ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 64(2): 69−76, 2022
Zvolen, Technical University in Zvolen
DOI: 10.17423/afx.2022.64.2.07

ASSESSMENT OF WEAR OF THE BANDSAW TEETH IN INDUSTRIAL CONDITIONS

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ABSTRACT

A methodology for measuring bandsaw tooth wear is presented in this paper. This type of measurement is proposed as an alternative way of determining tooth wear in industrial conditions. The method is based on determining the KE value, i.e., the distance of the radius of the rounded cutting edge of the tooth and the intersection of the surface of the back and the surface of the face of the cutting wedge of the bandsaw tooth. The rate of wear of bandsaw teeth is determined by comparing the measured value with the *KE* values given in the literature. During the development of the methodology, experimental cutting tests were performed at a sawmill that specializes in the production of floors from multi-layer glued laminated wooden boards. The investigated band saw was applied in the sawing process of oak (*Quercus* L.) boards. The average moisture content of the wood was MC = 32.9% when using the "wet" technology of lamella production. Since the monitored wear values are not very high, the use of certified measuring instruments is strongly recommended.

Key words: bandsaw, oak wood, wear, sawmill conditions, digital caliper.

INTRODUCTION

All cutting tools wear during machining either metal or wood and continue to do so until they come to the end of their tool life. In general, wear is defined as loss of material, which usually progresses continuously, on an asperity or micro-contact, or in smaller scale, down to molecular or atomic removal mechanisms (GRZESIK 2017). In practice, some directly measured dimensional characteristics of typical wear patterns, while metal cutting (i.e., crater and flank wear, and notch wear at the depth-of-cut extremities) for high speed steel HSS, cemented carbide and ceramics tools are standardized in ISO 3685 (1982). The latter does not valid for cutting tools in case of wood machining.

For many years, research on woodworking tools has focused on the issue of cutting edge wear KLAMECKI (1979) has stated that: *"The change in the cutting tool with use has generally been monitored in two ways, by observing the change in the edge geometry, and by observing changes in the forces acting during cutting"*. The accuracy of cutting, especially with narrow-kerf saw blades of low initial stiffness, depends mainly on the state of the cutting edges. It was found that the values of feed forces, occurring during wood cutting on sash gang saws, depend not only on cutting parameters but mainly on the stereometric features of the teeth and the accuracy of their manufacture (PROKOFIEV *et al.* 2020). An increase in feed forces may cause a reduction of initial stiffness values to operating stiffness values (ORLOWSKI *et al.* 2022). The quality of sawn surfaces could depend also on geometry of the bandsaw teeth (ORLOWSKI *et al.* 2020; CSANDADY and MAGOSS 2020), terms and conditions of use (GLIGORAŞ and BORZ 2015; IŠTVANIĆ *et al.* 2009), and the state of cutting edges after grinding (ORLOWSKI and WASIELEWSKI 2006; ORLOWSKI *et al.* 2021). Moreover, the surface roughness of the saw wood was investigated in case of the use of circular saw blades (KMINIAK *et al.* 2015; ĐUKIĆ *et al.* 2022). ŠUSTEK and SIKLIENKA (2012) examined the effect of the saw blade overlap setting on the cutting wedge wear, whereas KMINIAK *et al.* (2016) inspected tool wear during milling of medium density fibres boards MDF. The state of machine tool can also affect tool life and the results of cutting (GOCHEV and VUKOV 2017).

