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Determination of twist drill bits wear: the effect of the composition and structure of the steels

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The aim of the study was to relate the influence of the chemical composition, structure, and basic properties as hardness of the tested drill bits on resistance to their wear. The chemical composition of the drill bit was investigated using the electric excitation emission spectrometry method and EDS microanalysis. Metallographic specimens were prepared and observed to determine the structure of each tool. Hardness tests were carried out on the shank and the working part of the tools. Material wear tests were carried out on the basis of measuring the wear of the drill bit flank. It has been shown that the appropriate selection of the chemical composition and heat treatment has a significant impact on the wear resistance of cutting tools, which directly translates into their quality.

Keywords: drilling, high-speed tool steel, EDS, tool wear, microstructure

INTRODUCTION

Drilling is a very common, but demanding machining process, considered to be the most popular used method of making holes[1]. It is based on the use of a multipoint tool (drill bit) to remove an undesirable fragment of material in the place where the hole is to be made[2]. The process itself can be divided into two parts: the first involving the operation of the cutting edges and the second related to the operation of the chisel edge at the centre of the drill bit[3]. During operation, the drill is subject to mechanical and thermal effects, which cause damage and change the parameters of its initial state[4]. Drilling is used not only in machine building, the aviation industry[5], electronics and other industries, but also in everyday life during home renovation works[6]. While in the last of the mentioned areas of application it can be said that the quality of drill bits and their wear resistance are of little importance, in industrial applications it determines the high-quality level of holes made, which directly and indirectly translates into production costs. For this reason, it seems reasonable to use advanced tools while taking into account the economic aspect of the chosen solution. This selection should be made on the basis of the knowledge of the operating conditions of the tools, the type of load, the maximum temperature in the cutting process, etc. The profitability of choosing steel with a lower alloy content must always be considered comprehensively, taking into account not only the expenditure on alloying additives but also the production costs tools and their durability[7]. On the basis of theoretical and experimental tests, it is necessary to determine the possible changes in the condition of tools in the process of exploitation, define the criterion of the tool condition and the criterion of the loss of the cutting capacity of the drill bit[7].

The heat generated when drilling in the cutting zone is distributed among the environments involved in this process (more than 50% of the total heat is transferred to the processed material). On the basis of the conducted research, it was observed that the place of wear is a heat source (so quantitatively the heat increases with the increase of wear). When drilling steel, such a heat source that increases with time is the wear on the flank (VB) because its power increases with increasing wear. With an increase in VB, the thermal deformation of the workpiece also increases, and the drilled holes in the body-type parts deform in such a way that their diameter decreases. After some time, when the deformation exceeds the clearance resulting from the reverse tapering of the drill, the treated surface of the hole will cause the contact surface of the plaques to change, their wear, and consequently catastrophic wear on the drill bit[7]. Moreover, the wear of the drill bit directly affects the value of the axial force and the cutting torque[8].

Drill bits are made of tool materials that allow cutting other materials. The most popular group of tool materials is tool steels. They present desirable properties such as good strength with sufficient hardness, abrasion resistance, and impact strength. Their significant advantage is also a relatively lower price compared to other materials[2, 9].

The holes made are required to be of high accuracy and quality[10]. These features can be provided only by an unharmed and undamaged drill bit, which in practice means the need to use high-alloy tool steels, capable of working at high temperatures and allowing slow wear of the cutting edge made of them[2]. A very important aspect is the diagnostics of the entire cutting process in the context of assessing the proper condition of the tool and associating it with the serviceability condition[4]. In addition to the properties of the drill bit itself at least a few variables affect the quality of the drilled holes. The most important are cutting parameters and configurations of cutting tools[1, 11].

In machining, the twist drill bit is most often used, the cutting geometry of which is much more complex than in the case of other cutting tools[12]. The geometry of tool, the materials of the drill bit and workpiece as well as the operational parameters of the process are the most important factors affecting the performance of the drill bit, the efficiency of the process and the quality of the hole[13]. The defect on the hole wall is influenced by the interaction between the cutting edges of the drill bit and the drilled material[14]. When drilling in a metal sheet, burrs are formed at the entrance and exit of the hole as a result of plastic deformation of the workpiece material[15]. The Taguchi method can be used to optimize the surface and hole quality. The results of the experiments show that the feed speed and drill diameter directly affect the pressure force, while the feed and spindle speed have the greatest influence on the surface roughness[16]. It was observed that the tool wear was primarily influenced by the depth of cut[17].

