac{m_i}{\sum m_i} \cdot 100 \quad (1)$$

where $m$ is weight of fraction (g).

Separation of individual fractions of waste material was carried out in a vortex separator (Fig. 2). The vortex separator works on the centrifugal and inertial principle of a double vortex. Gravitational force also acts during the separation of particles. The supplied heterogeneous mixture (air and solid pollutant particles) is fed into a swirling screw movement through the inlet tube (A), which subsequently creates centrifugal force and particle separation. Particles are collected near the wall of the cylindrical chamber and move downward near the inner surface of the cylindrical part of the separator under the influence of gravity. In the lower part of the separator, the air rotates and is directed into the exit tube (5) and then through the outlet tube (C). The separated fractions fall into the collection container (12).

The internal diameter of the separator is DN 200, the inlet pipe for the heterogeneous mixture and the outlet pipe for air is DN 40. The diameter of the bottom container for captured fractions is DN 335 with a volume of 40 liters. For better handling of the separator, rotating wheels are attached to the lower container. The fan is housed in a circular console made of plexiglas and its drive is provided by a 12V source.

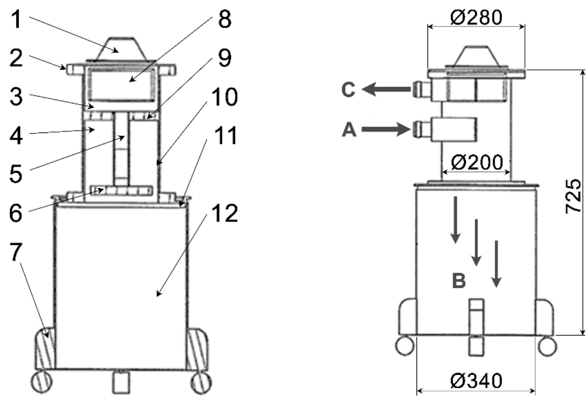



Fig. 2. The scheme of the vortex separator with the main dimensions
A – inlet of heterogeneous mixture, B – separated fractions, C – air outlet, 1 – electric motor, 2 – fan cover, 3 – upper chamber, 4 – lower chamber, 5 – exit tube, 6 – inner ring, 7 – handling wheel console, 8 – fan, 9 – dividing plane, 10 – separator body, 11 – lid of collection container, 12 – collection container

Obr. 2. Schéma vírového odlučovača s hlavnými rozmermi
A – vstup heterogénnej zmesi, B – odlúčené frakcie, C – výstup vzduchu, 1 – elektromotor, 2 – veko ventilátora, 3 – horná komora, 4 – dolná komora, 5 – odťahové potrubie, 6 – medzikružie, 7 – konzola manipulačných kolies, 8 – ventilátor, 9 – deliaca rovina, 10 – teleso odlučovača, 11 – veko zbernej nádoby, 12 – zberná nádoba

## RESULTS

In the first step, individual samples of waste material subjected to separation in a new design type of vortex separator were divided into fractions using sieve analysis. The percentages of individual fractions in sample *f*, and the values of retained $Z_a$ and passing $P_a$ are shown in Table 1. The percentage of the representation of individual fractions in each sample *f* was calculated according to equation (1) and graphically the results are shown in Fig. 3.The distribution of individual fractions is expressed using bar diagrams - histograms, where the percentage numbers of fractions *f* (%) are plotted for individual size intervals *a* (mm).

Wood fractions were separated by sieve analysis into sizes from 4 mm to less than 0.125 mm. All fractions were separated by the vortex separator above 97%, while the highest separation efficiency of 99.99% was achieved by fractions with a size of 1 mm (Fig. 3a). Plastic samples from car tanks reached the highest representation at a grain size of 2 mm (56.21%), and their separation efficiency reached up to 100.00%. As the grain size of the material decreases to 1 mm and 0.6 mm, the separation efficiency also decreases to 99.94% and 99.03%, respectively (Fig. 3b). Rubber samples from old tires could be divided by sieve analysis into two fractions, while the fraction with a grain size of 2 mm had a representation of up to 88.48% and the separation efficiency reached 99.97%. At a grain size of 4 mm, the separation efficiency dropped to at least 99.92% (Fig. 3c). Gravel and sand could be divided into fractions from 4 mm to <0.125 mm. The highest separation efficiency of 100.00% was achieved by fractions with a grain size of 4 mm, while a significant decrease in separation efficiency occurred with fractions smaller than 0.125 mm (96.73%). Fractions in the range of 0.125 mm to 2 mm achieved a separation efficiency of over 99% (Fig. 3d).

