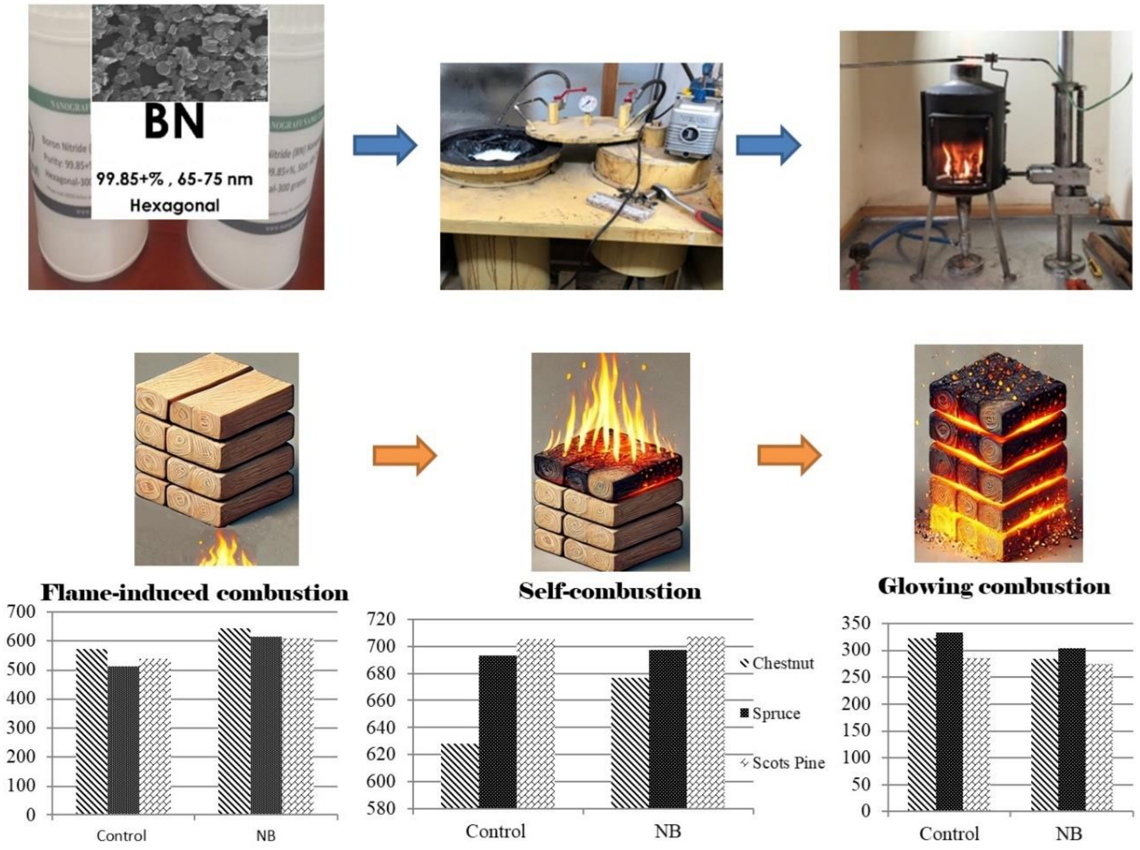
Effect of Nano Particulate Preservation Materials on the Combustion Temperatures of the Wood

Sekip Sadiye Yasar,[a] Eyup Cicek,[b] and Mehmet Yasar [a],*

* *Corresponding author: myasar@aku.edu.tr*

DOI: 10.15376/biores.19.4.9158-9168

GRAPHICAL ABSTRACT



Effect of Nano Particulate Preservation Materials on the Combustion Temperatures of the Wood

Sekip Sadiye Yasar,[a] Eyup Cicek,[b] and Mehmet Yasar [a,]*

It is acknowledged that boron, ammonium, and nitrogenous compounds, which are used today as fire retardants, cause an increase in the hygroscopicity of wood materials. In this study, Scots pine (*Pinus sylvestris* L.), Anatolian chestnut (*Castanea sativa* Mill.), and Eastern spruce (*Picea orientalis* Link) woods were impregnated with 1.5% nano-sized hexagonal boron nitride (NB) according to ASTM D1413-76 (1976) standards. Flame-induced combustion (FIC), self-combustion (SC), and glowing combustion (GC) temperatures were determined. The highest retention amount was measured in spruce and the lowest was in chestnut among the wood samples taken for testing and measurement. When compared with the control samples, NB application caused an increase in SC and FIC temperatures (at higher rates). According to the glowing combustion temperature control samples, an increase was observed in chestnut and spruce and a decrease was observed in Scots pine among the samples applied with NB.