Tool wear monitoring is essential to reduce costs and improve productivity in the machining industry[18]. In the source literature, there are many publications showing how to optimize the geometry of the drill bit, which determines its longer durability[19, 20, 21]. A number of experiments and calculations were also carried out to confirm the impact of the appropriate selection of drill bit geometry on the reduction of e.g. delaminations[22]. In many works, information on special techniques or process parameters that allow to achieve optimal cutting conditions can be found[1, 23, 24]. Wong et al.[24] and Waqar et al.[25] conducted an experimental test on the effects of drill point geometry and drilling technique on the tool life and the quality of the holes. The holes were drilled in Titanium alloy (Ti alloy) material. The analysed variables were: different geometries of drill bits, various cutting speeds and drilling methods. The authors showed that all analysed variables affect tool wear performance when drilling titanium alloy. It has been observed that lower cutting speeds contribute to a longer tool life. In this way, the best solution was a spiral point drill. It was related to the advantages of low thrust, torque, energy, and burr size. A correlation between feed rate and hole diameter was non-linear. The analysis of the literature data shows that it is worth conducting research on the influence of other factors, such as the exact diameter or material of the drill, on the wear of the tool.

The type of material the drill is made of undoubtedly affects its durability. The use of a hard coating reduces the friction coefficient between the drill bit and the workpiece. A properly adjusted coating, e.g. of titanium nitride, may contribute to the reduction of wear due to adhesive processes occurring during machining[2]. Jaromi conducted tests to develop empirical correlations between drill bits wear in function of cutting speed and feed rate for three different coatings[23].

A very important issue is the detailed knowledge about the chemical composition and structure of the material from which the drill bit was made. This will make possible to predict its behavior under certain operating conditions[26].

The aim of this study was to evaluate the effect of chemical composition, structure, and other basic properties (such as e.g. hardness) of selected commercial drill bits on resistance of mechanical wear. Although there is a large database of information that provides guidelines for selecting the right drill for a specific, defined machining process, the literature lacks a simple relationship showing the differences in drill wear depending on the type of drill material. An additional purpose was to compare the information provided by the manufacturer with the real data.

MATERIALS AND METHODS

The subject of the research was commercial twist drill bits with a diameter of φ = 10 mm, with the same apex angle and shank with the same application recommen--dations from the manufacturer intended for drilling in metal. The drill bits are designated conventionally as A, B, and C. These drill bits were produced by the same manufacturer. In order to investigate the effect of the chemical composition and structure of steel on the