Table 1. Results of the sieve analysis of the individual waste material samples
Tabuľka 1. Výsledky sitovej analýzy jednotlivých vzoriek odpadového materiálu

| Sieve size (mm) | Total weight of sample (g) | Fraction ratio *f* (%) | Retained $Z_a$ (%) | Passing $P_a$ (%) |
|---|---|---|---|---|
| *Wood fractions* | | | | |
| **4** | 1,204.83 | 19.24 | 19.24 | 80.76 |
| **2** | | 5.68 | 24.92 | 75.08 |
| **1** | | 7.04 | 31.96 | 68.04 |
| **0.6** | | 23.46 | 55.42 | 44.58 |
| **0.125** | | 39.23 | 94.65 | 5.35 |
| **<0.125** | | 5.35 | 100.00 | 0 |

| | | | | |
|---|---|---|---|---|
| *Plastic fractions (automobile tanks)* | | | | |
| **2** | 740.38 | 56.21 | 56.21 | 43.79 |
| **1** | | 39.20 | 95.41 | 4.59 |
| **0.6** | | 4.59 | 100.00 | 0 |
| *Rubber fractions (tires)* | | | | |
| **4** | 803.84 | 11.52 | 11.52 | 88.48 |
| **2** | | 88.48 | 100.00 | 0 |
| *Fractions of gravel and sand* | | | | |
| **4** | 7,351.44 | 22.19 | 22.19 | 77.81 |
| **2** | | 18.12 | 40.31 | 59.69 |
| **1** | | 12.58 | 52.90 | 47.10 |
| **0.6** | | 17.28 | 70.17 | 29.83 |
| **0.125** | | 26.00 | 96.17 | 3.83 |
| **<0.125** | | 3.83 | 100.00 | 0 |
| *Fractions of iron dust* | | | | |
| **0.6** | 2,606.74 | 16.10 | 16.10 | 83.90 |
| **0.125** | | 41.97 | 58.07 | 41.93 |
| **<0.125** | | 41.93 | 100.00 | 0 |
| *Fractions of aluminum dust* | | | | |
| **2** | 568.62 | 72.33 | 72.33 | 27.67 |
| **1** | | 27.67 | 100.00 | 0 |

Iron dust waste could be divided into three fractions by sieve analysis, with the highest separation efficiency achieved by fractions of 0.125 mm (99.98%), but with decreasing grain size, the separation efficiency also decreased to 98.85% for fractions smaller than 0.125 mm (Fig. 3e). Aluminum dust waste could be divided by sieve analysis into fractions with a grain size of 1 mm and 2 mm, while the fractions of 2 mm achieved a separation efficiency of up to 99.93% and the fractions with a grain size of 1 mm a slightly lower 99.85% (Fig. 3f).

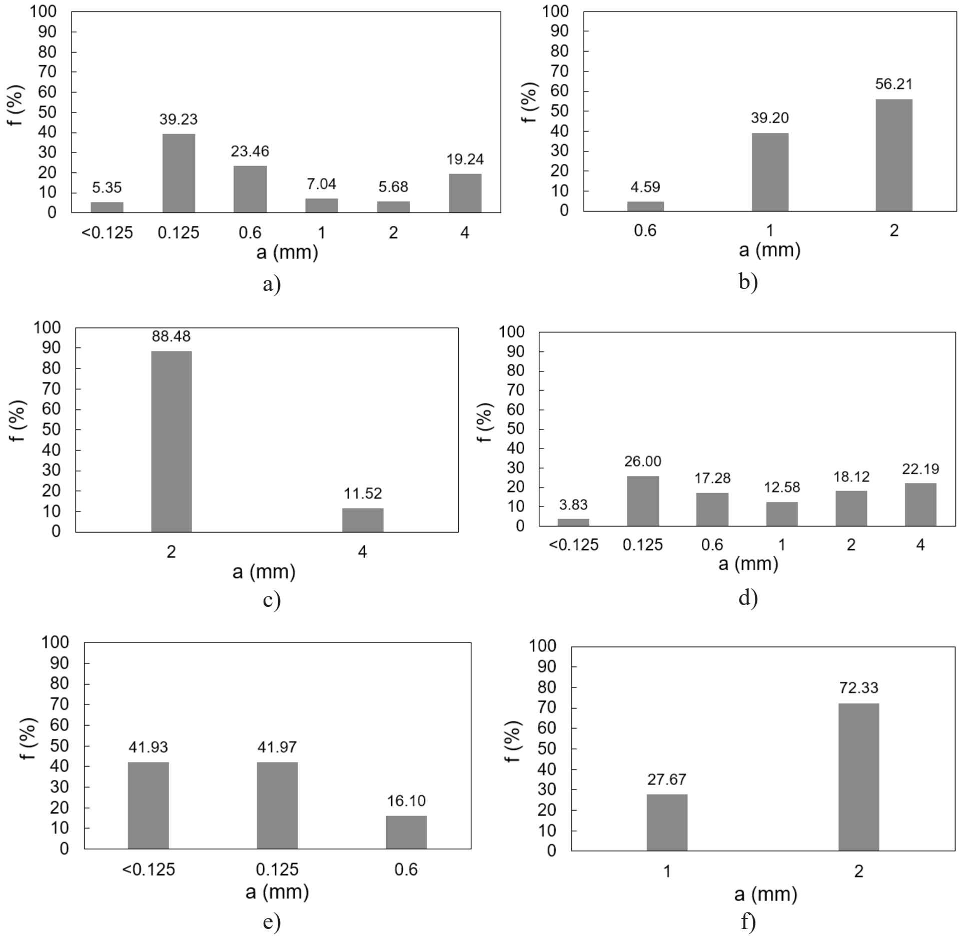
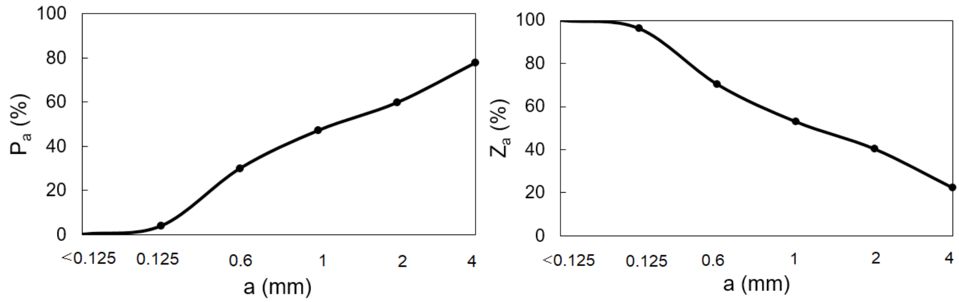
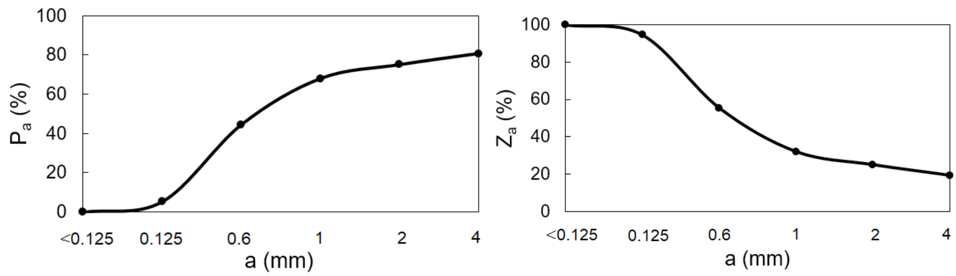