DOI: 10.15376.biores.19.4.9158-9168

Keywords: Wood; Nano hexagonal boron nitride; Combustion temperatures; Flame-induced combustion; Impregnation

*Contact information: a: Afyon Kocatepe University, Department of Industrial Design, Afyonkarahisar, 03400, Turkey; b: Gumushane University, Department of Environmental and Forest Sciences, Gumushane, Turkey; * Corresponding author: myasar@aku.edu.tr*

INTRODUCTION

Wooden material is an engineering and construction resource that has been in use since the earliest times in human history. Although the variety of materials increases in parallel with technological developments, wood is still widely preferred due to its superior features such as being light, easy to process, its aesthetic appearance, being renewable and environmentally friendly, having heat-sound insulation, and its high resistance to collapse in fire and earthquake (Kurtoglu 2000). In addition to all these positive characteristics, wood material can be negatively affected by variables including termites, bacteria, fungi, insects, sunlight, seasonal changes, rain, frost, humidity, chemicals, and fire, which can damage its physical and chemical structure. Studies are being conducted to increase the resistance of wood to the combustion and factors in the usage area (Rowell and Dietenberger 2005; Esteves and Pereira 2009; Percin *et al.* 2015; Fidan *et al.* 2016b; Reinprecht 2016; Yasar *et al.* 2016; Sandberg *et al.* 2017; Godovčin *et al.* 2022).

Wood preservatives can increase the service life of the wood material by protecting it from fire, mechanical wear, weather conditions, biological pests, and physical and chemical degradation. Creosote, pentachlorophenol, chromium-copper-arsenic (CCA), acid-copper-chromium (ACC), alkaline-copper-quat (ACQ), copper-chromium-boron (CCB), copper-chromium-phosphate (CCP), and copper -azole compounds are widely used wood preservatives. It is of great importance that today's preservatives are resistant to environmental conditions, can bond well to wood materials, have a good level of effectiveness, and do not harm the environment and are not harmful to human health. The Environmental Protection Agency (EPA) stated that it is appropriate to make label changes by taking mitigating measures for arsenic, pentachlorophenol, and creosote (Archer and Lebow 2006; EPA 2006; Ibach 2013; Mai and Militz 2023).

In recent years, new "wood modification" methods have been used to adjust the properties of the wood material and increase their service life in parallel with the acceleration of technological developments. Thermal (Thermowood, Platowood), chemical (acetylation, furfurylation, resin impregnation), coating with layer-forming agents, and impregnation applications are used as common modification methods (Yildiz *et al.* 2006; Xing and Li 2014; Reinprecht, 2016; Sandberg *et al.* 2017; Mai and Militz 2023). Ammonium, nitrogen, sulfur, silica, and boron compounds, which are widely utilized today to delay the combustion of wood materials, prevent thermal deterioration by preventing the production of flammable gases with the help of a charcoal layer that they form (Park *et al.* 2017; Deng *et al.* 2022). Studies have been conducted to prevent these compounds from scouring onto wood. Nanotechnology is a branch of science that studies substances in the size range of 1 to 100 nm. In parallel with technological developments, nanotechnology has found use in many sectors (Siegel 1999).

In this study, the combustion properties of wood material were examined using hexagonal boron nitride (NB), which is one of the nano-sized substances that is thought to penetrate deeply into the wood. For this purpose, Anatolian chestnut (*Castanea sativa* Mill.), Scots pine (*Pinus sylvestris* L.), and eastern spruce (*Picea orientalis* Link) woods were impregnated with 1.5% nano NB according to ASTM D1413-76 (1976) standards. Flame-induced combustion (FIC), self-combustion (SC), and glowing combustion (GC) temperatures were examined according to ASTM E160-50 (1975) standards.

EXPERIMENTAL

The wood materials used in the research were obtained from Scots pine (*Pinus sylvestris* L.) and eastern spruce (*Picea orientalis* Link) trees, which are among the coniferous trees, and Anatolian chestnut (*Castanea sativa* Mill.), which were randomly selected from first class timber. Samples were chosen carefully in accordance with TS 2470 (1976) standards from normal and regularly grown wood material pieces that did not contain resin and knots and had regular fibers.

