Capacity of Surface Production of Band Sawing in Manufacture of Oak Floor Upper Layers

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Thin lamellae, corresponding to the layer components of structural glued members, *i.e.*, 2-ply or 3-ply glued flooring, can be manufactured in re-sawing operations of kiln-dried wood blocks or in wet technologies, which currently seem to be more common because of the shorter drying time. The re-sawing process in wet technology is conducted on dedicated thin-cutting band sawing machines with stellite-tipped band saws. The goal of this research was to demonstrate the capacity of surface production (m^2/ tool life) of visible layers of oak engineered flooring composites in a function of both a new band saw and a re-sharpened band saw blade. Additionally, the state of teeth of each band saw blade was examined at the end of the tool life. A series of cutting tests were performed in sawmill production conditions. The conducted tests revealed that a three times higher capacity of surface production was obtained for the new tool compared to re-sharpened tool. Additional microscopic observations of some re-sharpened teeth showed deformed plastic characteristics.

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Keywords: Band saw blade; Band sawing machine; Lamellae; Rate of surface production; Teeth wear; Tool life; Industrial conditions

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INTRODUCTION

The cost of raw material has a crucial role in the wood industry. Steele *et al.* (1992) stated that raw material cost might account for even 75% of the total sawmill manufacturing process cost. To lower the material cost of the thin lamellae re-sawing operations, narrow kerf sawing processes based on the use of either frame sawing machines or the use of narrow kerf circular saws were developed (Orłowski *et al*. 2001; Schultz and Haas 2001). The technologies mentioned mainly concern the cutting of dry wood. The narrow kerf saws are used mainly in floorings (Orlowski and Walichnowski 2013; Orlowski *et al*. 2020), glulam, and sports equipment production, where the reduction of the waste brings the highest profits. The reduction of wood waste plays an important role in the balance between the net wood growth per capita and wood consumption per capita (Bowyer and Stockmann 2001).

The currently observed increase in energy prices has enforced a change in the technologies used for re-sawing wood to lamellae from dry to wet. In this case, narrow kerf frame sawing machines are being replaced by band sawing machines in which narrow kerf band saws are applied (DSB Singlehead 2022). This reduces the kiln drying time of wood from a period of 4 to 6 weeks, even to one week (Milić *et al*. 2021; Solak and Greinke

2022). Hence, the simultaneous use of saws with narrow kerf overall sets and wet technologies of re-sawing operations is an example of sustainable development of manufacture in sawmilling.

The main disadvantage of narrow kerf cutting tools is that the reduction of the kerf size decreases the blade's stiffness (Orlowski 2003), which causes lower cutting accuracy (Orlowski *et al*. 2020). In the literature, some band saw blade stiffness determination approaches have been considered (Orlowski *et al*. 2022b). The model proposed in this paper, which uses numerical simulations, may support the design of the reduced kerf cutting tools with a smaller accuracy reduction. Dynamics of band saws and band sawing machines were analyzed by Ulsoy *et al.* (1978) and Okai (2009).

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 is not valid for cutting tools during wood machining. Nevertheless, the cutting edge wear parameters listed in this paragraph can be classified as geometric criteria (Cichosz 2006; Grzesik 2017).

Many works have focused on the cutting edge dulling problem as the major indicator of tool wear. They revealed that the wear of the cutting edge depends on the cutting conditions as well as the mechanical properties of the processed material. Factors for wood processes are more numerous than for metals *e.g.*, moisture content, defects (knots), wood species, annual rings, *etc.* (Klamecki 1979; Orlicz 1988; Kminiak *et al*. 2015, 2016; Kvietková *et al*. 2015; Górski *et al.* 2019; Nasir *et al*. 2019). For frozen beech band sawing, Siklienka *et al*. (2015) found that stellite tipped teeth had significantly higher wear resistance in comparison to swaged steel teeth. Cristóvão *et al.* (2011) investigated under laboratory conditions the relationship between tool wear and some chemical and physical properties for four Mozambican lesser-known tropical species: *Pseudolachnostylis maprouneifolia* (ntholo), *Sterculia appendiculata* (metil), *Acacia nigrescens* (namuno), and *Pericopsis angolensis* (muanga). The wear mechanism of a tool was investigated using a scanning electron microscope. Simplified wear measurements in industrial conditions, which might provide information about the state of the band saw, could be based on the overall sets of the worn teeth measured with the digital caliper (Orlowski *et al*. 2022a).