Fig. 3. Bar chart of percentage representation of fractions in the sample
a) wood fractions, b) plastic fractions (automobile tanks), c) rubber fractions (tires),
d) fractions of gravel and sand, e) fractions of iron dust, f) fractions of aluminum dust
Obr. 3. Stĺpcový diagram zastúpenia frakcií vo vzorke
a) drevné frakcie, b) plastové frakcie (automobilové nádrže), c) gumené frakcie (pneumatiky),
d) frakcie štrku a piesku, e) železné prachové frakcie, f) hliníkové prachové frakcie

The passing and retained curves for the gravel and sand sample and the wood waste sample are shown in Fig. 4. The passing curve $P_a$ expresses the dependence of the relative weight of smaller grains in the analyzed sample than the particle size $a$. The retained curve $Z_a$ expresses the dependence of the relative weight of larger grains in the analyzed sample than the particle size $a$. The total of the values within the passing and retained curve of one sample represents 100% (Dzurenda, 2007).




a)




b)

Fig. 4. Passing and retained curves
a) fractions of gravel and sand, b) wood fractions
Obr. 4. Krivky prepadov a zvyškov
a) frakcie štrku a piesku, b) drevné frakcie

The separation efficiency η of the individual fractions of the examined waste material samples is graphically shown in Fig. 5. The maximum separation efficiency of 100% is achieved by the vortex separator for plastic fractions with a size of 2 mm and gravel and sand fractions with a size of 4 mm. On the contrary, the lowest separation efficiency (96.73%) is achieved by fractions of gravel and sand with a grain size smaller than 0.125 mm.

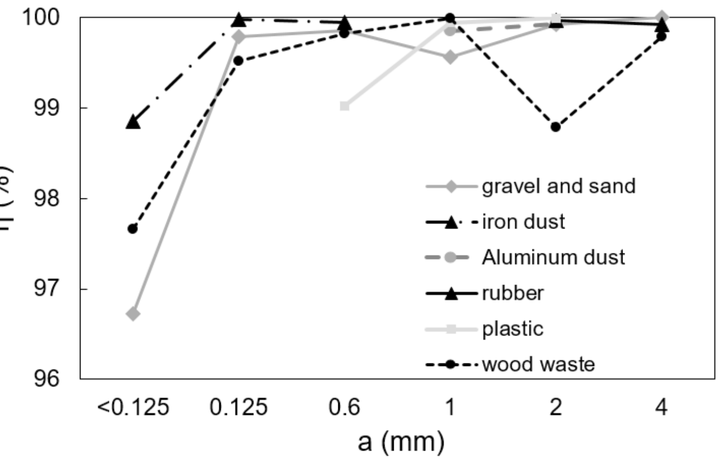



Fig. 5. Distribution of separation efficiency of individual fractions of examined waste material samples
Obr. 5. Priebeh účinnosti odlučovania jednotlivých frakcií skúmaných vzoriek odpadového materiálu