The nano-sized hexagonal boron nitride used in the study was 99.85% pure with dimensions between 65 and 75 nm (Nanografi 2024). Hexagonal boron nitride is a material with low density and low thermal expansion and better thermal conductivity than steel (Haubner *et al.* 2002; Ebin 2007; Oz 2016). It has a wide application area in the fields of chemistry, metallurgy, high temperature technology, electrotechnics, and electronics. Hexagonal boron nitride can be used pyrolytically as a powder coating and as a preservative for composite materials in sprayed, hot-pressed, dense forms (Paine and Narula 1990; Lelonis *et al.* 2003).

Randomly selected timber was subjected to climatization at 20 ± 2 °C and 65 ± 3% relative humidity until a constant moisture content of 12% was achieved before the rough cutting. Test pieces were prepared in dimensions of 13 x 13 x 76 mm^3 (radial x tangential x length) according to ASTM E160–50 (1975) standards. Nano hexagonal boron nitride was penetrated wood pieces with 1.5% concentration with the vacuum-pressure method according to ASTM D1413-76 (1976) principles. In impregnation application, a prevacuum of 600 mm Hg was applied first to the test pieces for 120 min, and then a pressure of 7 atmospheres was applied for 240 min.

The impregnated sample pieces were kept in the conditioning room at 20 ± 2 °C and relative humidity of 65 ± 3% until they reached a constant weight so that the solvent would evaporate. To measure the retention rate of NB during the impregnation process, the samples were weighed before and after the impregnation process.

In each combustion period, 24 pieces were stacked on a wire stand, and a total of 72 pieces were used in 3 replicates for each test. A total of 432 pieces were combusted for each wood group (3), including control and NB application (2).

Samples were prepared from the sapwood part of randomly selected first class material that had uniform fiber, did not have knots or cracks, and had no color and density difference, and the annual rings were upright to surface ISO 3129 (2019). The retention amount of the nano hexagonal boron nitride used in the study was calculated as in Eq. 1 after the impregnation application was conducted and the solvent material evaporated,

$$R = \left[\frac{G \times C}{V}\right] \times 10 \left(\frac{kg}{m^3}\right) \tag{1}$$

where G is T_2 - T_1, T_1 is the weight of the test sample before impregnation (g), T_2 is the weight of the test sample after impregnation (g), V is the sample volume (cm^3), and C is the solution concentration (1.5 %).

To determine the weight loss during combustion, each experiment group was weighed with a precision scale and placed on a wire stand. The weight losses of the woods used in the study during combustion were obtained for chestnut (88.3%), Scots pine (87%), and spruce (86.8%), respectively. According to the application type, 87.5% was obtained in control samples and 87.2% in NB. After the impregnation application, measurements were recorded on the combustion test device shown in Fig. 1, in accordance with ASTM E160–50 (1975) principles, to measure the combustion properties of the samples.

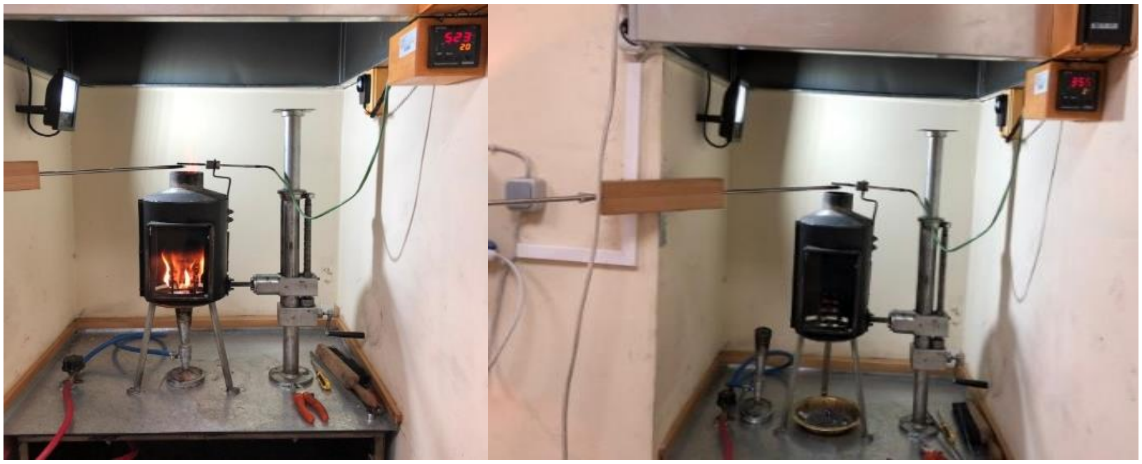


Fig. 1. Combustion test device

While the samples were being placed in the combustion device, the Meeker burner located under the combustion device was positioned according to the center of the flame output. The combustion experiment was started by setting the gas pressure to 0.5 kg/cm² and the flame mechanism to 25 ± 1.3 cm before placing the stack.