CRISTÓVÃO *et al.* (2011) investigated the relationship between tool wear and some chemical and physical properties for four different Mozambican lesser-known tropical species: *Pseudolachnostylis maprounaefolia* (ntholo), *Sterculia appendiculata* (metil), *Acacia nigrescens* (namuno) and *Pericopsis angolensis* (muanga). The experiments were conducted in laboratory conditions, and the wear mechanism was investigated using a scanning electron microscope. OKAI *et al.* (2006) proved that silica accumulation species could have a significant effect on the tool wear of high-speed steels. Stellite inserts have the lowest cutting tool edge recession when machining wood samples of Oil palm (*Elais guineensis)*. On the other hand, they were characterized by the largest recession when machining Afina (*Strombosia glaucescens*). ŠUSTEK and SIKLIENKA (2012) measured the wear of circular saw blade teeth with the portable microscope, and the images observed were recorded with a digital camera. The same measurement equipment was applied by KMINIAK *et al.* (2015, 2016). The tool wear degree can be assessed according to the tool force data, vibration data, acoustic emission signal (SVOREŇ *et al.* 2016), temperature data (IGAZ *et al.* 2019), and other multi-sensor data, which were analysed with the Elman_Adaboost strong predictor (LIU *et al.* 2020). Other methods of wear assessment could base on vision technics (PALUBICKI *et al.* 2014; WASIELEWSKI and ORLOWSKI 2005).

Knowledge about the state of the cutting edge is important, since the cutting forces during sawing can be used as a basis for determining raw material properties such as shear yield stresses in the cutting zone and fracture toughness (SINN *et al.* 2020). Nevertheless, a prerequisite is the sharpness of the cutting blades, otherwise the fracture toughness results may be overestimated (BLACKMAN *et al.* 2013). Moreover, the state of cutting edges, both the main cutting edge and minor cutting edges, might affect cutting forces while sawing wood (MEULENBERG *et al.* 2022a, 2022b).

The most of presented methods for wear measurements, both direct and indirect ways, are good under laboratory conditions, nevertheless, are of limited use in industrial practice. For example, when studying the wear of circular saw blade teeth in the industrial conditions of the door manufacturing process, the evaluation of the degree of teeth wear was carried out on equipment under laboratory conditions (WILKOWSKI *et al.* 2022). Therefore, the goal of this work was to develop methodology of wear measurements which could providing information about the state of the bandsaw and at the simultaneously appropriate in industrial practice.

THEORETICAL BACKGROUND

Stellite-tipped teeth of narrow kerf saw blades sharpened under industrial conditions were examined (ORLOWSKI *et al.* 2021). The same methodology for bandsaw teeth with the use of a NIKON ECLIPSE Ti-S microscope equipped with a NIKON DS-Fi2 recording camera was used to take pictures of teeth (Fig. 1a, b), which were analyzed in a graphical software to measure the radii of the main cutting edges. The high-quality images obtained were used to determine the values of the rounding radii of the cutting edges, and an exemplary tooth of the bandsaw is shown in Fig. 1c.

a) b) c)