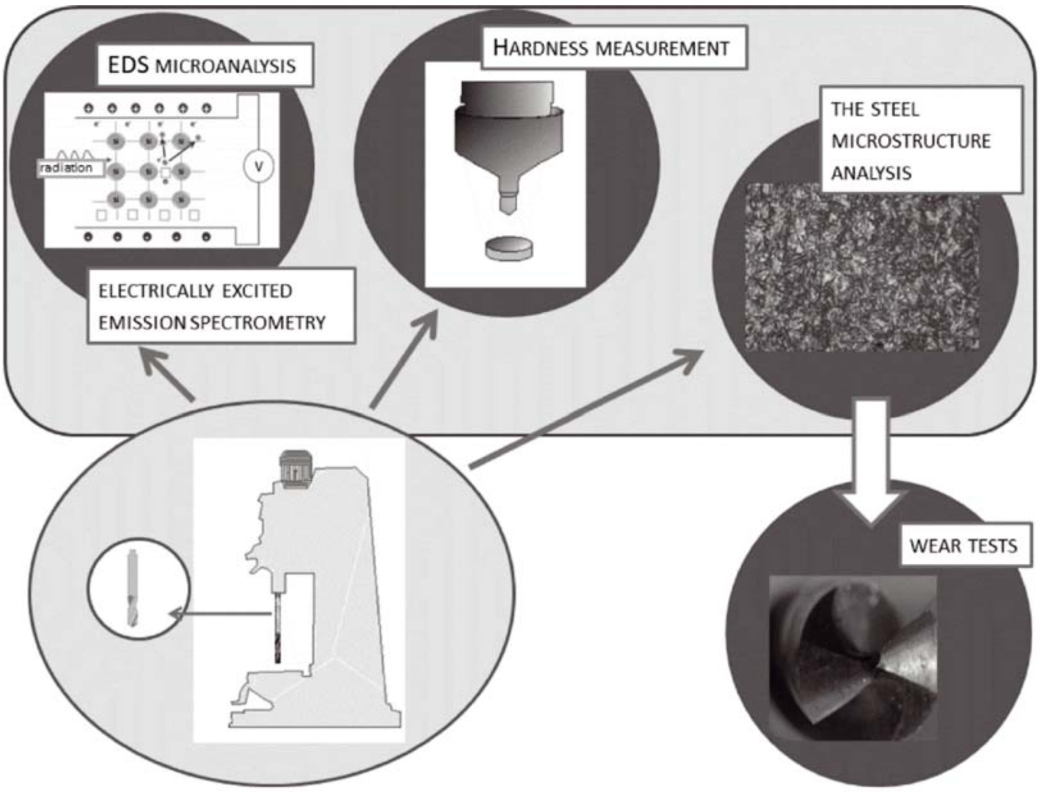

Figure 1. Methodology of measurements

wear of drill bits, a number of tests were carried out, as schematically shown in Figure 1.

The research methodology included: the determination of the chemical composition of the tested drills, the measurement of the hardness of the samples, and the observation of their microstructure. Then, tests related to the wear of drill bits were carried out. The parameters of the drilling process were selected on the basis of the tests carried out in order to prevent the socalled catastrophic wear of the drill bit, loss of drill machinability, and that the drilled holes comply with the prescribed requested requirements. Wear observations were initially made on all cutting parts of the drill. Based on the obtained data and literature reports on drilling in metal[27], the drill bit wear indicator was selected. The wear rate was assessed on the basis of the maximum linear wear values on the drill flank.

RESULTS

Determination of the chemical composition of steel

The compositions of the drill bits steels were determined using electrically excited emission spectrometry and, for verification and comparative purposes, by EDS microanalysis. For this purpose, a scanning electron microscope (Tescan Vega 5135) equipped with an EDS X-ray (PGT Prism 200 Avalon) spectrometer was used. The obtained results are presented in Figures 2–4.

From the analysis of the chemical composition, it can be concluded that not all drill bits were made of high-speed steel, which was stated by the manufacturer on the package. The steel with the highest alloying value is the steel from which the B drill bit was made. The C drill bit has a lower content of alloying elements. The lowest alloyed steel is the steel marked as A. In the steel from which the B drill was made the content of carbide-forming elements is the highest. The analysis of the composition of the remaining two drill bits showed that the steels used in their fabrication contain slightly more carbon than in the case of the B drill bit, however, the proportion of elements such as W, V, and Mo is lower. It should be noted that the difference in the amount of carbon is very insignificant considering the detection errors.

The steels marked with A and C are tool steels for hot and cold work, respectively. Steel C has a composition similar to X100CrMoV5-1 (1.2363) steel and steel A – X37CrMoV5-1 (1.2343). Steel B, in turn, has a composition similar to HS6-5-2 (1.3343) – is high-speed steel.

