ANALYSIS OF THE WEAR OF SAW BLADE TEETH AND THE PROPOSAL OF METHODS OF INCREASING THEIR WEAR RESISTANCE

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DOI: 10.17973/MMSJ.2016_11_201694

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The article focuses on the methods for evaluating wear of two types of saw blades. One type does not have sintered carbide plates and another are the plates soldered on. The article also addresses application of various methods with respect to increase the life of saw-blade teeth. Gradual wear of saw blade cutting knives gives rise to certain phenomena, which have impact on the whole process of cutting. The wear of cutting wedges of a saw blade considerably influences the entire system - the machine - tool - work piece, and thus it is crucial to correctly assess the wear of cutting wedges. Several methods were chosen and applied in order to ensure correctness of such an assessment and the results were compared. Subsequently, the materials commonly used for production of tools were evaluated with respect to their microstructure, suitability of the methods to increase their wear resistance and so increase their useful life. The analysis of the factors which need to be considered, will allow us to draw conclusions significant for further experiments.

KEYWORDS

saw blade, cutting edge, wear, tool steel, coating

1 INTRODUCTION

Woodcutting is the basic technological process in wood production and influences the organisation of production, its efficiency as well as safety at work, quality of products, and the amount of energy and so on. The wear of cutting wedges of a saw blade considerably influences the entire system - the machine - tool - work piece, and thus it is crucial to correctly assess the wear of cutting wedges. There are several methods which allow for assessing and numerical expression of the degree of wear. [Kovac 2011] [Slabejova 2009] Saw blades are made of tool steel. In order to increase wear resistance, and at the same time their working life, the teeth are chrome-plated, they have stellite surface applied or them, or they feature sintered carbide tips [Muller 2013]. [Prokes 1982] argues that such measures resulted in increasing useful life of saw-blade teeth 2-3-fold when compared with untreated saw-blade teeth. Moreover, durability was 30 - 50 times better in case a saw blade featured teeth with sintered carbide tips. Suitable coating is another, less conventional method to reduce the wear of saw-blade teeth. Their application is determined by the tempering temperature of steel - the material of which are saw blades commonly produced. [Naprstkova 2014]

2 MATERIALS AND METHODS

2.1 *Measuring of cutting edge wear*

There are several ways how to measure cutting edge wear [Kovac 2011] recognises:

- the weight method,
- using a rocker,
- the cross-sectional method,
- the strip method,
- the method of the change of cut quality ,
- the method of energy consumption change,
- the method of the change of tool temperature,
- measurement of the profile by a profilograph and profiloprojector,
- the contact method,
- the contactless method,
- the metallographic analysis,
- using an automated profilometer,
- using NIS software - Elements to determine the extent of wear.

All the aforementioned methods are principally the same. Based on the change of one parameter, the change of another one - cutting edge sharpness - is evaluated. Wood species, its properties and the model of cutting may also affect cut quality [Lisican 1996].

The software NIS-Elements Advanced Research offers a complete solution together with capturing of images, archiving and analysis. It was developed for more demanding systems, that require full control over the functions of a camera and a microscope. The software aims to maximise performance and ensure that experiments run smoothly. It can perfectly handle capturing as well as displaying of multi-dimensional images - up to six dimensions at once (X, Y, Z, wavelength, time, multipoint). It run the whole range of additional editing tools such as highly efficient deconvolution, a module of extended depth of focus (EDF) or an image database.

In the first method, the wear was expressed by the shift from the ideal cutting wedge profile. In the second method, the wear was expressed by the radius of a circle ro inscribed from the ideal cutting edge and touching the nearest point of the actual cutting edge. The third method was performed by means of the alteration calculation of the worn cutting wedge angle β.

2.2 Possibilities of increasing saw blade working life

There are various viable method how to increase the working life of a tool. Brazing carbide tips onto saw blade teeth or application of polycrystalline diamond belong to the most common ones. However, while life of saw-blade teeth treated this way increases, the acquisition and operating costs are higher many times. [Vinas 2013] [Bendikiene 2015]

Alkaline blacking of steel is a classic and well-tested method of steel treatment also known as burnishing. The process leads to forming of a conversion oxidic layer of iron. It is a thin black chemical film on the surface of a saw blade, which prolongs its life by up to 20% compared to a conventional SC saw blade. [Valasek 2013]

Electroless nickel plating is an auto-catalytic reaction that creates a thin coating of milky colour. In the process of electroless nickel plating, the layer thickens by depositing nickel-phosphorous onto a steel surface. The layer grows over the surface of a part. The layer prevents resin and other impurities from sticking onto a blade. This lowers friction and heating, and thus extends the life of a saw blade. Such treatments also prevents corrosion which might be caused by cutting wood with increased content of moisture [Hricova 2014].