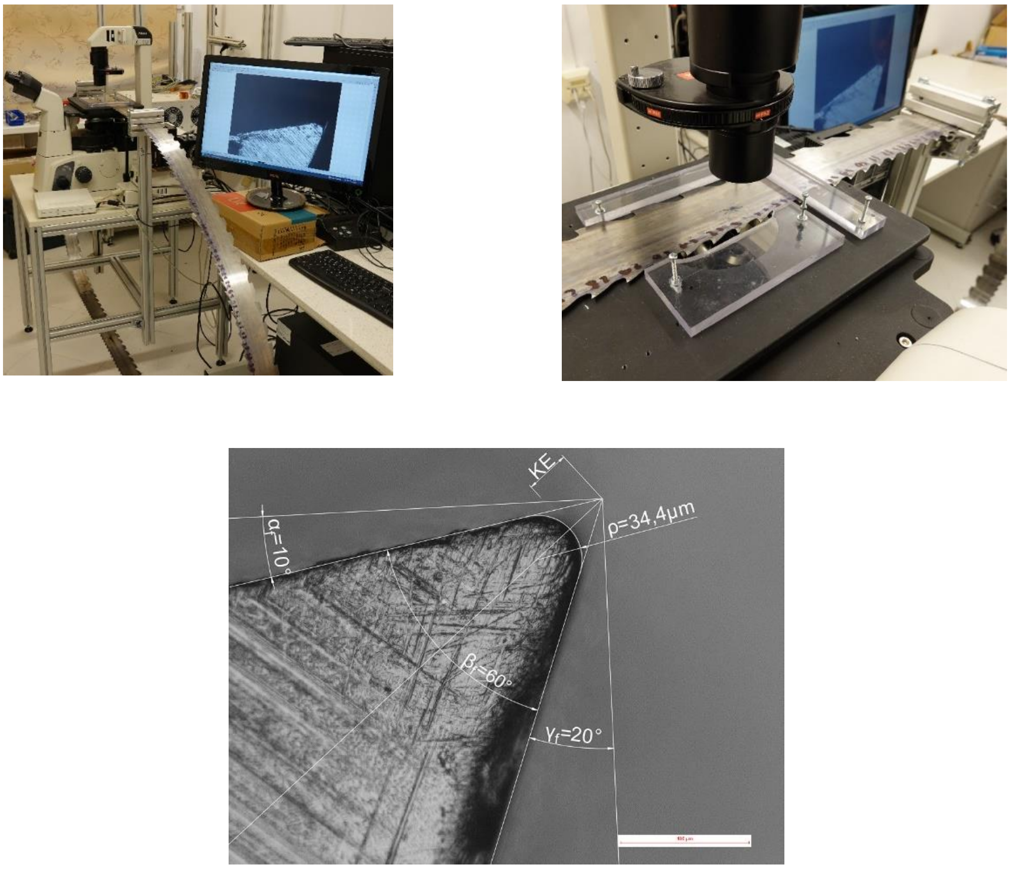

Fig. 1. NIKON ECLIPSE Ti-S microscope, where: general view of the laboratory stand (a), a special system for clamping of the band saw (b), and an exemplary dull cutting tooth edge (c), where: γ_f—tool side rake angle; α_f—tool side clearance angle; β_f—tool side wedge angle; ρ – radius of the cutting edge (ρ = 34.4 μm).

CSANADY and MAGOSS (2020) proposed a relationship for determining the cutting edge radius based on the value of the wedge angle and the measured value of the radial displacement of the tool corner *KE*. This relationship is right for the symmetrical shape of the worn edge. After transformation, this relationship can take the form of Equation (1) and based on the measured values of the cutting edge radii ρ, can be used to determine the radial displacement of the tool corner *KE*.

$$KE = \rho \cdot \frac{1 - \sin\left(\frac{\beta_f}{2}\right)}{\sin\left(\frac{\beta_f}{2}\right)} \tag{1}$$

In order to create a simplified model of the saw tooth, it was rotated by the rake angle $\gamma_f = 20°$ and a half of the edge angle $\beta_f/2 = 30°$ in the counterclockwise direction. It should be emphasized that the subscripts *f* of the angles indicate the geometry of the teeth is considered in the assumed working plane P_f, containing the assumed direction of feed motion (ISO 3002:1, 1982). The tooth simplified model of the bandsaw is presented in Fig. 2.

a) b)