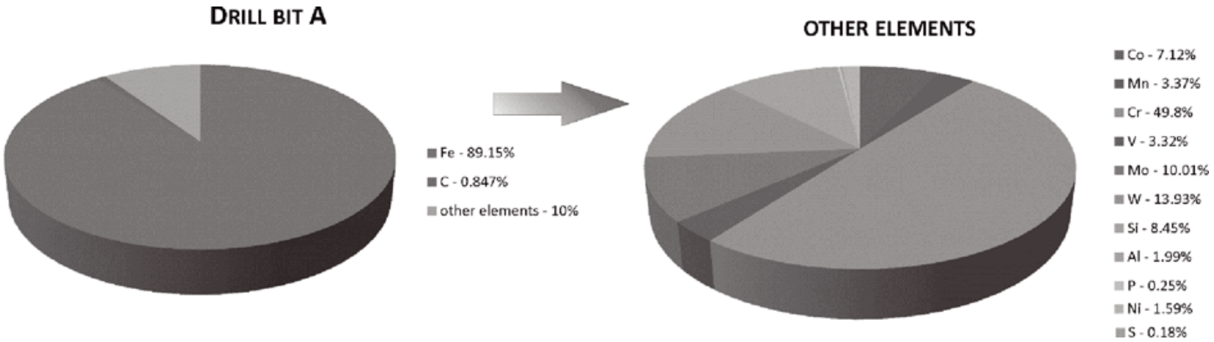

Figure 2. Chemical composition of steel of tested drill bit A- percentage of alloying elements

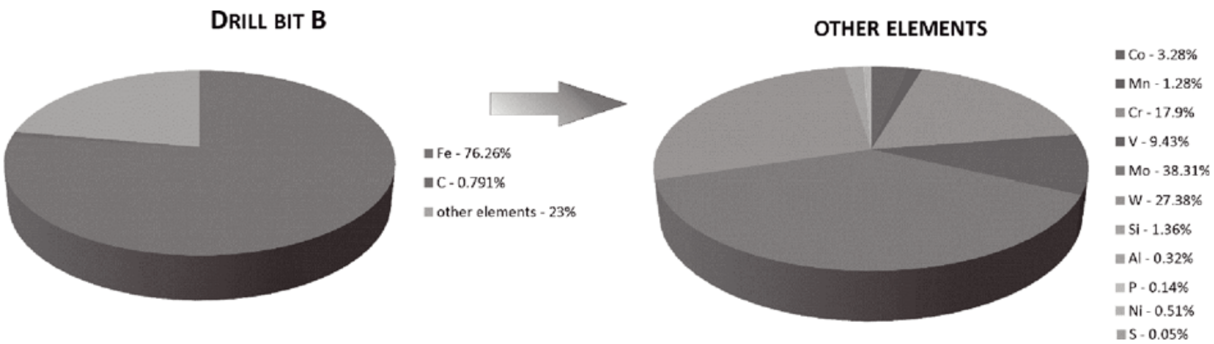

Figure 3. Chemical composition of steel of tested drill bit B- percentage of alloying elements

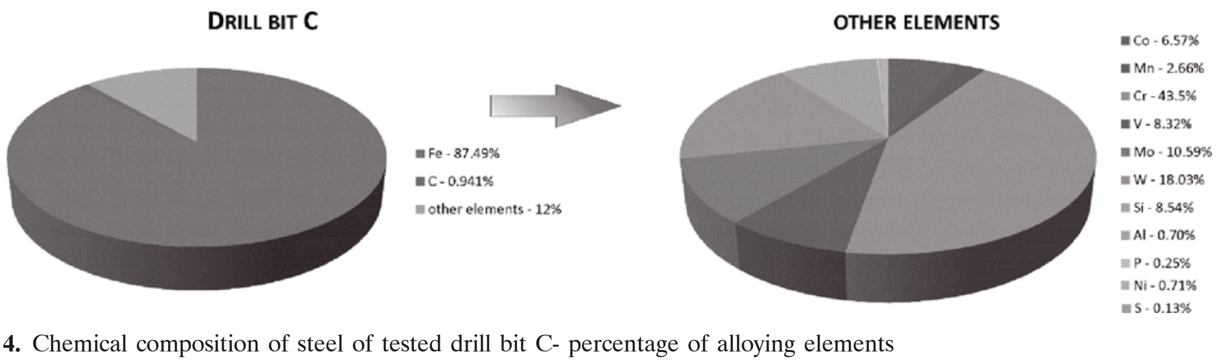

Figure 4. Chemical composition of steel of tested drill bit C- percentage of alloying elements

Hardness measurement

The Rockwell method was used to test the shank part, in a system with a diamond cone indenter and the C scale (the standard scale used to test the hardness of heat-treated steels up to 67 HRC)[28]. The Vickers method was used to measure the microhardness of the working part[29]. The obtained results are presented in Table 1. The experimental tests were carried out on a microhardness tester Walter VMHT MOT, model VMH-002VD. The microhardness measurement on the working part of the drill was performed on previously prepared metallographic specimens from this area. The average results presented in the tables were standardized to one scale using an appropriate hardness converter. The mean value was calculated from 8 results.

