PRELIMINARY STUDIES ON THE EFFECT OF FEED SPEED ON THE COLOUR CHANGE OF WOOD

Daniel Chuchala – Sandra Karpinska – Aleksandra Suchta – Kazimierz A. Orlowski

Abstract
This paper presents the results of preliminary analyses of the effect of cutting parameters on changes in the colour of wood. Beech wood cut with use circular saw was analysed. The cutting parameter tested was the feed speed, represented by the feed per tooth. Sawing processes with different feed per tooth ranging from 0.0008 mm to 0.09 mm were analysed. It was observed that over the entire range of feed rate per tooth analysed, the colour of the wood changed noticeably, while at certain values the change was very large. However, from a certain limit of feed per tooth, the values of total colour change begin to stabilise. The observed phenomena need to be analysed more extensively and confirmed using other wood sawing processes.

Key words: *sawing process, beech wood, feed speed, colour changes, circular sawing*

INTRODUCTION

Wood is natural and renewable resource has been popular by humans life for millennia. Currently, the wood usage is increasing in modern architecture (SEKULARAC *et al.* 2016) and civil construction (AHMED AND AROCHO 2021; BUKAUSKAS *et al.* 2019) because wood has the specific mechanical and physical properties and is very good storage of carbon (BRUNET-NAVARRO *et al.* 2021).
The wood properties can be changed by use different technological processes. VILKOVSKÝ *et al.* (2021) showed that the storage conditions have an affect on mechanical properies of beech and oak wood. Mechanical properties also change during the wood drying process. The scale of these changes depends on the drying process type used as showed by CHUCHALA *et al.* (2020). Whereas, KLEMENT *et al.* (2020) showed that the contact-drying process affects the physical properties of beech wood. Also, the impregnation process of wood affects its mechanical properties (SINN *et al.* 2020) and physical properties (LICOW *et al.* 2020). Thermal treatments such as drying or steaming of wood, as well as impregnation of wood, also affect to some extent the granulation of chips and dust produced during the machining processes (ROGOZINSKI *et al.* 2021; KMINIAK *et al.* 2020; ORLOWSKI *et al.* 2019). Thermal treatment processes for wood significantly vary the colour of the treated wood. This is noticeable both for drying processes (BARANSKI *et al.* 2020; KLEMENT *et al.* 2019) and in steaming processes using higher temperatures (DZURENDA 2022; GEFFERT *et al.* 2017). In addition, the structural structure of the wood also influences the colour differences (KLEMENT and

Gdansk University of Technology, Faculty of Mechanical Engineering and Ship Technology, Institute of Manufacturing and Materials Technology, Narutowicza 11/12, 80-233 Gdansk, Poland
e-mail: danchuch@pg.edu.pl, sandrakarpi@wp.pl, alekonop@pg.edu.pl, korlowsk@pg.edu.pl

VILKOVSKÁ 2019). Therefore, it can be concluded that the process temperature has a noticeable effect on the colour changes of the wood. However, KONOPKA *et. al.* (2021) showed that colour change of beech wood during kiln drying process and steaming process is only on very thin external layer of wood.

The wood colour is more important an aesthetic property. Machining processes are often the last processes in the manufacturing process of wooden components. The parameters of the machining processes affect the cutting forces (CHUCHALA *et al.* 2020; SINN *et al.* 2020), noise during the process (LICOW *et al.* 2020) as well as the granulation of chips and dust (ORLOWSKI *et al.* 2019; ROGOZINSKI *et al.* 2021; KMINIAK *et al.* 2020). The cutting parameters also have a significant effect on the temperature in the cutting zone (IGAZ *et al.* 2019). The heat generated during the cutting process can affect the wood and consequently change its colour. A change in colour during the cutting process can be an aesthetically undesirable effect on the finished product.

The aim of the research was to carry out preliminary tests to verify how the feed speed of the sawing process affects the colour change of beech wood.