The other methods include teflon-coating, chrome plating a o. However, these modifications are not commonplace and far from abundantly used. The aforementioned method may be applied onto entire saw-blade bodies or only their cutting parts.

Curing teeth with suitable coatings is a more progressive method of increasing the life of a saw blade. Nanolayer and multilayer coating achieve high hardness, low friction coefficient, high resistance to abrasive and adhesive wear and high thermal conductivity. There are many types of coatings such as TiN, CrN, TiCN, TiAlN, which can be applied by a host of methods e.g. PVD, CVD, PVAD and the like. The choice of a particular method depends on the type of the material to be coated, required thickness of the coating layer and the conditions in which the tool will operate. [Kalincova 2014] Temperature of the coating agent is important for tempering the material which leads to the reduction in hardness. If the tempering temperature greatly exceeded its normal values within the process of coating, the tempered material would lose its required hardness and thus render the material unusable. Heat resistance of the coating is equally important. Based on the type of coating, it ranges from 400 to 1100 ° C. The thickness of the coatings are usually from 1 to 4 µm. [Staton 2016] The coatings applied at high temperatures (450-500 °C) form a larger layer, and thereby ensure a longer tool life, in contrast to the coating of temperature lower than< 200°C which allow for forming the layer not thicker than 3 µm.

The saw blades for wood are usually made of tool alloyed steel 75Cr1 (DIN 1.2003), intended for cold work. They are cured to the hardness of 44-48 HRC for the bodies with the thickness up to 3mm, if the body is thicker than this hardness of the body ranges between 42-46 HRC. Their final shape is carved by laser.

The experiment was conducted using two types of saw blades. The first one did not feature sintered carbide tips, so cutting was performed only by teeth made from tool steel. Another one had brazed tips L-Ag49Cu with sintered carbide plates (WC). Parameters of the saw blades are listen in the Table 1.

Table 1. Dimensions of the saw blades

Basic dimensions	Saw blade diameter D (mm)	Saw blade thickness a (mm)	Clearance angle α (°)	Rake angle γ (°)	Number of teeth
Saw blade without WC	600	3.5	20	20	56
Saw blade with WC	600	3.5	15	20	54

2 RESULTS AND EVALUATION

Currently, there is no generally acknowledged indirect method of precise and accurate measuring of the wear of a saw blade cutting edge. Therefore, several method were chosen to measure this quality and the most accurate on will be selected. The accuracy will be determined by the variance σ2.

Briefly said, calibration allows measurement of objects and structures in the images in real units. The computer-processed digitised image consists of a large number of small square elements, called pixels. Calibration means assigning real dimension (real units) to the dimensions of one pixel. Quantifying the number of pixels of known dimensions will then allow for performing various planimetric measurements (Fig. 1, 2).

The wear of the cutting edge was evaluated by two methods which were compared. Measurement of each tooth was repeated 6 times (Fig. 1, 2).

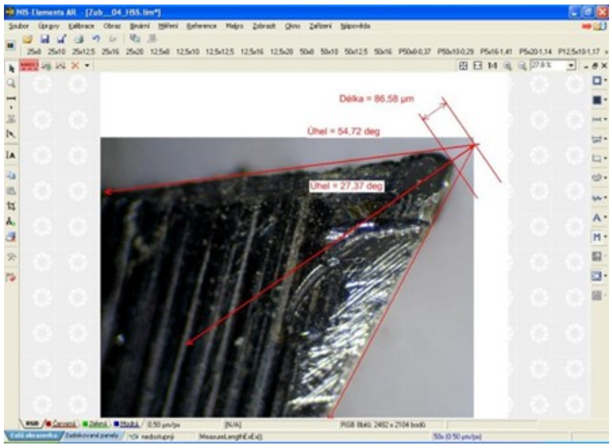

Figure 1. Evaluation of the wear of a saw blade without sintered carbide plates expressed by the deviation from the ideal cutting wedge profile