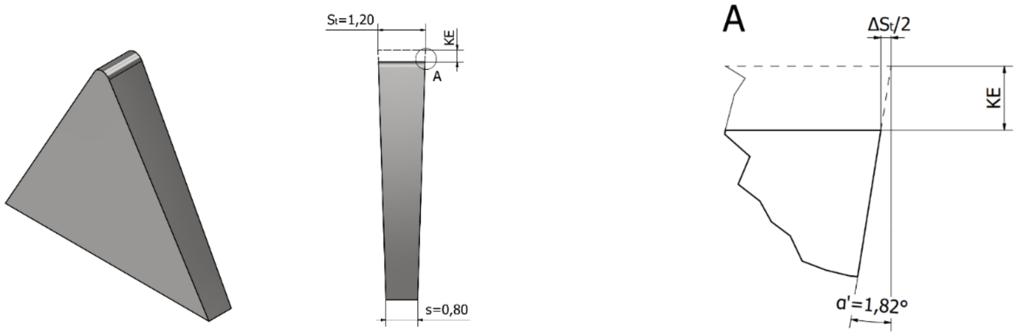

Fig. 2. A simplified model of the bandsaw tooth, where: a) – 3D general view and a view in direction of feeding; b) detail A; *St* – overall set (theoretical kerf); *KE* – radial displacement of the tool corner (tool cutting edge); Δ*St*/2 – side displacement of the tool corner; *α'* – minor flank clearance angle.

As a result of wear, its main cutting edge shifted by the value of KE, and thus, it shortened per side by the value of $\Delta S_t/2$:

$$\frac{\Delta S_t}{2} = KE \cdot \tan\alpha' \tag{2}$$

Hereafter, the overall set of the tooth could be calculated as follows:

$$S'_t = S_t - \Delta S_t = S_t - 2 \cdot KE \cdot \tan\alpha' \tag{3}$$

If the overall set of the worn tooth S'_t is measured it possible in rough estimation to calculate a radial displacement of the tool corner (tool cutting edge) *KE*. In the next step, the estimated values of *KE* might be compared with the values of *KE* in the book by CSANADY and MAGOSS (2020) and could allow the user to assess the state of the cutting edges.

MATERIAL AND METHODS

Experimental cutting tests were carried out at the Łączy - Kołczygłowy Sp. z o.o. plant in Barnowo (Pomerania Region, PL), which specializes in production of engineered floorings composed of multi-layer glue-laminated wooden boards. The examined bandsaw was applied in re-sawing process of oak (*Quercus* L.) boards of average dimensions 221 × 2450 mm^2 (width × length, respectively). The nominal thickness was 10 mm. The average moisture content of wood was MC = 32.9% (standard deviation of MC 2.1%) as a "wet" technology of the lamellae production applied on the bandsawing machine.

The bandsaw had 220 teeth, each with the overall set S_t = 1.20 ±0.001 mm (size distribution at the significance level of 0.05 (*t*-Student)), and saw blade thickness was equal to 0.8 mm, pitch was equal to P = 25 mm. Each tooth was stellite tipped with the rake angle γ_f = 20° and clearance angle α_f = 10°. The applied bandsaw type PRIME ST 0.8/1.2 (Wintersteiger, Austria) was manufactured with a special design to reduce saw dust accumulation and had scraper teeth on the saw blade back (Fig. 1a, b), pitch equal to P_s = 50 mm.

The examined bandsaw ran during one shift on the band sawing machine DSB Singlehead NG XM (Fig. 3) by Wintersteiger (Austria) (DSB Singlehead, 2022) with cutting speed v_c = 28 m·s^{-1} and feed speed in average v_f = 8 m·min^{-1}.

Fig. 3. Cutting zone of the band sawing machine DSB Singlehead NG XM (DSB Singlehead, 2022).

Every tooth overall set, as a value of blunting, was manually measured twofold with a digital caliper (type Gedore No. 711, 0–150 mm, UK).

RESULTS AND DISCUSSION

The overall sets (kerf) of the examined bandsaw PRIME ST 0.8/1.2 measured twofold with a digital caliper are shown in Fig. 4.

The average value of the overall set (kerf) S'_t of dull teeth was determined from two series of caliper measurements and it was equal to S'_t = 1.189 mm and obtained standard deviation was $s(x)$ = 0.0172 mm.