Stages in combustion:

- “Flame-induced combustion (FIC)” for 3 min upon starting the flame source,
- “Self-combustion (SC)” by turning off the flame source and self-combustion process

- After self-combustion ends, “glowing combustion (GC)”.

To monitor the combustion stages, temperature changes were measured with the thermometer in the combustion mechanism for every 15 s in flame-induced combustion and 30 s in other combustion stages. At the end of the combustion analyses, combustion temperatures (°C) were determined.

The software MS Excel 2010 (Microsoft Corp., Redmond, WA, USA) was used for data evaluation and MSTAT-C 2.1 statistical program (Michigan State University, East Lansing, MI, USA) was utilized for statistical analysis, and multiple analyses of variance (ANOVA) were conducted between all groups. If the factor effects were significant with a margin of error of $p \leq 0.05$, comparisons were made using the Duncan test. Variance analysis was conducted using SPSS 20.0 (2011) statistical program (Sun Microsystems, Inc., Network Circle, Santa Clara, CA, USA) package software to determine whether the changes in the combustion temperature data measured at the end of the experiment were significant. Mean values were compared using the least significant difference (LSD) test.

RESULTS AND DISCUSSION

The retention values of the nano-sized hexagonal boron nitride used in the study for the wood materials are shown in Table 1.

Table 1. Retention Amount (kg/m^3)

Wood Type	R (kg/m^3)
Anatolian Chestnut	45.7
Scots Pine	70.5
Eastern Spruce	49.4

The highest retention amount was determined in Scots pine, then in Eastern spruce, and the lowest was in Anatolian chestnut. Parallel values were obtained in retention rate values (Bozkurt *et al.* 1993).

The results of multiple variance analysis regarding the effect of wood species and application type on temperature values in flame-induced combustion are given in Table 2.

Table 2. Variance Analysis Belonging to FIC Process

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F- value	Sig.
Wood Type (A)	2	6874.009	3437.005	0.676	0.527
Application (B)	1	30370.718	30370.718	5.974	0.031*
Interaction (AB)	2	1060.314	530.157	0.104	0.902
Error	12	61004.087	5083.674		
Total	18	6173718.472			

*: Statistically significant difference $\alpha \leq 0.05$

As seen in Table 3, the one-way effect of the application type on flame-induced combustion temperature values was found statistically significant, and other interactions were found insignificant. Duncan test was conducted to determine among which groups the difference was significant (Table 3).

Table 3. Temperature Values (°C) in FIC Process According to Application Type

Application	Means	95% Confidence Interval	
		Lower Limit	Upper Limit
Control	540	488	591.6
NB	622	570.2	673.8

Std. Error:: 23.767

In flame-induced combustion, the highest temperatures by the application type were determined in the samples where NB was applied (622 °C). The average, maximum, and minimum values for flame-induced combustion are given in Table 4.

Table 4. Average Temperature Values in FIC Process According to Wood Type and Application Type

Parameters		Average Temperature Values in FIC (°C)	
Wood Type	Application	Means	Std. Error
Chestnut	Control	572.4	6.26
	NB	643.5	1.90
Spruce	Control	510.5	157.65
	NB	614.4	12.59
Scots Pine	Control	536.6	73.37
	NB	608.1	7.99

In average values, the highest temperatures were obtained in Chestnut+NB (643.5 °C) and the lowest was in spruce control samples (510.5 °C). The graph of temperature changes in flame-induced combustion is shown in Fig. 2.