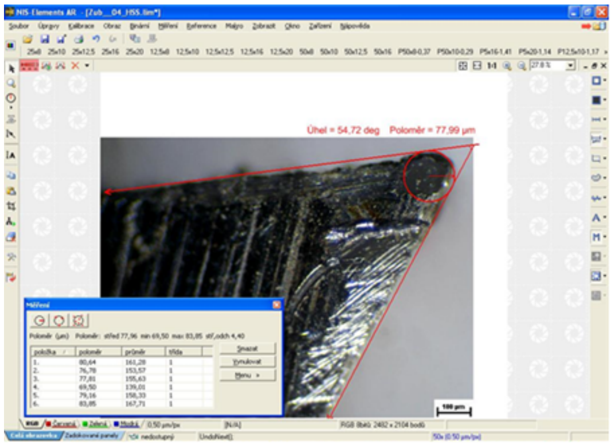

Figure 2. Evaluation of the wear of the blade with sintered carbide plates by means of the inscribed circle method

The first evaluation is expressed by a distance between the tip of an ideal cutting edge and the closest point of an actual cutting edge (Fig. 1). The wear was further evaluated by the radius of a circle inscribed into the profile of a cutting edge. Both radius and diameter of the inscribed circle were evaluated in many different points and a variance between the gained values was calculated (Fig. 2). Fig. 3 depicts the calculation method of the alteration of the worn cutting wedge angle β without sintered carbide tips. Figure 4 shows the same method, but with the sintered carbide plates. The goal is to determine the wear of a cutting wedge by calculation method of the alteration of the worn cutting wedge angle β (Fig. 3, 4). Fig. 3 demonstrates clearly visible wear on the front and back of the cutting wedge (protrusions, craters).

Moreover, the wear based on the deformation of cutting wedge (the radius of blade curvature, the length and depth of abrasion of the face and back) - determining the length parameters "x" and "y". The wear on the face ("x") and back ("y") of the cutting wedge (Fig. 4), and the radius of blade curvature. The measurements also revealed that the distance between “x” and “y” are identical as was the cutting edge curvature „ϕ“. This implies that the wear of the cutting edge (the front and the back of a cutting wedge) is equidistant.

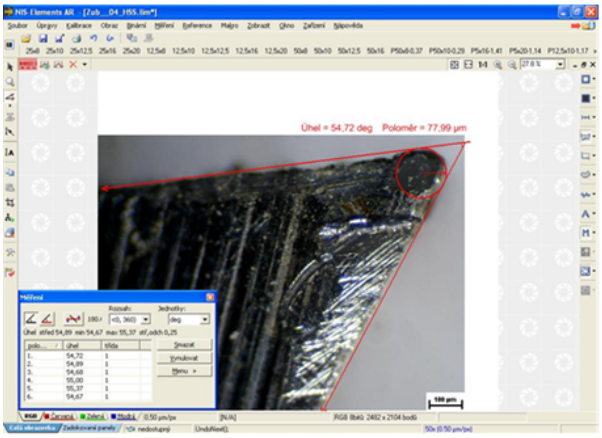

Figure 3. Wear of a cutting wedge - the alteration of the angle β - saw blade without sintered carbide plates

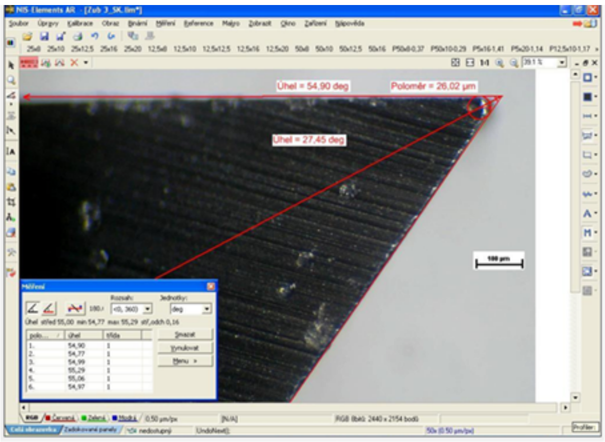

Figure 4. Wear of a cutting wedge - the alteration of the angle β - saw blade with sintered carbide plates

It is necessary to conduct input analysis for experiments aimed at increasing the life of saw blades, more specifically their teeth, by conventional and progressive methods of coating the material surface.

The following material analyses were run:

A) Chemical analysis of saw blades,

B) Hardness measurement by the HRC method,

C) Assessment of the microstructure of saw blades - optical microscopy.