The separation efficiency η is expressed as the ratio of the weight of the fraction after separation to the weight of the fraction before separation. The specific weights of the individual fractions of the investigated samples are shown in Table 2. Wood fractions with a size of 4 mm, 1 mm, 0.6 mm, and 0.125 mm, plastic fractions (0.6 mm and 1 mm), rubber fractions (2 mm and 4 mm), gravel and sand fractions from 2 mm to fractions of 0.125 mm, iron dust fractions (0.6 mm and 0.125 mm), and aluminum dust fractions (2 mm and 1 mm), achieved separation efficiency above 99%. It cannot be unequivocally stated that with a decrease in the size of the fractions, the separation efficiency of the vortex separator also decreases. Each fraction entering to the vortex separator has different conditions for separation. These conditions depend on several factors, e.g. the weight and grain of the particles, the resistance coefficient, the velocity and turbulence in the separator, the position of the particles in the inlet pipe of the separator. For this reason, the implementation of experimental determination of the separation efficiency of the given vortex separator is indispensable.

Table 2. Separation efficiency of individual waste material samples
Tabuľka 2. Hodnoty účinnosti odlučovania jednotlivých vzoriek odpadového materiálu

| **Sieve size** ***a*** **(mm)** | **Fraction weight before separation (g)** | **Fraction weight after separation (g)** | ***Separation efficiency*** **η (%)** |
|---|---|---|---|
| *Wood fractions* | | | |
| **4** | 231.81 | 231.33 | 99.79 |
| **2** | 68.46 | 67.63 | 98.79 |

| | | | |
|---|---|---|---|
| **1** | 84.76 | 84.75 | 99.99 |
| **0.6** | 282.70 | 282.19 | 99.82 |
| **0.125** | 472.61 | 470.35 | 99.52 |
| **<0.125** | 64.49 | 62.98 | 97.66 |
| *Plastic fractions (automobile tanks)* | | | |
| **2** | 416.19 | 416.17 | 100.00 |
| **1** | 290.21 | 290.05 | 99.94 |
| **0.6** | 33.98 | 33.65 | 99.03 |
| *Rubber fractions (tires)* | | | |
| **4** | 92.58 | 92.51 | 99.92 |
| **2** | 711.26 | 711.04 | 99.97 |
| *Fractions of gravel and sand* | | | |
| **4** | 1631.15 | 1631.13 | 100.00 |
| **2** | 1332.20 | 1331.18 | 99.92 |
| **1** | 925.16 | 921.18 | 99.57 |
| **0.6** | 1270.10 | 1268.25 | 99.85 |
| **0.125** | 1911.15 | 1907.10 | 99.79 |
| **<0.125** | 281.68 | 272.46 | 96.73 |
| *Fractions of iron dust* | | | |
| **0.6** | 419.58 | 419.36 | 99.95 |
| **0.125** | 1094.12 | 1093.90 | 99.98 |
| **<0.125** | 1093.04 | 1080.46 | 98.85 |
| *Fractions of aluminum dust* | | | |
| **2** | 411.30 | 411.00 | 99.93 |
| **1** | 157.32 | 157.09 | 99.85 |

## CONCLUSION

By using the newly designed construction type of vortex separator, a separation efficiency higher than 96% for fractions of waste material with a size of 4 mm to <0.125 mm can be achieved. Wood waste fractions, plastic fractions from car tanks, rubber fractions from used tires, gravel and sand fractions, iron dust fractions, and aluminum dust fractions, were used for separation research. The mentioned waste material arises in the woodworking, engineering, and building industries. The highest separation efficiency of up to 100% was achieved by the vortex separator for plastic fractions with a size of 2 mm and gravel and sand fractions with a size of 4 mm. Wood fractions of size 4 mm, 1 mm, 0.6 mm, and 0.125 mm, plastic fractions (0.6 mm and 1 mm), rubber fractions (2 mm and 4 mm), gravel and sand fractions from 2 mm to 0.125 mm, iron dust fractions (0.6 mm and 0.125 mm), and aluminum dust fractions (2 mm and 1 mm), reached separation efficiency above 99%. The lowest separation efficiency of 96.73% was achieved by fractions of gravel and sand with a grain size smaller than 0.125 mm.

The experimental results confirmed that the constructed vortex separator can be effectively used not only for separation of larger sizes fractions, but also material with low grain size. By separating of solid pollutants, they do not enter the surrounding environment, which has a positive effect not only on the air, but also on the health of workers within closed industrial operations.


## ACKNOWLEDGMENT

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# MATERIAL ANALYSIS OF THE SPLITTING WEDGE AND SUGGESTIONS OF POSSIBILITY TO GROWTH ITS OPERATING LIFE.