Table 1. Measurement of the hardness of samples

Drill bit	Shank hardness (HRC)	Microhardness of the working part (HRC)
A	–	60.00
B	46.00	66.00
C	–	63.00

Hardness measurements on the shank of the tools showed a very low hardness of the two tools. Measurements for drill bits marked as A (10.25 HRC) and C (2.75 HRC) gave results below 20 HRC, which means incorrect measurement. This is due to the fact that the C scale in the Rockwell method is intended for materials with higher hardness – above 20 HRC[28]. Below this value, the B scale should be used. The drill bit marked B has a hardness of 46 HRC. The situation was different in the case of the hardness of the working parts of drill bits. Tool A showed a hardness of 60 HRC while C – 63 HRC. The highest hardness was demonstrated by testing the working part of the B – 66 HRC drill bit.

The steel microstructure analysis

Figure 5 shows the obtained pictures of the microstructure of metallographic specimens made for the analysed drill bits.

The structure of the drill bit marked as A (Fig. 5a) is the structure of tempered martensite and retained austenite. Such a structure was obtained as a result of hardening and low tempering of the tool. Martensite is visible as elongated black needles, and the bright areas visible on the plane are retained austenite. The structure of the drill bit marked as C (Fig. 5c), also consists mainly of tempered martensite and retained austenite. A small amount of primary carbides can be seen on the figure of a sample made of this drill bit.

The microstructure of the B drill bit (Fig. 5b) differs significantly from the others. This is due to a very large number of primary carbide precipitates, which is not observed in the microstructure of drill bits A and C. Such a structure was obtained by hardening and low tempering of the tool. The carbides visible on the specimen were formed by elements such as W, V and Mo. Moreover, the observed microstructure is finer-grained.

Wear tests

The wear tests were carried out on a KSB 25A benchtop drill. The drill bits were mounted in a three-jaw chuck. A 10 mm thick low carbon steel plate (AISI 304 stainless steel of the characteristics of the steel is as follows: 0.2% Offset Yield Strength, psi (MPa): 42 (290); Ultimate Tensile Strength, psi (MPa): 90 (621); Elongation % in