The cutting edge radius or the radial displacement the cutting edge are applied for description of the wear process, which leads to bluntness of the cutting edge (Csanady and Magoss 2020). Beer (2002) demonstrated that modifying a knife by creating microphase on the cutting edge (14 μm) while beech wood veneer was peeled allowed for increasing tool life almost 5 times. This phenomenon can be explained by the fact that the first phase of accelerated cutting edge wear (Cichosz 2006; Grzesik 2017) was artificially induced, and not in the cutting process. Moreover, the cutting surfaces of sharpened hobs should be lapped to eliminate edge chipping (Piotrowski 2015).

Evaluation of the sawing process as a function of time (understood implicitly tool wear) can be made on the assessment of cutting accuracy of sawn products such as lumber for band sawing (Eklund 2000) or lamellae during sash gang sawing (Orlowski *et al.* 2020). The above-mentioned parameters connected with sawing accuracy belong to the technological group of criteria of wear (Cichosz 2006; Grzesik 2017).

The changes in the cutting tool geometry as well the tool wear degree can be also assessed according to physical criteria of wear as follows: the tool force data (Meulenberg *et al.* 2022), vibration data (Górski *et al.* 2019; Nasir *et al.* 2019), acoustic emission signal (Svrzic *et al*. 2021; Svoreň *et al.* 2021), and temperature data (Igaz *et al.* 2019).

Another group of criteria that the wear of cutting edges is considered is economic. In this case, performance issues, such as capacity of linear output (m/ tool life), raw material removal capacity (m^3/ tool life), and capacity of surface production (m^2/ tool life), could be taken into consideration. For tools that can be sharpened, the number of sharpenings per service life (the sum of tool lives) is considered. Therefore, the goal of this research was to demonstrate the capacity of surface production (m^2/ tool life) of visible layers of oak engineered flooring composites in a function of both a new band saw blade and a re-sharpened band saw blade. Additionally, the state of teeth of each band saw blade was examined at the end of the tool life.

EXPERIMENTAL

Machine Tool and Tools

Experimental cutting tests were performed at the Łączy - Kołczygłowy Sp. z o.o. sawmill in Barnowo (Pomerania Region, PL), which specializes in production of engineered floorings composed of multi-layer glue-laminated wooden boards. Tests were conducted on the band sawing machine DSB Singlehead NG XM by Wintersteiger (Ried im Innkreis, Austria) (Fig. 1a). Cutting conditions were as follows cutting speed v_c = 28 $m \cdot s^{-1}$ and feed speed in average v_f = 8 $m \cdot min^{-1}$. The machine tool was equipped with a counter to measure the total length of the boards being cut.

a) b)

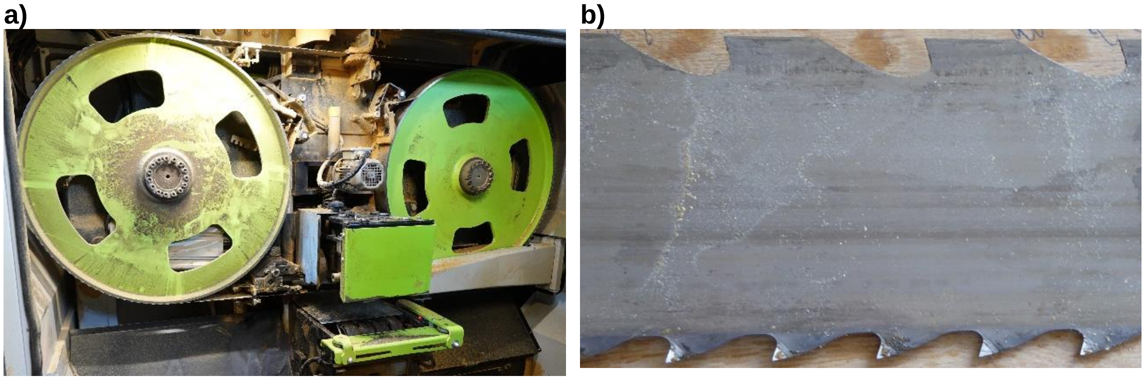

Fig. 1. General view of the working section of the band sawing machine DSB Singlehead NG XM (a), and a bandsaw with working (at the bottom) and scraper teeth (on the top) (b)

The band saw blade had 220 teeth, each with the overall set S_t = 1.20 mm, and saw blade thickness equal to 0.8 mm, with pitch equal to P = 25 mm. Each tooth was stellite tipped with the rake angle γ = 20° and clearance angle α = 10°. The applied band saw blade type PRIME ST 0.8/1.2 (Wintersteiger, Ried im Innkreis, Austria) was manufactured with a special design to reduce saw dust accumulation and had scraper teeth on the saw blade back, with pitch equal to P_s = 50 mm (Fig. 1b). In the experiment two band saws were used:

- The first band saw was in a new state. The band saw worked until it reached its lifetime, which was defined online by the sawing machine operators when the boards were not made in accordance with the requirements of both the sawmill measure and the standard PN-EN 13226 (2004);

- The second tool was a re-sharpened band saw, which was the first band saw usage after re-sharpening.