MATERIALS AND METHODS

Materials

The beech wood (*Fagus sylvatica* L.) was a analysed material. The analysed wood was obtained from the regions of southern Austria. For the analysis, 11 rectangular samples of (wood blocks W = 30 mm × H = 20 mm × L = 200 mm) were prepared, cut from beams coming from one log. The test material was free from defects that could affect the colour change, e.g. false heartwood, reaction wood etc. One of the samples was selected as a reference sample (no. 0), which was not subjected to sawing tests. The surface of the reference sample created by the sawmilling process was handly sanded to remove a layer of wood, which colour may have changed as a result of the sawmilling process.

Machine tool, tools and cutting process

Cutting tests of the analysed wood were carried out under industrial conditions on a SERON CNC milling machine dedicated to wood processing. The cutting tool used for the tests was a saw milling cutter PI-401 from FABA S.A. (Poland) with cemented carbide teeth and straight cutting edges in GM shape. The applied cutting tool was sharp, the cutting edges and other basic dimensions as follows: overall set (kerf width) (S_t), 4 mm; saw blade thickness (s), 3 mm; diameter (D), 125 mm; number of teeth (z), 24; tool side rake (γ_f), 15°.

The cutting process was conducted with one and constant value of cutting speed for all samples, v_c = 50 m·s^{-1} The only varying cutting parameter was feed speed (v_f), which was adopted in the range from 115 mm·min^{-1} to 16509 mm·min^{-1}, divided into 10 steps (Table 1).

Table 1. Cutting parameters used in tests

Sample number	Cutting speed, v_c	Feed speed, v_f	Feed per tooth, f_z
	$m \cdot s^{-1}$	$mm \cdot min^{-1}$	mm
1	50	154	0.0008
2	50	384	0.002
3	50	768	0.004
4	50	1152	0.006
5	50	1536	0.008
6	50	1834	0.01
7	50	5503	0.03
8	50	9172	0.05
9	50	12840	0.07
10	50	16509	0.09

Colour measurement and analysis

Colour measurements were carried out using a portable Konica Minolta CR-10 Colour Reader spectrometer. The newly created surfaces as a result of cutting through each sample at different feed speeds were subjected to colour measurements at 10 equally spaced points. Changes in wood colour were analysed using the CIELAB system (ISO 11664-2:2007; ISO 11664-4:2019):

$$\Delta E = \sqrt{(L_i - L_0)^2 + (a_i - a_0)^2 + (b_i - b_0)^2}[-] \quad (1)$$

where L_0, a_0, b_0 are the values of color spectra for reference sample without sawing, and L_i, a_i, b_i are the values of color spectra for each sawing samples, where $i = 1,\dots,10$.
In addition, colour changes were assessed according to the scale proposed by CIVIDINI *et al.* (2007), as follows:

$\Delta E < 0.2$: invisible colour change;
$2 > \Delta E > 0.2$: slight change of colour;
$3 > \Delta E > 2$: colour change visible in high filter;
$6 > \Delta E > 3$: colour changes visible with the average quality of the filter;
$12 > \Delta E > 6$: high colour change;
$\Delta E > 12$: different colour.

RESULTS

The results of the measured colour change parameters during the sawing process with different feed rates per tooth are shown in Table 2. Sample number 0 shows the results of the measurement of the colour parameters for the reference sample, while the subsequent numbers from 1 to 10 represent measurements for successive cutting processes with different values of one of the main parameters of the cutting process, which is the feed speed v_f. In this case this parameter is represented by the basic parameter such as feed per tooth f_z.