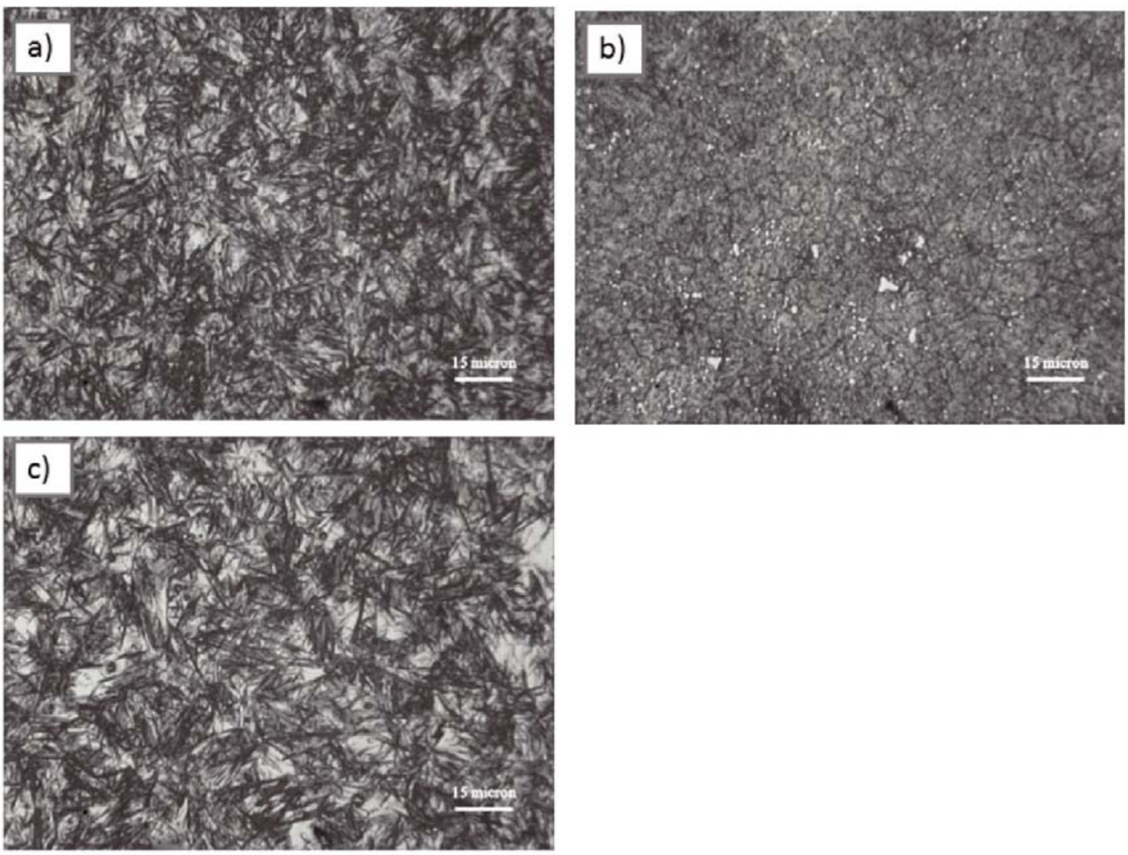

Figure 5. The microstructure of the drill bit (the same magnification): a) A, b) B, c) C

2 in. (50.8 mm): 55; Hardness Rockwell: B82) was used as the workpiece. Three series of through holes were drilled, in each series one hole was made with each drill bit. Flank wear was measured after each series. The process was carried out with the following parameters:
– rotational speed – 315 rev/min
– cutting speed – 9.90 m/min
– feed – 0.224 mm/rev

The maximum wear on the flank face (VBBmax) (in millimeters) was adopted as the measure of wear. Image processing for computer vision function plays an essential aspect in the manufacturing industries for the tool condition monitoring. The authors wear detection of drill bit by image-based technique described in the literature[30]. Its value was determined after each series of holes using a laboratory microscope and a computer program. The results are summarized in Figure 6. Five holes were made in each series of measurements. The tests were repeated three times on new, identical drill bits for the results to be statistically significant.

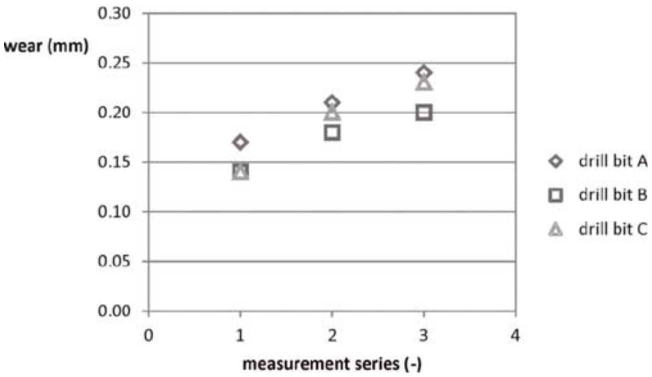

Figure 6. Wear measurement of drill bit

In the work[31], the effect of three surface-treated drills and one AlCrN (Alcrona) coated drill have been investigated at different levels of the cutting speed for drilling holes in AISI 304 SS. Three different high-speed steel (HSS) grades, including M2, M42, and M35, were utilized for the said purpose. The authors showed that in terms of tool life, M2-ST drill outperformed the other evaluated counterparts with 48 holes being the maximum tool life at the cutting speed of 11 m/min. The M35 drill bit less than 3 holes at the cutting speed below 5 m/min. The obtained results are similar to those obtained in this study.

The observation of the flank and the cutting edge was carried out also on a scanning electron microscope. Figure 7 shows the worn cutting edge at 178x magnification.