Overall sets of every tooth of a new band saw before and after cutting were manually measured with a digital caliper (type Gedore No. 711, 0–150 mm, UK). In addition, the teeth of re-sharpened band saw were measured at the end of its tool life.

A NIKON ECLIPSE Ti-S microscope (Nikon Europe B.V., Amstelveen, Netherlands) equipped with a NIKON DS-Fi2 recording camera was used to take pictures of some selected teeth. The camera is equipped with NIKON lenses with magnifications of 5×, 10×, 20×, and 50×. The obtained teeth images were additionally equipped with a scale.

Materials

The examined band saws were applied in re-sawing processes of oak (*Quercus* L.) boards, which were obtained from the Forest District Bytów of the State Forests (timber supplier, Poland), Sawmill Łąccy Kołczygłowy Sp. z o.o. Kołczygłowy, Poland (boards supplier):

1. Average dimensions 221 × 2450 mm^2 (width × length), the nominal thickness was 28 mm. The average moisture content of wood was MC = 32.41% with standard deviation (SD) = 2.26. The test No 1 was conducted in the winter time with the use of a new band saw.
2. Average dimensions 250 × 2423 mm^2 (width × length), the nominal thickness was 28 mm. The average moisture content of wood was MC = 33.3% with SD = 7.41. The test No 2 was led at the beginning of summer with the re-sharpened band saw applied.

Both experiments were classified to a “wet” technology of the lamellae production.

RESULTS AND DISCUSSION

The overall sets (theoretical kerfs) of the examined band saws PRIME ST 0.8/1.2 measured with the caliper are presented as follows: in Fig. 2a, overall sets for the new band saw, values of overall sets after re-sawing process while tool life is achieved for test No 1 in Fig. 2b, and in Fig. 2c, overall sets for the re-sharpened band saw when tool life is reached for the test No 2.

When the lamellae were not made in accordance with the requirements of the sawmill measure, the band sawing machine operators stopped the sawing process, and the tested band saw was replaced with a new one. The worn out band saw was sent for re-sharpening by a specialized company.

The presented range of values of total tooth overall sets S_t for the new band saw (Fig. 2a) and after the first use (Fig. 2b), until tool life was reached, was the same and equaled 0.03 mm. For the re-sharpened the band saw after reaching the tool life, the range of total tooth overall sets was larger and equal to 0.05 mm. The dispersion of averages DAv S_t can be calculated from Eq. 1,

$$\text{DAv } S'_t = \pm \frac{t_{cr} \cdot s(x)}{\sqrt{n_x}} \tag{1}$$

where t_{cr} is a critical value of the Student *t* test (Sachs 1984), $s(x)$ is a coefficient of variation, and n_x is a number of degrees of freedom.