A) Chemical analysis

The chemical analysis of the saw blades was performed using a spectrum analyzer (Tabl. 1 and 2).

Table 1. Chemical analysis of the saw blade material without sintered carbide plates

Element	C	Si	Mn	Cu	Cr	Ni	Ti
Contents (%)	0.797	0.207	0.637	0.009	0.295	0.031	0.003

Table 2. Chemical analysis of circular saw material with carbide plates

Element	C	Si	Mn	Cu	Cr	Ni	Ti
Contents (%)	0.753	0.253	0.608	0.006	0.318	0.037	0.002

The values of the elements corresponds to the value of the material 75Cr1 (DIN 1.2003).

B) Hardness measurement

This measurement was performed employing the HRC method. Table 3 lists the hardness values read on five points on the body of the saw blade, which was calculated from the average hardness values.

Table 3. Hardness values measured on the saw blades

Measuring procedure	Saw blade without sintered carbide plates	Saw blade with carbide plates
1.	44.5 HRC	43.0 HRC
2.	44.5 HRC	43.0 HRC
3.	45.0 HRC	42.0 HRC
4.	44.5 HRC	42.5 HRC
5.	43.5 HRC	44.5 HRC
Average	**44.3 HRC**	**43.0 HRC**

The hardness values coincide with the values declared by the manufacturer of the saw blades.

C) Microstructure evaluation

A sample for the metallographic analysis was prepared in a standard manner, namely, it was embedded in detakryl, subsequently grounded, polished and then immersed in 2% solution of Nital. [Michna 2012] Fig. 4,5 shows microstructures of the saw blade material with and without sintered carbide plates. Comprise they are of low-tempered martensite with carbides. The structure conform to the character of the material, which is suitable and used for wood cutting tool.

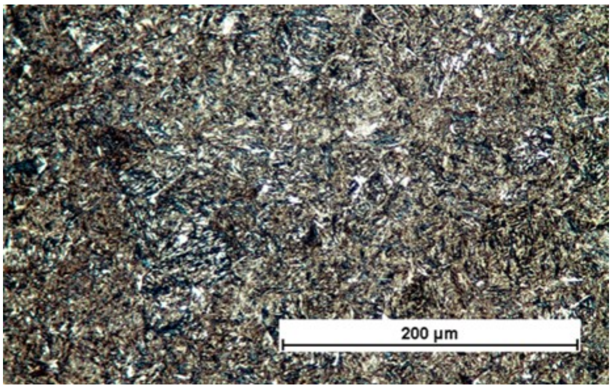

Figure 4. Microstructure of the saw blade material without sintered carbide plates (zoom 200x)

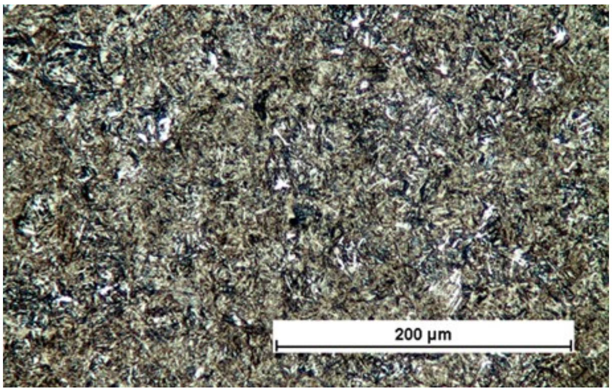

Figure 5. Microstructure of the saw blade material with a sintered carbide plates (zoom 200x)

3 RESULTS AND DISCUSSION

There is no simple way to state when a tool is sharp and worn. Measurement of only one parameter is not sufficient for expressing the full extent of wear of the cutting edge and it is necessary to measure more parameters, or produce a graphical description of the cutting edge before and after its use. A considerable downside of the measurements of the individual wear characteristics are their low values and nearly imperceptible transitions from their curved to the straight form. [Novacek 2006] The aforementioned shows that there is no unified methodology for measuring the wear of the cutting edge in wood processing, which poses a problem for the comparability of experimental results.

It can be concluded that the most applicable method for the measurement of the wear is the method of a circle inscribed into the profile of a cutting edge. This method exhibited lower variance.

A chemical analysis, hardness measurement and optical microscopy were carried out for both materials of the two saw blades. The examination confirmed that the steel in question was 75Cr1 (1.2003), as indicated by the manufacturer [Pilana 2016]. However, this steel has no equivalent in STN 42 0002.