# MATERIÁLOVÁ ANALÝZA ŠTIEPACIEHO KLINA A NÁVRHY MONŽNOSTÍ ZVÝŠENIA JEHO ŽIVOTNOSTI

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**ABSTRACT:** Articel focuses on the material analysis of the splitting wedge for the production of wood chips, in order to identify opportunities to increase its life. The theory of splitting wedges, the most frequently used materials, types of wear of materials, possibilities of increasing the service life and requirements and procedures in tests are presented in the article based on sources from the professional literature. A chemical analysis, hardness test and microstructure evaluation were performed on the assessed tool - splitting wedge, which showed us what material was used for the production of the tool. According to the facts found, we can conclude that the steel used for the production of the splitting wedge can be material 12 040 or 19 065. However, our analyzes show that the steel used is 12 040, which is confirmed by the measured values during the experiment such as HBW, detected micropurity and microstructure analysis. Based on the detected parameters, we have more options to increase the life of the tool. One of them is cementation, which would increase the carbon content on the tip of the tool and the subsequent clouding and tempering of the structural steel will increase the hardness of the tip of the tool. The second option is to replace structural steel 12 040 with tool steel 19 065 and its subsequent coating, which will significantly increase the hardness of the coated part of the tool. This in turn gave us more options on what methods and procedures to design to improve the life of the splitting wedge.

**Key words:** material analysis, splitting wedge, material wear, service life, microstructure

**ABSTRAKT:** Článok sa zameriava na materiálovú analýzu štiepacieho klina pre výrobu drevnej štiepky, za účelom zistenia možností zvýšenia jeho životnosti. V práci na základe zdrojov z odbornej literatúry je uvedená teória týkajúca sa štiepacích klinov, najčastejšie používaných materiálov, druhy opotrebení materiálov, možnosti zvyšovania životnosti a požiadavky a postupy pri skúškach. Na posudzovanom nástroji – štiepacom kline sa vykonala chemická analýza, skúška tvrdosti a hodnotenie mikroštruktúry, čo nám ukázalo aký materiál bol na výrobu nástroja použitý. Podľa zistených skutočností môžeme konštatovať, že oceľ použitá na výrobu štiepacieho klina môže byť materiál 12 040 alebo 19 065. Naše analýzy ale poukazujú nato, že použitá oceľ je 12 040 čo potvrdzujú merané hodnoty počas experiment ako je HBW, zistenej mikročistoty a analýze mikroštruktúry. Je viac možností ako zvýšiť životnosť nástroja. Jednou z nich, je cementovanie, čo by zvýšilo obsah uhlíka na hrote nástroja a následné zakalenie a popustenie konštrukčnej ocele nám zvýši tvrdosť hrotu nástroja. Druhou možnosťou, je výmena konštrukčnej ocele 12 040 za oceľ nástrojovú 19 065 a jej následné povlakovanie ktoré výrazne zvýši tvrdosť povlakovanej časti nástroja.To nám následne dalo viac možnosti, aké metódy a postupy navrhnúť pre zlepšenie životnosti štiepacieho klina.

**Kľúčové slová:** materiálová analýza, štiepací klin, opotrebenie materiálu, životnosť, mikroštruktúra

## INTRODUCTION

The cutting tool is an active member of the cutting process, which removes excess material in the form of chips. It consists of a cutting (active) part called a cutting wedge and a clamping part - a shank that serves to fasten the tool to the machine. The cutting wedge of the tool is the part of the tool that is able to penetrate the material being machined (Mečiarová, Kalincová, 2012). During mechanical splitting, the splitting wedge is pressed between the wood fibers most often at the front of the cutout in the longitudinal direction. Because in this direction the wood fibers offer the least resistance against separation from each other. The splitting wedge first compresses the wood fibers and only then penetrates between the fibers and widens the resulting crack with its sides (Mikleš, 2011, Melicherčík, Krilek 2018). In mathematics, certain predictions are made about the force and energy that must be used to drive a wedge into a material. For all wedge structures, the force rises to a maximum at the beginning and then decreases. The maximum force required will be greater when using wider angle wedges. However, the force will continue to decrease in the wider angle wedges to a lower constant value due to the reduced friction between the wedge and the wood so the energy required to produce a given length of cut will be lower. It follows that the higher the coefficient of friction between the wedge and the wood, the greater the force and energy required to split the wood.

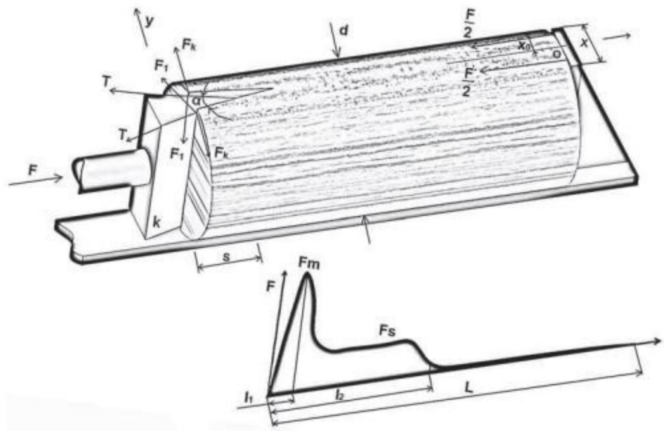


Fig. 1 Diagram of the forces acting during wood splitting (Krilek and Remper, 2012)
Obr.1 Diagram síl pôsobiacich pri štiepaní dreva (Krilek and Remper, 2012)

Figure 1 shows a diagram of the forces acting during wood splitting, where: k- splitting wedge, o- support, d- diameter of the splitting log, L- length of the splitting log, F- pushing force on the wedge, α- front angle of the wedge, $F_m$- Maximum splitting force, $F_1$- force perpendicular to the face of the wedge, $F_k$- force causing splitting of the log, s- wedge path, x- width of support, $x_o$- arm of center of support reaction, $l_1$- length of approach wedge with maximum thrust, $l_2$- length of intrusive wedge with average thrust, $F_S$- average splitting force.