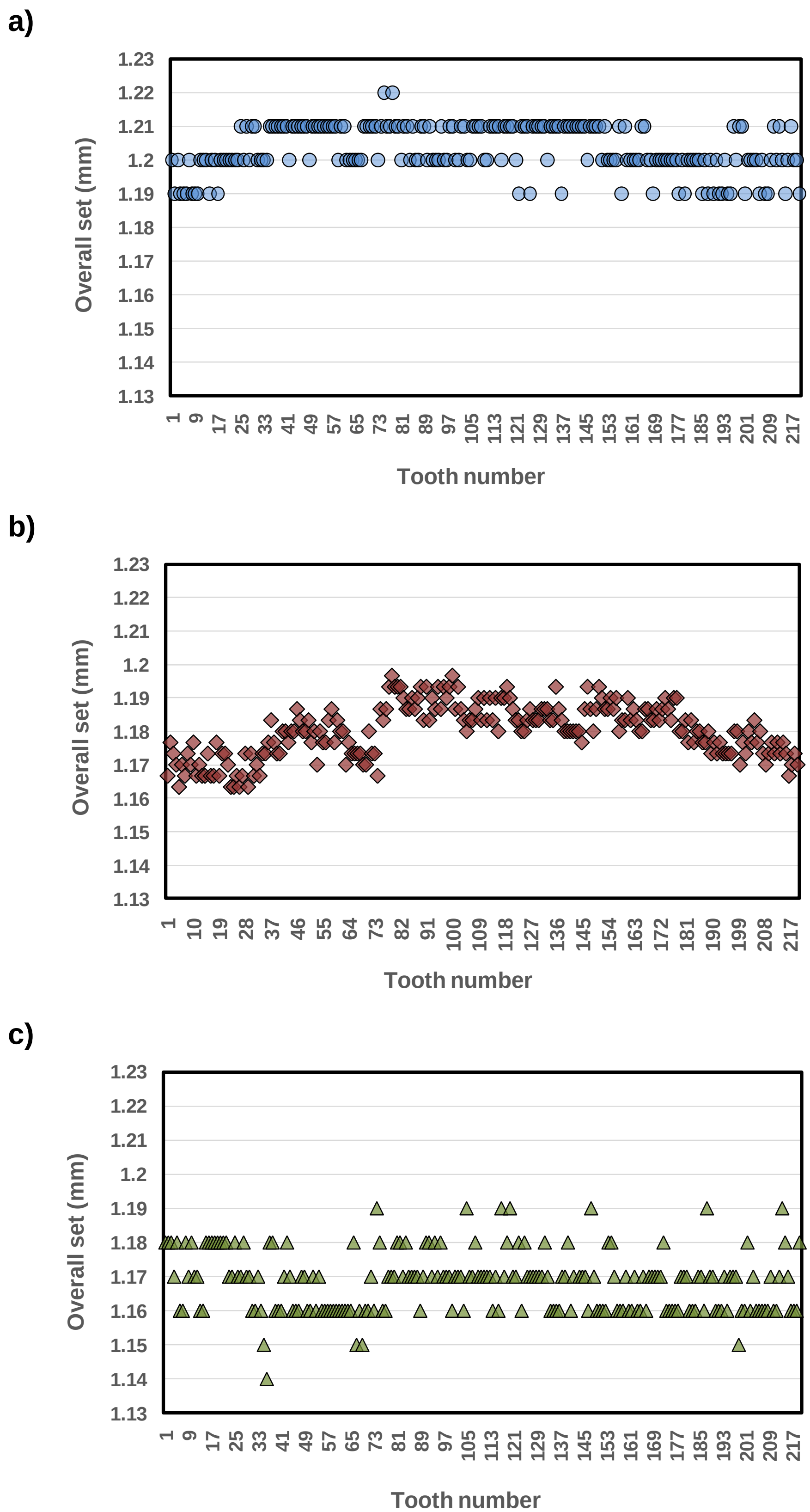

Fig. 2. Overall sets of band saws, where: new band saw (a), after re-sawing process while tool life is achieved for test No 1 (b), and after re-sawing process when tool life is reached for test No 2 (c)

In the cases under consideration, the values of the dispersion of averages DAv S_t were computed with Eq. 1, for a number of degrees of freedom n_x = 219, and t_{cr} a critical value of the Student's t test t_{cr} = 1.9685 (for a significance level α = 0.05) (Sachs 1984). The obtained value of the dispersion of averages were as follows: for a new band saw (Fig. 2a) DAv S_t = 0.0009 mm, for the band saw after the test No 1 (Fig. 2b) DAv S_t = 0.001 mm, for the case shown in Fig. 2c DAv S_t = 0.0011 mm thus, the average overall sets of the worn teeth are $S_t = 1.175 \pm 0.001$ mm (Fig. 2b) and $S_t = 1.151 \pm 0.0011$ mm (Fig. 2c).

The first observed tool life for the new band saw after re-sawing process of oak boards was equal to 220 min (test No 1), which corresponded to 1760 m of the total length of sawn boards. For the re-sawing process with the re-sharpened band saw applied, the tool life was equal to 63 min, which corresponds only to 504 m of the total lengths of sawn boards in the test No 2. Because the width of boards were different, a much better indicator to compare these processes is the capacity of surface production (Fig. 3), which for test No 1 was equal to 389 m^2, and in test No 2 equaled 126 m^2.