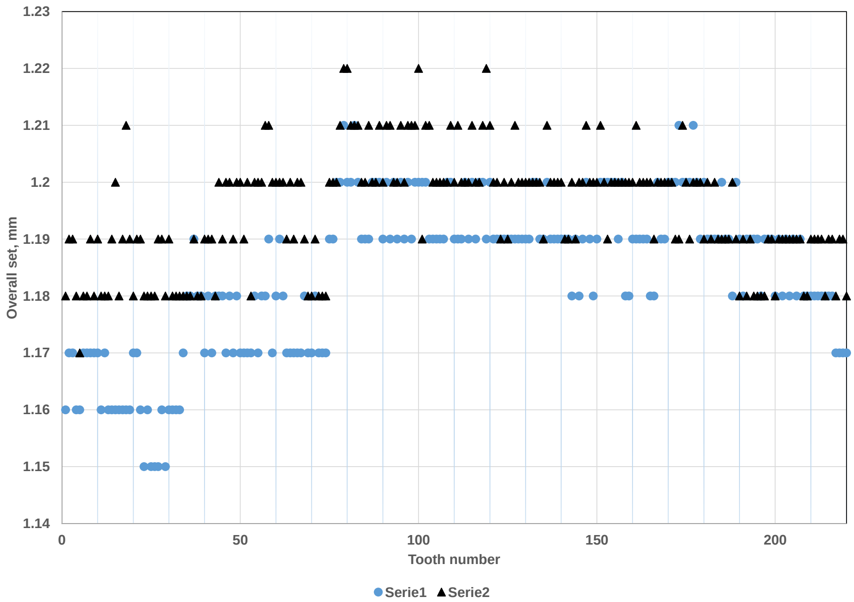

Fig. 4. Overall sets (kerf) of the examined bandsaw PRIME ST 0.8/1.2 measured twofold with a digital caliper.

The dispersion of averages DAv S'_t can be calculated from the equation:

$$\text{DAv } S'_t = \pm \frac{t_{cr} \cdot s(x)}{\sqrt{n_x}} \tag{4}$$

Where: t_{cr} is a critical value of the t Student test (t STUDENT 2022), $s(x)$ is a coefficient of variation, n_x is a number of degrees of freedom.

In the case under consideration, the value of the dispersion of averages DAv S'_t have been computed with Equation (4), for a number of degrees of freedom n_x = 439, and t_{cr} a critical value of the *t* Student test t_{cr} = 1.9659 (for a significance level α = 0.05) (t Student, 2022). The obtained value of the dispersion of averages DAv S'_t c= 0.002 mm, thus, the average overall set of the worn teeth is S'_t = 1.189 ±0.002 mm.

The obtained result confirms the correctness of such an approach when used in the evaluation of saw blades wear in industrial conditions with the use of simple measurement tools.

It was proved that saw blades after re-sharpening have larger values of cutting edge radii ρ than new saw blades (ORLOWSKI *et al.* 2021). Similar phenomenon was observed by JAWORSKI *et al.* (2016), who also stated that as the number of sharpenings increases, the mean value of the pull broach tooth wear on the clearance face also increases, which has an impact on the quality of the machining process. Hence, in the case of sharpened bandsaw blades, it will be necessary to choose cutting parameters for the sawing process that will take into account the possibility of generating higher values of cutting forces during the sawing process with this saw blade. These more important cutting parameters will be the feed speed, and the height of the material being cut.

CONCLUSIONS

The analysis carried out to develop methodology of wear measurements which could provide information about the state of the bandsaw allowed the following conclusions:

- the overall sets of the worn teeth S'_t measured with the digital caliper might be used in rough estimation the state of wear in industrial conditions;
- since the wear values are not very impressive, the use of certified measuring tools is toughly recommended;
- theoretically, it is possible to roughly estimate a radial displacement of the tool corner (tool cutting edge) *KE*, which values might be compared with the values of *KE* given in the literature.

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ACKNOWLEDGEMENT

Financial support of these studies from Gdańsk University of Technology by the DEC – 4/2022/IDUB/III.4.1/Tc grant under the Technetium Talent Management Grants - 'Excellence Initiative - Research University'program is gratefully acknowledged.
Authors would like to acknowledge the sawmill Łączy - Kołczygłowy spółka z o.o. for its support of the experiment.

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