## Types of wear of wood splitting tools

Wear is a permanently undesirable change in the surface (dimensions) caused by the interaction of functional surfaces or the functional surface and the wearing medium. It manifests itself as the removal or displacement of particles from the worn surface by mechanical effects, sometimes accompanied by other influences (e.g. chemical, electrochemical, electrical). According to the standard, we define 7 types of consumables:

- adhesive wear
- abrasive wear
- erosive wear
- cavitation wear
- fatigue wear
- vibration wear
- other wear and tear (STN 01 5050:1968).

To increase the service life of splitting wedges, we can use various methods, such as heat, chemical-heat treatment and coating (Ťavodová, Kalincová, 2019, Vargová et al.2022, Votava et al.2005,).

Among the most widespread technological processes of heat treatment are annealing, hardening and tempering, and for chemical-heat treatment it is cementation and nitriding. Another way can be coating the surfaces of cutting tools (Ťavodová, Kalincová, Krilek, 2016, Peković et al.2018, Müller et al. 2018). Heat treatment includes technological procedures in which changes in the structure and subsequently changes in the properties of alloys in the desired direction are achieved through a controlled thermal regime. The essence of heat treatment consists in phase transformations that take place during heating and cooling.

## MATERIAL AND METHODS

The experiment was carried out on a splitting knife (Fig. 2) for the production of wood chips, in order to propose the improvement of the service life in various suitable ways. We did not know what the knife was made of, therefore, in order to make suggestions for increasing the service life, it was necessary to perform input analyses. We performed a chemical analysis of the material, then measured the hardness of the material, and then prepared and subjected the sample to micropurity analysis and microstructure evaluation.

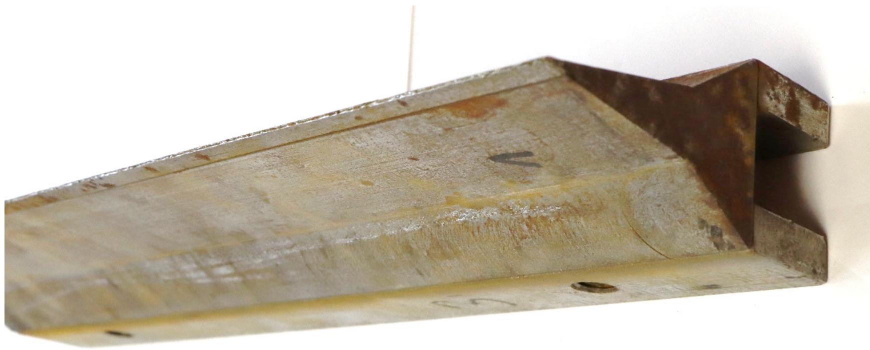

Fig. 2 The splitting wedge used in the experimental measurement
Obr. 2 Štiepací klin použitý pri experimentálnom meraní

### Chemical analysis

In order to identify the material used in the production of the splitting wedge, an elemental chemical analysis was performed on a Q4 TASMAN spark spectrometer at the Institute of Materials and Machine Mechanics of the SAV detached workplace of INOVAL in Žiar nad Hronom. Based on the chemical analysis, we found out the chemical composition of the knife, which is shown in Table 1. Subsequently, they were compared with possible steels according to the material sheets obtained from the lexicon of metals.

Table 1 Chemical composition of the investigated fission wedge
Tabuľka 1 Chemické zloženie skúmaného štiepacieho klina

| Element | C | Si | Mn | P | S | Cr | Cu | Al | Fe |
|---|---|---|---|---|---|---|---|---|---|
| hm [%] | 0,242 | 0,043 | 0,385 | 0,035 | 0,079 | 0,076 | 0,115 | 0,014 | zvyšok |

From the above, we can conclude that our material can be:

- carbon steel for refining STN 41 2040,
- tool carbon very tough steel of the 3rd quality group STN 41 9065.

For carbon steel for refining 12 040 (C35E), the chemical composition is according to the material sheet in Table 2.

