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Influence of thermal modification in nitrogen atmosphere on the gloss of black poplar (*Populus nigra* L.)

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Abstract: *Influence of thermal modification in nitrogen atmosphere on the gloss of black poplar* (*Populus nigra* L.). Heat treatment of wood is a process to which improve mechanical and physical properties. During this treatment is observed changes aesthetic properties of wood among others gloss. The aim of this research was to conduct the influence of time and temperature on surface gloss of black poplar wood (*Populus nigra* L.). Wood was modified by heat treatment process in nitrogen atmosphere in temperaturę from 160 °C to 220 °C, and during the following time periods 2 h - 8 h. Under the influence of modification Surface of modified wood change the gloss of black poplar wood. There was correlation between temperaturę and gloss changing and longer time of treatment. In temperaturę 220 °C decrease og gloss was 45 % for radial section and 52 % for tangential section. Influence of time and temperature on modified black poplar wood was different and depend on section. Temperature of modification was in 20 % accountable for gloss change on radial section and in 38 % for gloss change on tangential section. Influence of time during the proces was much smaller then temperaturę parameters and was 3 % and 5 % respectively for radial and tangential section.

Keywords: black poplar, gloss, nitrogen, radial section, tangential section, thermal modification

INTRODUCTION

Wood was a important material for people from ages. Nowadays wood is also very popular material because of many advantages. Wood is a renewable, environmentally friendly and has a high strength (depend from the species) and natural durability (Nguyen et al. 2018). Additionally wood have a natural aesthetic qualities, has a wide range of color and attractive wood drawing. Nowadays the huge cutting of forest around the world reduce the level of forest resources. This proces has a negative influence on environmental (Machoń 2013). Consuming of wood and wood products is still rising up because of that area of wood plantation of fast growing species also rising up (Kelty 2006, Szostak et al. 2013, Dimitriou et al. 2015, Liesebach 2020).

One of the species which is using to cultivate on the plantation system is black poplar wood (*Populus nigra* L.) (Niemczyk 2016). Depsite black poplar wood is rarely using as solid wood to produce elements among others noon intensive color of heart wood and monotonous wood figure. Moreover most of the application needs to be improved their properties like durability dimensional stability. These properties limited using of black poplar wood by what poplar wood is mainly consumed by cellulose industry and as a fuel material (Kozakiewicz et al. 2019).

One of the way to change the properties of this wood and widening potential uses in new sectors of wood industry is thermal modification process (Gunduz et al. 2009, Sandberg et al. 2017). This is alternative for chemicals modifications and much environmentally friendly (Olek and Bonarski 2008). Nowadays thermal modification proces is considered as environmental friendly (Boonstra and Tjeerdsma 2006, Olek and Bonarski 2008). The most popular wood modification at the world are: ThermoWood® in Finland, Retification® and Torrefaction® in France, PLATO-wood® in Netherlands, and Oil-Heat Treatment (OHT) in Germany (Sahin 2017, Slabejová et al. 2021, Suri et al. 2021).

Thermal modification of wood is lead a temperature rage from 160 °C to 230 °C (Zauer et al. 2014, Candelier et al. 2017). Chemical properties, physical properties and also mechanical of wood after modification process are permanently changing (Esteves and Pereira 2009; Rautkari et al. 2014, Hill et. al. 2021). One of the most important properties of wood using after thermal modification process is change of color. The most important parameters of modification process which influence on wood color are temperaturę and time of modification. After heat treatment wood is darknes. Darkening has a positive correlation with time and temperature of modification process (Bekhta and Niemz 2003, Kamperidou et al. 2013, Icel et al. 2015, Bytner et al. 2022), evenly on whole cross section (Barcík et al. 2015, Gao et al. 2016). Heat treatment process give possibllity to take a wood color from light brown to dark brown, most often resembling or substitution exotic species of wood (Gunduz et. al 2009). In the literature also are topics connected with gloss of wood. According to Aksoy et al. (2011) heat treatment caused a decrease in gloss values of Scots pine. Decrease of gloss during heat treatment process observe Gurleyen et al. (2018) on hornbeam, poplar, chestnut and Uludağ fir wood.

Heat treatment process causes irreversible changes in chemical composition and structure of treated wood. To the greatest extent are degraded hemicelluloses (Chen et al. 2012, Bytner et al. 2021). Some authors show that there is a positive correlation betwen decomposition of hemicelluloses changes in extractives substances to darkening of wood . This changes are causes high temperaturę and changes in structure of lignin composition. (Sundqvist and Morén 2002).

The aim of this research was to term influence of temperature and time of modification process in nitrogen atmosphere on gloss of black poplar wood in cross section (radial and tangential). This research should to broadening the knowledge on the thermal modification of fast growing wood as black poplar in the context in future implementation as a alternative for exotic species.