It can be seen that the drill bit B wears the slowest. The drill bit marked with A wear the fastest. A large increase in the wear value after the first series of machining is the result of lapping the blade (stage 1 on the wear curve). Increments in wear value after more holes are drilled, indicating that after lapping, the tool wears slower and more evenly. When analyzing the pictures, it was observed, that clearly, visible wear through abrasion.

According to the literature, the value of tool costs in the drilling process is about 6–8% of the value of the manufactured item[32, 33]. According to the author's own data, the purchase cost of the B drill bit was 2.5 times

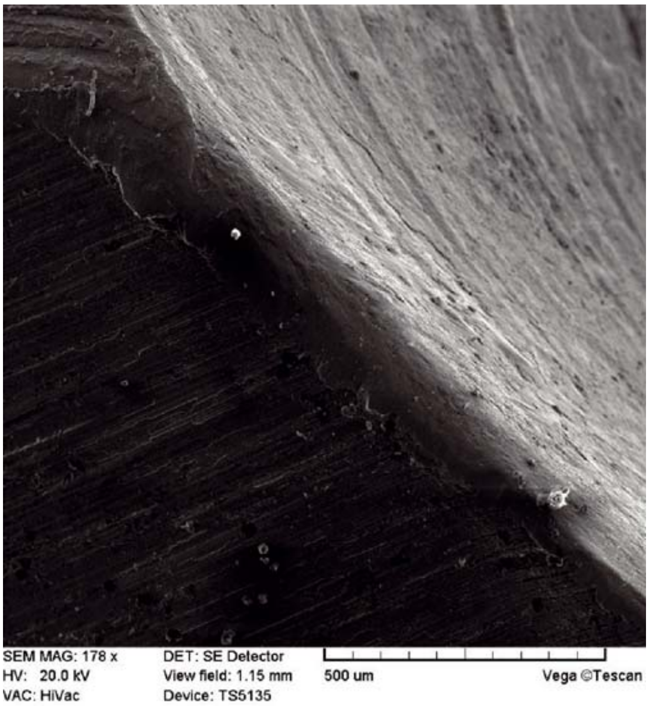

Figure 7. The worn edge – drill bit A

higher than the A drill bit and 1.75 times higher than the C drill bit. It has been shown that the use of the C drill makes sense when its cutting time will be, e.g. 250% longer than in the case of the A drill bit.

CONCLUSIONS

The paper analyses: the chemical composition, structure, and hardness of twist drill bits used for metal processing. The compared tools differed slightly in the content of carbon. Larger differences were noticed when comparing the amounts of alloying elements.

The markings on the packaging of each tool indicate that it is a high-speed steel drill bit. Analysing the chemical composition (with the use of two techniques), it was found that two of the three tested tools were not made of such steel. The chemical compositions of drill bits were compared to tool steels and high-speed steels, respectively, but in no case was a direct equivalent found. The chemical composition of A and C are similar to each other with no evident difference.

Measurements of the hardness of the tools showed that the drill marked as B has the highest hardness both on the shank and of the working part.

By analysing the previous data, i.e. chemical composition and structure, and comparing them with the obtained results of the hardness test, it can be concluded that there is a relationship between them. Steel with the highest content of alloying elements, especially carbide-forming elements, has the highest proportion of primary carbides in its structure. This, in turn, translates into the highest hardness of the tool. In turn, the least alloy steel (A) does not contain primary carbides in the microstructure, which makes its hardness the lowest (60 HRC is the hardness of martensite, which is the main component of the microstructure of this steel, for a carbon content of approx. 0.85% C). The wear test conducted showed that the B drill bit wears the slowest, while the A drill bit wears the fastest.

The wear test results can be compared with the hardness test results. It can be seen that the drill bit with the highest hardness was subject to the slowest wear, while the drill bit with the lowest hardness showed the highest wear values. It can be noticed that the appropriate selection of the chemical composition and heat treatment has a significant impact on the wear resistance of cutting tools, and thus also on their quality. Tools made of higher alloyed steels and heat treated to a high hardness structure can withstand more severe conditions and be used to machine more demanding materials. Such tools, however, are more expensive, which is supported by the drills used in this study. The most expensive drill bit, has the most favourable structure and properties, which directly translates into the durability of the tool.

ACKNOWLEDGMENTS

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