Table 2 Chemical composition of steel 12 040
Tabuľka 2 Chemické zloženie ocele 12 040

| Element | C | Si | Mn | P | S | Cr | Cu | Fe |
|---|---|---|---|---|---|---|---|---|
| hm [%] | 0,32-0,40 | 0,15-0,40 | 0,5-0,8 | Max 0,04 | Max 0,04 | Max 0,25 | Max 0,30 | Zvyšok |

Depending on the possible semi-finished product, the hardness of this steel can be 155-208 HB for thicker hot-rolled sheets and 135-202 HB for forgings. The technological data for this steel are:

- normalizing annealing 840 – 870°C,
- soft annealing 680 – 870°C,
- quenching (Cooling in water) 840 – 870°C,
- quenching (cooling in oil) 850 – 880°C,
- tempering 540 – 680°C.

Material STN 12 040 is mainly used for large shafts of stable combustion engines, steam engines and pumps, eccentrics, columns and cylinders of presses, pins, pins, piston rods, connecting rods, rods. (STN 41 2040:1989).For carbon tool steel 19 065 (C35W3), the chemical composition is according to the material sheet in Table 3.

Table 3 Chemical composition of steel 19 065
Tabuľka 3 Chemické zloženie ocele 19 065

| Prvok | C | Si | Mn | P | S | Cr | Ni | Fe |
|---|---|---|---|---|---|---|---|---|
| hm [%] | 0,3-0,4 | Max 0,3 | 0,3-0,6 | Max 0,035 | Max 0,035 | Max 0,20 | Max 0,25 | Zvyšok |

The hardness of this steel, depending on the suitable semi-finished product, can be max. 170HB (forging). The technological data for STN 19 065 are as follows:

- normalizing annealing 850 – 880°C,
- soft annealing 680 – 710°C,
- annealing to reduce stress 600-650°C,
- cementation in gas 840 – 880°C,
- hardening (cooling in water cement. Layer min. 62 HRC) 770 – 800°C,
- quenching (cooling in water without cementation min. 48 HRC) 850 – 880°C,
- tempering 100-200°C,
- hardness of the cemented layer 60-63 HRC.

This type of material is used in the production of hand tools such as files and for cemented tools such as plates for steel printing (STN 41 9065:1967).

**Hardness measurement**

The Rockwell hardness measurement method was used in the experiment. When measuring on the sample, it was not possible to measure the Rockwell hardness values, as the material was too soft. From this we can conclude that the material was not heat treated. Subsequently, the hardness measurement method according to Brinell HBW 10/100 was used. During this test, a ball of sintered carbide or steel is pushed into the material. Pushing the ball takes place with a uniformly increasing force up to the prescribed value. The measured values are in Table 4.

Table 4 Brinell hardness measurement results
Tabuľka 4 **Výsledky z merania tvrdosti podľa Brinella**

| **Number of measurements** | **1** | **2** | **3** | **Average** |
|---|---|---|---|---|
| **Measured hardness** | 184 HBW | 195 HBW | 177 HBW | 185 HBW |

The hardness measurement was carried out at the Institute of Materials and Machine Mechanics SAV detached workplace INOVAL in Žiar nad Hronom using a Duravision 300 device.

**Preparation of sampling material**

The experiment was carried out in the metallographic laboratory at the Department of Production Technology and Quality Management. First, a dentacrylic mass was prepared using dentacrylic powder and metalacrylic resin, which was used to cast the sample in the mold. Solidification of the sample took 2 hours. After the sample had hardened in the mold, the sample was removed and wet ground. Sanding papers with grits of 180, 220, 320, 400, 600 were used for sanding. During sanding, the sample was always rotated by 90º every time the sanding paper was changed. This achieved regrinding of the grooves from the previous grinding. The sanding process with the highest grain paper was completed and the prepared sample was rinsed. The polishing of the experimental sample was performed on two different polishing discs with 3 µm and 1 µm diamond suspension.

The polishing interval was from 4-5 minutes until sufficient polishing, which represents a mirror-glossy surface. In this step, the sample was prepared for the evaluation of the micropurity of the material.

## RESULTS AND DISCUSION

Micropurity was checked on a Versamet light optical microscope (Fig. 3a) on a polished sample at 200x magnification. This observation was made after polishing before etching the sample. After examining the sample, we found that the sample contains sulfides – A and aluminium oxides – B (Fig. 3b). According to the comparative scale for determining inclusions (impurities, inclusions) in steel according to Jernkontoret, we determined the number and content of inclusions in the observed material. We determined the content of sulphides - A as A2/4 and the content of aluminium oxides as B2/9.