MATERIALS AND METHODS

Black poplar wood samples

40 years old black poplar wood (*Populus nigra* L.) was used as research material. Poplar was cut in Poland (eastern part of the Mazovia province, State Forest District Sokołów Podlaski). The trees had a diameter at breast height (DBH) up to 0.5 m and a mean growth ring width greater than 5 mm. The dimensions of the samples used for modification were as follows: 20 mm (radial), 20 mm (tangential) and 300 mm (longitudinal). Beans used to modification process didn’t have any defects such knots, tangled fibres, cracks, insect trails or rot. The surface of the wood samples was finished by planting. One of the series of samples was a control group (without modification process). The density of non-modified poplar wood determined according to the ISO 13061-2:2014 standard, at 0 % moisture content, was 375 ± 38 kg × m^{-3}.

Black poplar thermal modification in nitrogen atmosphere

The modification of black poplar wood was carried out in nitrogen atmosphere at the temperatures of: 160 °C, 170 °C, 180 °C, 190 °C, 200 °C, and 220 °C. The modification time (for each of the modification temperatures) was: 2 h, 4 h, 6 h, and 8 h. Each variant of modification was performed on 30 samples, each of them characterised by a similar average density. The thermal modification process was carried out according to the methodology described by Bytner et al. (2021).

Wood gloss examination

Wood gloss was measured in two point on radiala and two point on tangential section. For each series was measured 15 samples. Summary were collected 30 measurement point for each series for each section (native and modified wood). To this investigation were used SPEKTROMASTER 565-D (ERICHSEN GmbH & Co. KG, Hemer, Germany) with 60-degree gloss head.

Statistical analysis

The statistical analysis of results was carried out with the use of the STATISTICA Version-13.3 software of StatSoft, Inc. (TIBCO Software Inc., Palo Alto, CA, USA). The analysis was based on the t-test or the ANOVA (Fischer's F-test), with a significance level *(p)* of 0.050. The percentual impact of the analysed factors (temperature and time of modification), the so-called Factor Influence on the gloss of black poplar wood was analysed. The control group was non-modified wood.

RESULTS

In table 1 were presented results of gloss in black poplar wood for radial and tangential section. The gloss value for non-modified black poplar wood (native) for radial and tangential section was respectively 6.7 (± 1.0) GU and 5.2 (± 0.6) GU. Differences were statistically significant ($p \leq 0.05$). After modification process depend on parameters of modification the gloss value for radial section and tangential section was respectively from about 4 GU to about 5 GU and from about 2.5 GU to about 4 GU.

Table 1. Values of the gloss of black poplar wood thermally modified in nitrogen atmosphere; standard deviation in parentheses

Poplar wood	Gloss (GU)											
	Radial section						Tangential section					
Native	6.7 (1.0)						5.2 (0.6)					
Modified	Modification temperature (°C)						Modification temperature (°C)					
Modification time (h)	160	170	180	190	200	220	160	170	180	190	200	220
2	4.9 (0.4)	4.8 (0.6)	4.8 (0.7)	4.9 (0.7)	4.6 (0.8)	4.3 (1.0)	3.7 (0.3)	3.5 (0.3)	3.6 (0.4)	3.5 (0.5)	3.5 (0.7)	3.4 (0.8)
4	5.1 (0.5)	4.7 (0.3)	4.8 (0.5)	4.8 (0.8)	4.1 (0.4)	4.1 (0.6)	4.2 (0.2)	3.3 (0.2)	3.4 (0.3)	3.4 (0.4)	3.0 (0.4)	2.5 (0.4)
6	5.1 (0.4)	4.6 (0.8)	4.7 (0.7)	4.7 (0.6)	4.2 (1.0)	3.9 (0.5)	4.2 (0.2)	3.5 (0.4)	3.4 (0.3)	3.4 (0.5)	3.1 (0.3)	2.5 (0.4)
8	4.9 (0.7)	4.7 (0.6)	4.4 (0.3)	4.4 (0.9)	4.0 (0.4)	3.7 (0.8)	3.6 (0.2)	3.6 (0.3)	3.2 (0.2)	3.3 (0.2)	2.8 (0.5)	2.5 (0.6)

Based on the result can be unequivocally stated that gloss value was higher on radial section then on tangential section and this differences were observe regardless the parameters of the modification process (time and temperature). This differences are statistically significant (table 2). Literature confirm this observation. Bekhta et al. (2014) check the influence of different wood veneer species such as alder, beech, birch, pine. All this species were modified by thermo-mechanical method and all of them have the same dependance of gloss – higher for radial section then fot tangential section. Dependance this, can be explain by anatomy of wood and degree of roughness of wood surface. Difference in arrangement of wood cells (vessels, fiber) on radial and tangential section influence on angle of incidence and reflection sunlight, and in this way is difference between the value of gloss in radial and tangential section. It should be noted that in the radial section, the rays have the form of "incontinuous bands", and in the tangential section they can be seen as very thin "strands" with wedge-shaped ends. Change in gloss of wood is a result of decrease density of wood during thermal treatment process. It is a result of high temperature - decomposition of structural and non-structural compounds of wood (decrease of wood weight which is connected with raising of temperature and time of proces parameters). In the result of this is higher roughness of wood surface what influence on dispersion of light during measurement and lower value of gloss.