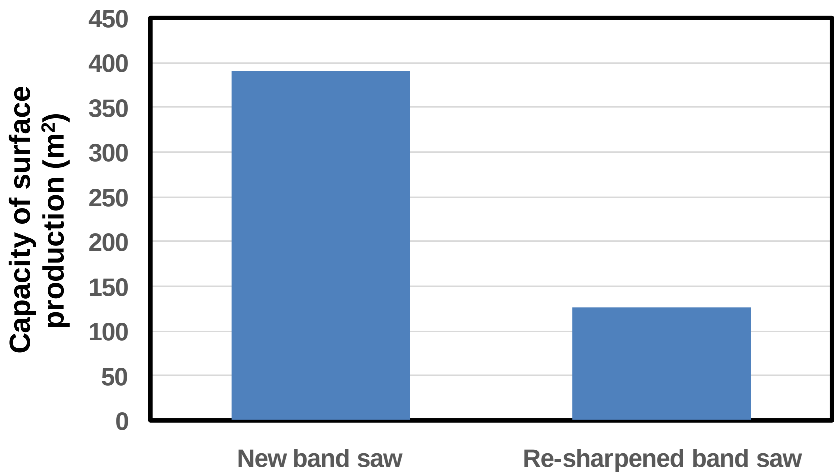

Fig. 3. Capacity of surface production as a function of band saw applied

Fig. 4. Marks visible on the sawn surface of the oak lamella caused by the broken down tooth #143

After additional observation of the teeth, it was found that tooth #143 had broken down (catastrophic tooth wear), which resulted in clear marks visible on the sawn surface (Fig. 4). For that reason, it is recommended to consider equipping the band saw with systems for automatic detection of cutting blade defects similarly to what the authors Zhu *et al*. (2000, 2001) presented. Furthermore, teeth numbered #25, #74, #148, and #202 probably underwent plastic deformation. For this reason, the listed teeth were cut from the saw blade and subjected to additional observations on the NIKON ECLIPSE Ti-S microscope. Exemplary views of teeth #25 and #202 in directions of the clearance face A_α and in direction of the rake face A_γ are presented in Fig. 5.