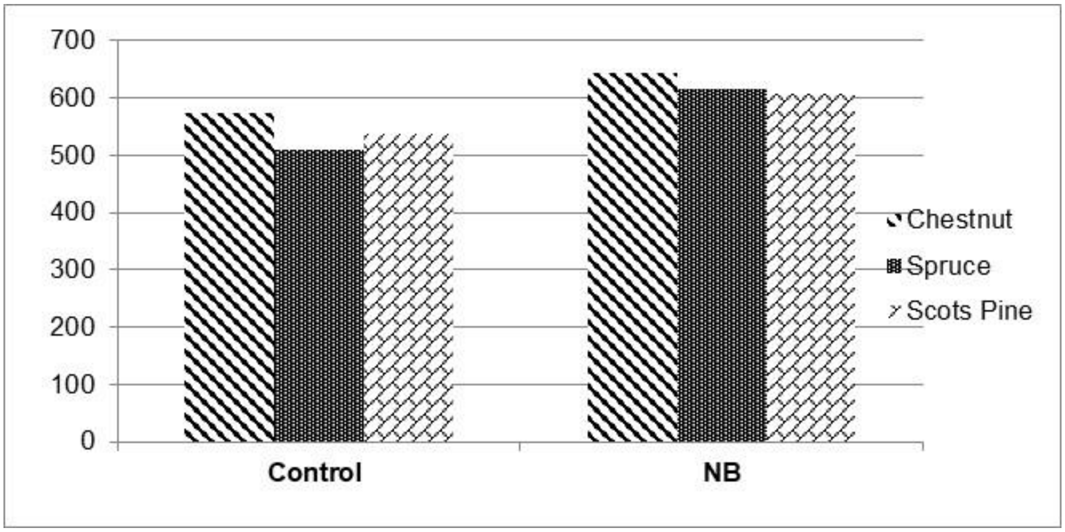


Fig. 2. Average temperature values (°C) in flame-induced combustion

In flame-induced combustion, the combustion degrees in the NB applied samples were measured with a maximum increase of 20.3% in spruce, 13.3% in Scots pine, and 12.4% in chestnut when compared with the control samples. The results of multiple variance analysis regarding the effect of wood type and application type on temperature values in self-combustion are given in Table 5.

Table 5. Variance Analysis of the Temperature Values in SC Process

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F- value	Sig.
Wood Type (A)	2	9705.337	4852.669	8.375	0.005*
Application (B)	1	1525.452	1525.452	2.633	0.131
Interaction (AB)	2	2087.171	1043.586	1.801	0.207
Error	12	6953.151	5083.674		
Total	18	8461677.058			

*: Statistically significant difference α ≤ 0.05

As observed in Table 5, the one-way effect of wood type on temperature values in self-combustion was found to be statistically significant, and other interactions were found to be insignificant. Duncan test was performed to determine among which groups the difference was significant (Table 6).

Table 6. Average Temperature Values in SC Process According to Wood Type

Wood Type	Means	95% Confidence Interval	
		Lower Limit	Upper Limit
Chestnut	652.6	631.2	674
Spruce	695.4	674	716.9
Scots Pine	706.4	685	727.8

In self-combustion, the highest temperatures were obtained in Scots pine (706.4 °C) and the lowest was in chestnut (652.6 °C). The average, maximum and minimum values for self-combustion are given in Table 7.

Table 7. Average Temperature Values in SC Process by Wood Type and Application Type

Parameters		Average Temperature Values in SC (°C)	
Wood Type	Application	Means	Std. Error
Chestnut	Control	628.2	10.61
	NB	677	8.32
Spruce	Control	693.3	32.94
	NB	697.6	14.76
Scots Pine	Control	705.3	43.84
	NB	707.5	8.34

Std. Error: 13.898

The highest average temperatures were obtained in Scots pine + NB (707.5 °C) and the lowest was in chestnut control samples (628.2 °C). Temperature changes during self-combustion are shown in Fig. 3.

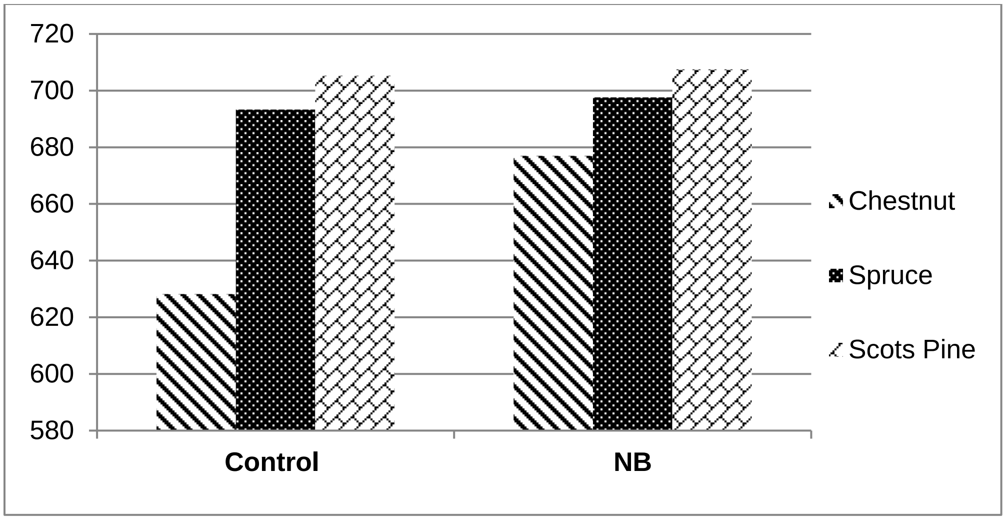


Fig. 3. Average temperature values in self-combustion (°C)