Table 2. Statistical analysis of the gloss results (t-test, $p \leq 0.050$, * – significant dependence, ns – no significant dependence)

Radial vs. Tangential	Native wood	160 °C_2 h	160 °C_4 h	160 °C_6 h	160 °C_8 h	170 °C_2 h	170 °C_4 h	170 °C_6 h	170 °C_8 h	180 °C_2 h	180 °C_4 h	180 °C_6 h	180 °C_8 h	190 °C_2 h	190 °C_4 h	190 °C_6 h	190 °C_8 h	200 °C_2 h	200 °C_4 h	200 °C_6 h	200 °C_8 h	220 °C_2 h	220 °C_4 h	220 °C_6 h	220 °C_8 h
Native wood	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
160 °C_2 h	*	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	*	*	*	*	*	*	*
160 °C_4 h	*	*	*	ns	ns	ns	*	*	*	ns	ns	*	*	ns	ns	*	*	*	*	*	*	*	*	*	*
160 °C_6 h	*	*	ns	*	ns	*	*	*	*	*	*	*	*	ns	*	*	*	*	*	*	*	*	*	*	*
160 °C_8 h	*	ns	*	*	*	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	*	*	*	*	*	*	*
170 °C_2 h	*	*	*	*	ns	*	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	*	*	*	*	*	*	*
170 °C_4 h	*	*	*	*	*	*	*	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	*	*	*	*	*	*	*
170 °C_6 h	*	*	*	*	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	*	*	*
170 °C_8 h	*	ns	*	*	ns	ns	*	ns	*	ns	ns	ns	*	ns	ns	ns	ns	ns	*	*	*	*	*	*	*
180 °C_2 h	*	ns	*	*	ns	ns	*	ns	ns	*	ns	ns	*	ns	ns	ns	ns	ns	*	*	*	*	*	*	*
180 °C_4 h	*	*	*	*	*	ns	ns	ns	*	*	*	ns	*	ns	ns	ns	*	ns	*	*	*	*	*	*	*
180 °C_6 h	*	*	*	*	*	ns	ns	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	*	*	*	*	*	*	*
180 °C_8 h	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	ns	*	ns	*	ns	*	*	*
190 °C_2 h	*	ns	*	*	ns	ns	*	ns	ns	ns	ns	ns	*	*	ns	ns	*	ns	*	*	*	*	*	*	*
190 °C_4 h	*	*	*	*	*	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	*	*	*	*	*	*	*
190 °C_6 h	*	*	*	*	*	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	*	ns	ns	*	*	*	*	*	*	*
190 °C_8 h	*	*	*	*	*	*	ns	*	*	*	ns	ns	ns	*	ns	ns	*	ns	ns	ns	*	ns	ns	*	*
200 °C_2 h	*	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	*	ns	*	*	*
200 °C_4 h	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	ns	ns	ns	ns	*
200 °C_6 h	*	*	*	*	*	*	*	*	*	*	*	*	ns	*	*	*	*	*	ns	*	ns	ns	ns	ns	*
200 °C_8 h	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	*	*	ns	ns	ns	*
220 °C_2 h	*	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	*	ns	ns	*
220 °C_4 h	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	*
220 °C_6 h	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	*	ns
220 °C_8 h	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	ns	*

Tangential (below diagonal) / Radial (above diagonal)

Table 3. The percentual influence of temperature, modification time, interaction between temperature and modification time on the gloss in the radial and tangential section of thermally modified black poplar

Factor	Section					
	Radial			Tangential		
	Fisher's F-test	Significance level	Influence of Factors (%)	Fisher's F-test	Significance level	Influence of Factors (%)
	F	p	X	F	p	X
Temp. (1)	38.34	0.000000	20	114.23	0.000000	38
Time (2)	9.68	0.000003	3	26.83	0.000000	5
(1) × (2)	1.50	0.097616	2	11.16	0.000000	11
Error	-	-	75	-	-	46

Observed tendence decrease gloss after thermal modification of wood confirm results in other scientist studies (Aksoy et al. 2011, Korkut et al. 2013). During this research, observed that influence of temperaturę and time of treatment value of gloss decrease. In this experiment based on black poplar wood Based on the results from black poplar is observed that in the range of temperaturę from 170 °C to 190 °C in the most analysis result don't find statistical differences of gloss value (table 2). It follows that in this temperatures gloss value are close (in the same section). Parameters of modification was different and influence from the section (table 3). The biggest difference were connected with temperaturę of modification. Ttemperature of heat treatment proces influence on changeing in gloss value in 20 % in radial section and in 38 % in tangential section. Influence of modification time was much lower but also was twic time iger for tangential section (5 %) then for radial section (3 %). High value of error inform that exist others parameters which influence on gloss value in wood after thermal treatment process.