Table 2. Color change measurement results after sawing process with different values of feed per tooth

Number of sample	Feed per tooth, mm	Statistic values	*L*	*a*	*b*	*ΔE* [%]
0	-	average value	66.61	11.01	16.80	-
		SD	0.18	0.08	0.29	
1	0.0008	average value	63.39	10.72	15.87	2.30
		SD	4.33	0.69	0.21	
2	0.002	average value	66,17	11.00	17.01	3.55
		SD	0.97	0.34	0.19	
3	0.004	average value	67.31	10.98	17.01	4.62
		SD	0.59	0.45	0.41	
4	0.006	average value	66.48	11.10	16.06	3.99
		SD	0.92	0.51	0.21	
5	0.008	average value	65.83	11.63	16.37	3.15
		SD	0.18	0.29	0.24	
6	0.01	average value	66.62	11.03	16.84	3.97
		SD	0.17	0.09	0.30	
7	0.03	average value	67.97	10.29	17.00	5.48
		SD	0.39	0.22	0.32	
8	0.05	average value	66.15	10.89	17.23	3.56
		SD	0.70	0.38	0.16	
9	0.07	average value	66.00	10.83	16.58	3.54
		SD	0.63	0.29	0.24	
10	0.09	average value	65.91	11.36	17.02	3.17
		SD	0.14	0.13	0.33	

Legend: *L*, *a*, *b* – colour changes parameters measured for reference sample without sawing process and for samples after sawing process, *ΔE* - total colour change, SD – standard deviation

When observing the individual values of the colour parameters (*L, a, b*), the large differences are not visible in the results. However, if observing the values of the total colour change parameter *ΔE*, can be notice that the values in the characteristic points reach almost the values of high colour change according to CIVIDINI *et al.* (2007), i.e. up to 6 % (sample no 3 and sample no 7).

Almost all used values feed per tooth resulted in achieving a total colour change *ΔE* of more than 3%. Only the value of f_z = 0.0008 mm produced a lower total colour change (*ΔE* = 2.30%). Which is an interesting phenomenon, as IGAZ *et al.* (2019) showed that at lower feed per tooth, the cutting process temperatures are higher than at larger feed per tooth values. Figure 1 shows the course of the total colour change as a function of the feed per tooth used in the sawing process. It can be observed that the total colour change values start be stabilised as feed per tooth of f_z = 0.05 mm. However, it still maintains values above 3% which indicates a noticeable change in colour.

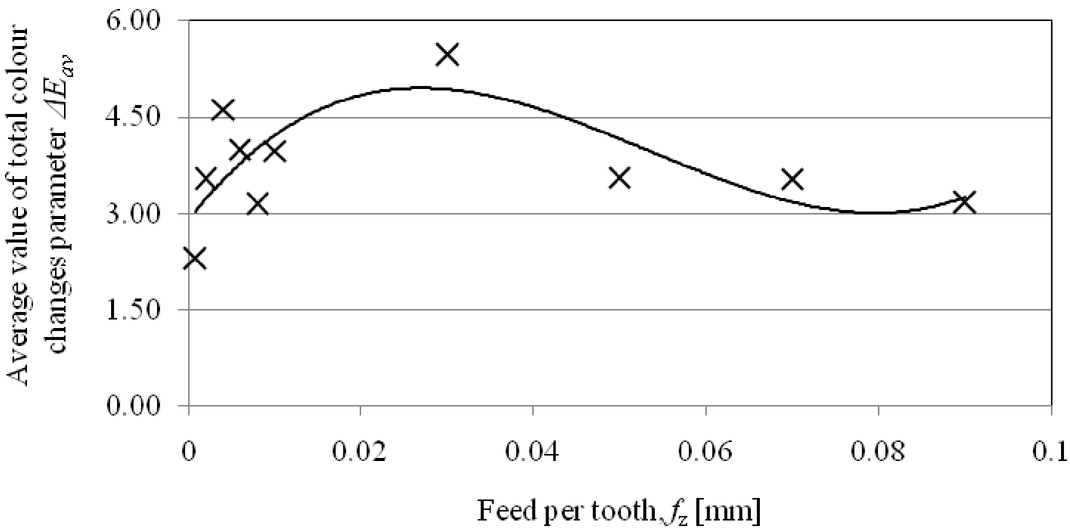

Figure 1. Average value of total colour changes parameter ΔE_{av} in relation to feed per tooth.