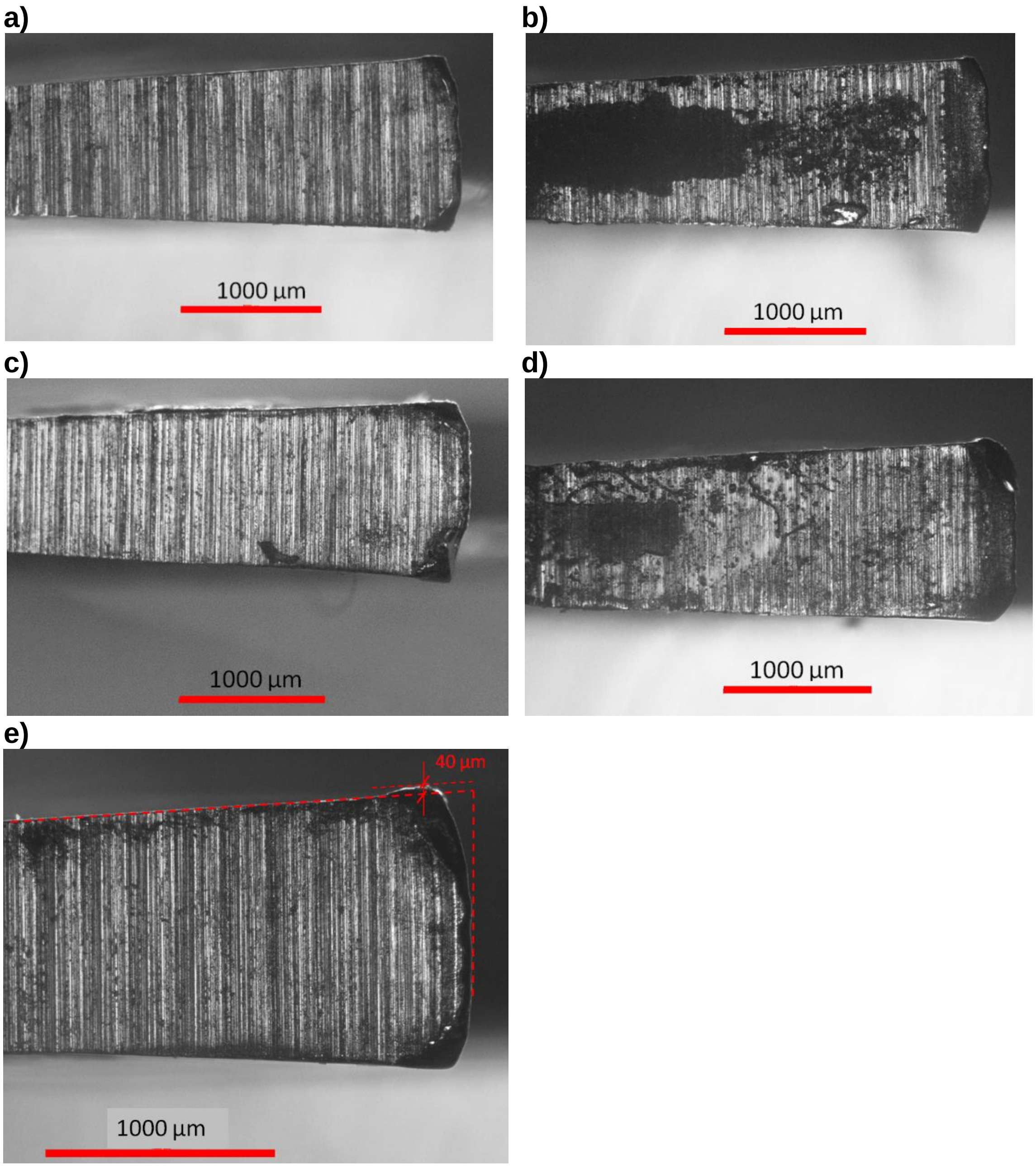

Fig. 5. Views in direction of clearance face A_α of the tooth #202 (a), tooth #25 (c), and tooth #148 with dimensioned plastically deformed corner (f), and in direction of rake face A_γ of the tooth #202 (b), tooth #25 (d) (magnification of 2.5×)

In each case presented, it can be seen that the corners of the cutting edges lying at the intersection of the main and minor cutting edges showed plastic deformation characteristics. In Fig. 5f there is shown as an example dimensioned plastically deformed corner of the tooth #148, which dimension equals 40 μm. This caused the minor (side) cutting edges to not be straight. Examination of the shape of the main cutting edges revealed their lack of straightness, which might have been caused by increased corner wear or additionally the presence of catastrophic failure as in tooth #25 (Fig. 5c).

A common error that occurs during sharpening of tools is the presence of burrs on the cutting edges. These burrs would probably have been removed during the initial stage of the sawing process, during the initial running-in period (the first part of the curve of natural wear) (Grzesik 2017). Moreover, for mini gang saw blades (Orlowski *et al*. 2001) the larger cutting edge radii for the new blade were caused by the presence of burrs after the cutting edge grinding process, which was the original sharpening process included in the blade manufacturing process. The observed phenomenon may lead to faster wear of the regenerated cutting edges, as shown by Jaworski *et al.* (2016). In Jaworski *et al.* it was observed that as the number of sharpening increases, the mean value of the pull broach tooth wear on the clearance face increases, which has an impact on the quality of the machining process. The cutting surfaces of sharpened hobs should be lapped to eliminate edge chipping, then as a result it has a direct effect on the higher quality of machined gear wheels (Piotrowski 2016). In the analyzed case of the process of re-sawing oak boards, a three times higher capacity of surface production was obtained for the new tool compared to the re-sharpened tool. Compared to the hob, the band saw is a much simpler tool, thus, adding an additional technological operation, such as lapping, would be irrational. This shows that the sharpening process should be performed carefully. In contrast, the same is true when cutting metals, where it is recommended that new band saw blades are run-in in a controlled manner. This allows an increase in the tool (blade) life, meaning in the authors' case, an increase in capacity of surface production. To achieve this, the user should reduce the feed rate during the first cuts to 50% of the recommended feed rate. After cutting a section, which should be determined experimentally, the feed rate can be gradually increased up to the optimum value (Perschmann Hoffmann Group 2016).

CONCLUSIONS

On the basis of the conducted experiments, the following conclusions can be derived:

1. In the process of re-sawing oak boards, a three times higher capacity of surface production was obtained for the new tool compared to re-sharpened tool.
2. The main reason of the above phenomenon is that the corners of the cutting edges lying at the intersection of the main and minor cutting edges have plastic deformation characteristics. Moreover, the shape of the main cutting edges revealed their lack of straightness, which might have been caused by increased corner wear or additional presence of catastrophic failure.
3. Clear marks visible on the sawn surface were caused by the catastrophic tooth wear of the tooth. To avoid this phenomenon the band sawing machine should be equipped with the automatic system for automatic detection of cutting blade defects.

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