After heat treatment in nitrogen atmosphere gloss value for blac poplar wood decrease from 24 % to 45 % for radial section and from 19 % to 52 % for tangential section. Baysal et al. (2014) after treat treatment conduct in hot air in oven for 2 h, 4 h, and 8 h at 140 °C, 170 °C, and 200 °C take decrease of gloss results in Oriental beech (*Fagus orientalis* Lipsky) wood from 0.63 % to 39.69 %. During this research at poplar wood observe highest decrease of gloss value. For example, gloss of poplar wood compared to to native wood decrease in temperature 200 °C for 2 h, 4 h, 6 h and 8 h respectively on 31 %, 39 %, 37 %, 40 % for radial section and on 33 %, 42 %, 35 %, 37 % for tangential section. According to Aksoy et al. (2011) for Scots pine wood (*Pinus sylvestris* L.) modified under atmospheric pressure and in the presence of air, in temperaturę 200 °C during 2 h, 4 h and 8 h, noticed decrease of gloss on 22.2 %, 36.6 % and 31.8 %. Whereas for the same parameters of treatment Baysal et al. (2014) for Oriental beech (*Fagus orientalis* Lipsky) wood, was observed decrease of gloss on 14.1 %, 33.8 %, 39.7 %. Similar resources made Can (2020), which modified pine wood (*Pinus sylvestris* L.) and poplar wood (*Populus euramericana*), and in the next steep used a coating for Surface of wood. Depsite the secure of wood surface by coating wood after modification process has a decrease a gloss value. Zhou et al. (2021) in his research were modified mahogany (*Swietenia)* wood. After heat treatment at temperature 200 °C gloss value in longitudinal direction parallel to fiber decrease from 3.86 GU to 2.59 GU.

CONCLUSIONS

Based on the conducted study the following conclusions were formed:

1. Poplar wood (*Populus nigra* L.) after wood modification in range of temperature from 160 °C to 220 °C and time from 2 h to 8 h give lower value of gloss then for native wood.
2. Longer time and higher temperature reduce gloss of poplar wood. but in the range from 170 °C to 190 °C don't observe significant difference between the gloss value.
3. Gloss for non-modified wood of black poplar wood was higher for radial section then for tangential section. The same dependance is observe also for modification wood (for all variants).
4. Influence of modification parameters on gloss black poplar wood was different and depend from section. Temperature of modification was respectlevy for 20 % of gloss change in radial section and 38 % in tangential section. Time of modification has much lower then influence of temperaturę. Observe changes in gloss value was twice time higher for tangential section (5 %) then for radial section (3 %).

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Streszczenie: *Wpływ modyfikacji termicznej w atmosferze azotu na połysk drewna topoli czarnej* (*Populus nigra* L.). Modyfikacja termiczna drewna przeprowadzana jest w celu poprawy właściwości fizycznych oraz mechanicznych. Pod wpływem obróbki następuje zmiana właściwości estetycznych drewna, w tym również połysku. Celem prowadzonych badań było określenie wpływu temperatury i czasu modyfikacji na połysk drewna topoli czarnej (*Populus nigra* L.). Drewno topoli czarnej było modyfikowane termicznie w atmosferze azotu w temperaturze od 160 °C do 220 °C, od 2 h do 8 h. Pod wpływem procesu modyfikacji nastąpiła zmiana połysku drewna topoli czarnej. Zmiany były intensywniejsze im wyższa była temperatura i dłuższy czas obróbki. W temperaturze 220 °C uzyskano spadek wartości połysku o 45 % oraz o 52 % odpowiednio dla przekroju promieniowego i stycznego. Wpływ parametrów modyfikacji na połysk drewna topoli czarnej był różny w zależności od analizowanego przekroju. Temperatura modyfikacji w 20 % odpowiadała za zmienność połysku na przekroju promieniowym, natomiast w 38 % za zmienność połysku na przekroju stycznym. Wpływ czasu modyfikacji był znacznie niższy niż wpływ temperatury i wynosił 3 % i 5 % odpowiednio dla przekroju promieniowego i stycznego.

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