CONCLUSIONS

The analysis carried out to investigate the effect of the feed speed during the sawing process on the colour change of beech wood has allowed the following conclusions:

- the sawing process noticeably changes the colour of the beech wood over a wide range of feed speeds used. The parameter of total colour change ΔE in almost the whole range of tested feed speeds reached values above 3%;
- for the circular sawing process analysed, the highest values of the total colour change parameter were observed for feed per tooth of 0.03 mm, ΔE = 5.48%. It is very close value to limit of high colour change;
- The issue of the effect of the cutting process parameters on the colour change of wood needs to be analysed in greater depth. Both an enlargement of the range of analysed feed per tooth values for the circular sawing process and an analysis of other cutting processes and other cutting parameters, such as cutting speed.

ACKNOWLEDGEMENTS

This work was supported by Polish National Agency for Academic Exchange (NAWA Poland), grant no BPN/BSK/2021/1/00033 and the Slovak Research and Development Agency under the contract no. SK-PL-21-0059 are kindly acknowledged.

The authors would also like to acknowledge the company STOLMACH from Nowy Dwor Gdanski, Poland, for sharing the machine tool and their assistance with the sawing tests.

REFERENCES

AHMED, S., AROCHO, I., 2021. Analysis of cost comparison and effects of change orders during construction: Study of a mass timber and a concrete building project. Journal of Building Engineering 33, 101856. DOI: 10.1016/j.jobe.2020.101856

BARANSKI, J., KONOPKA, A., VILKOVSKÁ, T., KLEMENT, I., VILKOVSKÝ, P., 2020. Deformation and surface color changes of beech and oak wood lamellas resulting from the drying process. Bioresources, 15(4), 8965–8980. DOI:10.15376/biores.15.4.8965-8980.

BRUNET-NAVARRO, P., JOCHHEIM, H., CARDELLINI, G., RICHTER, K., MUYS, B., 2021. Climate mitigation by energy and material substitution of wood products has an expiry date. Journal of Cleaner Production 303, 127026. DOI: 10.1016/j.jclepro.2021.127026

BUKAUSKAS, A., MAYENCOURT, P., SHEPHERD, P., SHARMA, B., MUELLER, C., WALKER, P., BREGULLA, J., 2019. Whole timber construction: A state of the art review. Construction and Building Materials, 213, 748–769, DOI: 10.1016/j.conbuildmat.2019.03.043

CHUCHALA, D., SANDAK, J., ORLOWSKI, K.A., MUZINSKI, T., LACKOWSKI, M., OCHRYMIUK, T., 2020. Effect of the Drying Method of Pine and Beech Wood on Fracture Toughness and Shear Yield Stress. Materials, 13, 4692. DOI: 10.3390/ma13204692

CIVIDINI, R., TRAVAN, L., ALLEGRETTI, O., 2007. White beech: A tricky problem in drying process. Proceedings of 7th ISCHP (International Scientific Conference on Hardwood Processing), 24-26 September 2007, Quebec City, Canada

DZURENDA, L. 2022. Range of color changes of beech wood in the steaming process. BioResources 17(1): 1690-1702.

GEFFERT, A., VÝBOHOVÁ, E., GEFFERTOVÁ, J., 2017. Characterization of the changes of colour and some wood components on the surface of steamed beech wood. Acta Facultatis Xylologiae Zvolen, 59(1), 49–57. DOI:10.17423/afx.2017.59.1.05.