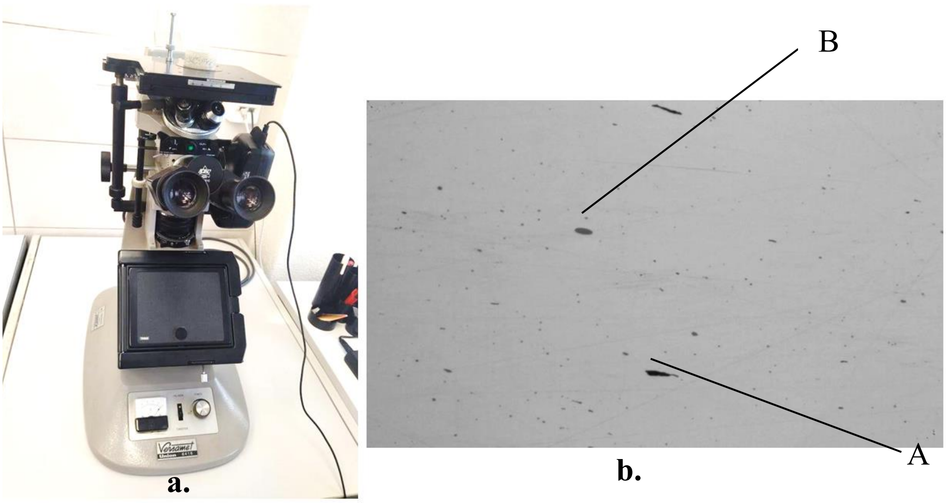


Fig. 3 **a.** Light optical microscope Versamet, **b.** Micropurity of the tested sample at 200x magnification

Obr.3 **a.** Svetelný optický mikroskop Versamet **b.** Mikročistota skúšanej vzorky pri zväčšení 200x

After evaluating the micropurity of the material, the sample was etched with a 4% Nital etchant. A Versamet light optical microscope at 200x magnification was also used to evaluate the microstructure. A photo of the microstructure was taken on a microscope with a Cannon camera (Fig. 4). In Fig. 4 we can observe the microstructure of the material. We can conclude that it is a ferritic-pearlitic steel, and that the carbon content approximately corresponds to the chemical analysis.

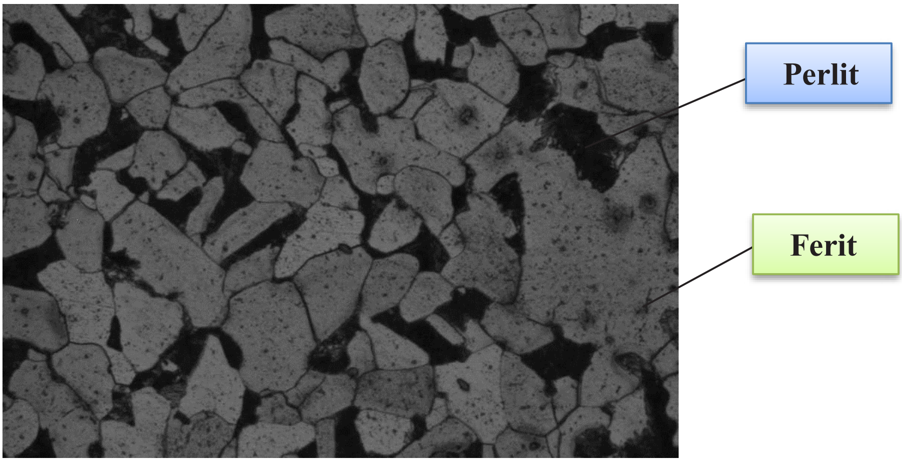


Fig. 4 Evaluation of the microstructure of the sample
Obr.4 Vyhodnotenie mikroštruktúry vzorky

## CONCLUSION

According to the facts found, we can conclude that the steel used for the production of the splitting wedge can be material 12 040 or 19 065. However, our analyzes show that the steel used is 12 040, which is confirmed by the measured Brinell hardness values, the micropurity of the material and the microstructure analysis. The ferritic-pearlitic structure is coarser than usual for tool steels. Possibilities and proposals for increasing the service life of the splitting wedge can be realized by the process of hardening and tempering. When hardening and tempering the 12 040 steel, we would achieve greater hardness of the cutting edge, but also greater fragility. Since our material has only 0.24% carbon, it is not ideal for hardening and would not achieve such an increase in hardness that would significantly affect the service life of the cutting wedge. Cementation, as a surface treatment of steel, significantly increases the hardness of the cutting edge, resulting in less wear. After cementing, the steel would cloud again and then yield.

The replacement of steel 12 040 will provide us with better properties of the material, which means a better service life of the material. Steel 19 065 has significantly better mechanical properties than steel 12 040. This steel is already heat treated, which will make it easier for us to further process the steel. The more the steel is contaminated with inclusions (Figure 3), the greater the possibility of a reduction in mechanical properties.

When using coating, we have to consider at what temperature the steel tempers and thus choose the right coating. For steel 19 065, the tempering temperature is 100 - 200°C, so we have to choose the coating so as not to affect the material thermally. The following coatings are suitable for application: CrN, CrCN, CrTiN, TiN, TiCN. These coatings have a very good use for cement steels. The TiN coating for mild steels reaches a hardness of 240-300 HV. For refined steel, it is from 400-500 HV (www.bohler.sk), which could significantly increase the service life of the cutting wedge.

According to the identified factors, we have more options to increase the service life of the tool. One of them is cementation, which would increase the carbon content on the tip of the tool. The subsequent clouding and tempering of the structural steel will increase the hardness of the tool tip. The second option is to replace structural steel 12 040 with tool steel 19 065 and its subsequent coating, which will significantly increase the hardness of the coated part of the tool. This would ensure smoother operation of the machine and reduce tool change costs.

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