The sawblades with the thickness of 3.5mm have hardness of 42-46 HRC. Considering the values, the tempering temperature might reach about 450°C, which could theoretically yield a toughness up to 43 HRC. Figure 6 depicts a tempering diagram of 75Cr1 steel, utilised for the production of saw blades. As demonstrated by the diagram, there is a viable alternative to use one of the coating requiring the coating temperature ranging between 450 - 500°C, without affecting the overall tool toughness. The temperatures in the tooth surface microlayer reach temperatures up to 800 – 1 000°C. [Droba 2015], therefore it is necessary to employ coatings with higher heat resistance as the given value.

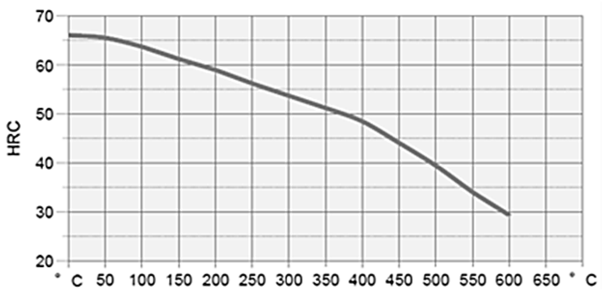

Figure 6. Tempering diagram of steel 75Cr1 [Bestar-steel 2016]

The tool steel, labelled as 19 418 and 19 419 according STN 41 0002 standard are then the closest to the mentioned material when considering the content of chemical elements. [Jech 1977] also claims that the steel 19 418 is also used for the production of saw blades for woodcutting and 19419 for saw blades for frame saws. Compliant with EN, both types of steel are labelled EN 80CrV2.

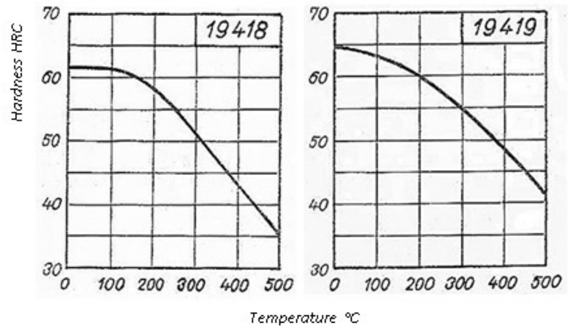

Figure 7. Tempering diagrams for steel 19 418 and 19 419 (Jech, 1977)

Tempering diagrams are shown in Fig. 7. As demonstrated by the tempering curve, the steel 19 418 reaches required hardness between 42-48 HRC at the temperature which does not exceed 400°C. On the other hand, required hardness of the steel labelled 19 419 can be yielded at the temperature of 450 - 500°C. However, it is necessary to consider the further use of steel, such as wood cutting tools - especially frame saws. [Jech 1977] Additional experiments are also required to test applicability of the mentioned options.

4 CONCLUSIONS

The goal of the article was to analyse the various methods of measuring the wear of a cutting wedge, and propose application of appropriate coating onto the teeth of a cutting tool.

At least two different and independent methods should be employed in the evaluation of the wear of a cutting wedge. Thus, it is problematic to conclusively state which method is the most feasible to yield the most accurate or the most appropriate. It is complicated by the fact that the selection of points is performed by an operator, so there is a chance that the variance might be influenced by a human factor. It can be concluded that the most applicable method for the measurement of wear is the method of a circle inscribed into the profile of a cutting edge. This method exhibited lower variance.

Enhancing the wear resistance properties of the tool teeth used in woodcutting results in increased tool life. Possibilities of the coating of saw blade teeth are further determined by the tempering temperature of the material. The analysis indicates the feasibility of using material already used, namely, 75Cr1 or 80CrV2. The tempering temperature of the materials analysed, while maintaining required hardness values, assumes application of appropriate coating, which may extend the working life and reduce the wear of tools. Another factor is the temperature of saw blade teeth in the cutting process which is related to the application of heat-resistant coatings. To conclusively prove these hypotheses, it is necessary to conduct further relevant experiments, whose results will enrich the practical knowledge on the subject.

ACKNOWLEDGMENTS

The paper has been produced as a part of the project: VEGA 1/0826/15 "Research of cutting mechanisms in the processing wood materials".

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