IGAZ, R., KMINIAK, R., KRIŠÁK, L., NĚMEC, M., GERGEĽ, T., 2019. Methodology of temperature monitoring in the process of CNC machining of solid wood. Sustainability, 11, 95. DOI:10.3390/su11010095

ISO 11664-2 (2007) Colorimetry – Part 2: CIE Standard Illuminants (Geneva: International Organization for Standardization)

ISO 11664-4 (2019) Colorimetry — Part 4: CIE 1976 L*a*b* Colour Space (Geneva: International Organization for Standardization)

KLEMENT, I., VILKOVSKÁ, T., BARANSKI, J., KONOPKA, A., 2019. The impact of drying and steaming processes on surface color changes of tension and normal beech wood. Drying technology, 37(12), 1490-1497. DOI: 10.1080/07373937.2018.1509219

KLEMENT, I., VILKOVSKÁ, T., 2019. Color characteristics of red false heartwood and mature wood of beech (Fagus sylvatica L.) determining by different chromacity coordinates. Sustainability, 11(3), 690. DOI: 10.3390/su11030690

KLEMENT, I., VILKOVSKÝ, P., VILKOVSKÁ, T., 2020. The effect of contact-drying on physical properties of European beech (Fagus sylvatica L.). Forests 11(8), 890. DOI: 10.3390/f11080890

KMINIAK, R., ORLOWSKI, K.A., DZURENDA, L., CHUCHALA, D., BANSKI, A., 2020. Effect of Thermal Treatment of Birch Wood by Saturated Water Vapor on Granulometric Composition of Chips from Sawing and Milling Processes from the Point of

View of Its Processing to Composites. Applied Sciences-Basel, 10, 7545. DOI: 10.3390/app10217545

KONOPKA, A., CHUCHALA, D., ORLOWSKI, K.A., VILKOVSKÁ, T., KLEMENT, I., 2021. The effect of beech wood (Fagussylvatica L.) steaming process on the colour change versus depth of tested wood layer, Wood Material Science & Engineering, AHEAD-OF-PRINT, 1-9. DOI: 10.1080/17480272.2021.1942200

LICOW, R., CHUCHALA, D., DEJA, M., ORLOWSKI, K.A., TAUBE, P., 2020. Effect of pine impregnation and feed speed on sound level and cutting power in wood sawing. Journal of Cleaner Production, 272, 122833. DOI: 10.1016/j.jclepro.2020.122833

ORLOWSKI, K.A., CHUCHALA, D., MUZINSKI, T., BARANSKI, J., BANSKI, A., ROGOZIŃSKI, T., 2019. The effect of wood drying method on the granularity of sawdust obtained during the sawing process using the frame sawing machine. Acta Facultatis Xylologiae Zvolen, 61, 83-92. DOI: 10.17423/afx.2019.61.1.08

ROGOZINSKI, T., CHUCHALA, D., PĘDZIK, M., ORLOWSKI, K.A., DZURENDA, L., MUZIŃSKI, T., 2021. Influence of drying mode and feed per tooth rate on the fine dust creation in pine and beech sawing on a mini sash gang saw. European Journal of Wood and Wood Products (HOLZ ALS ROH-UND WERKSTOFF), 79, 91-99. DOI: 10.1007/s00107-020-01608-8

SEKULARAC, J.I., TOVAROVIC, J.C., SEKULARAC, N., 2016. Application of wood as an element of façade cladding in construction and reconstruction of architectural objects to improve their energy efficiency. Energy and Buildings, 115, 85–93. DOI: 10.1016/j.enbuild.2015.03.047

SINN, G., CHUCHALA, D., ORLOWSKI, K.A., TAUBE, P., 2020. Cutting model parameters from frame sawing of natural and impregnated Scots pine (Pinus sylvestris L.). European Journal of Wood and Wood Products (HOLZ ALS ROH-UND WERKSTOFF), 78, 777-784. DOI: 10.1007/s00107-020-01562-5

VILKOVSKÝ, P., VILKOVSKÁ, T., KLEMENT, I., ČUNDERLÍK, I., 2021. Impact of storage conditions on shear strength of beech (Fagus sylvatica L.) and sessile oak (Quercus petraea (Matt.) Liebl.). Forests 12(8), 1025. DOI: 10.3390/f12081025