When compared with the control samples, the highest increase in self-combustion was measured in chestnut with 7.8%, spruce with 0.6%, and the lowest in was in Scots pine with 0.3% among the samples impregnated with NB. The results of multiple variance analysis for the effect of wood species and application type on temperature values in glowing combustion are given in Table 8.

Table 8. Variance Analysis of Temperature Values in GC Process

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F- value	Sig.
Wood Type (A)	2	4566.800	2283.400	1.680	0.227
Application (B)	1	3040.418	3040.418	2.237	0.161
Interaction (AB)	2	522.240	261.120	0.192	0.828
Error	12	16308.628	1359.052		
Total	18	1644076.434			

*: Statistically significant difference α ≤ 0.05

Table 9. Average Temperature Values in GC Process by Wood Type and Application Type

Parameters		Average Temperature Values in GC (°C)	
Wood Type	Application	Means	Std. Error
Chestnut	Control	321.3	15.43
	NB	283.3	9.45
Spruce	Control	332.3	74.92
	NB	304.1	27.92
Scots Pine	Control	285.3	35.28
	NB	273.5	13.80

As can be observed from Table 8, all interactions in glowing combustion temperature values were found to be insignificant. Maximum and minimum values for glowing combustion are given in Table 9.

The highest average temperatures were obtained in the spruce control samples (332.3 °C), and the lowest was in the Scots pine NB samples (273.50 °C). The application of NB, which showed high temperatures in the FIC and SC stages, may have caused cooling in the GC (Ors *et al*. 1999; Temiz *et al*. 2008; Fidan *et al*. 2016a; Gan *et al*. 2020). Temperature changes during glowing combustion are shown in Fig. 4.

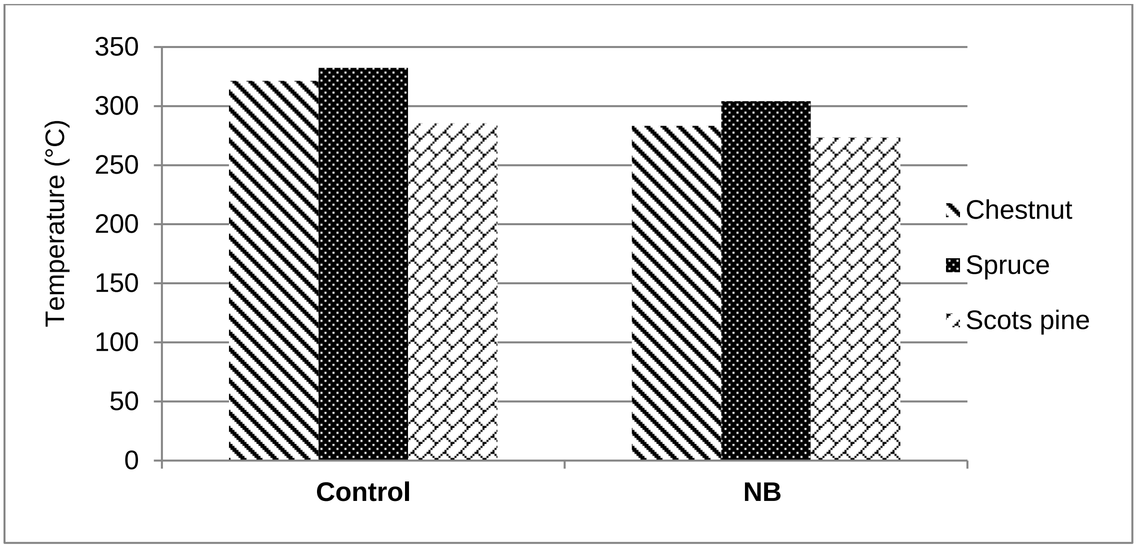


Fig. 4. Average temperature values in glowing combustion (°C)

For the control samples, the glowing combustion temperature showed a decrease of 11.8% in chestnut, 8.5% in spruce, and 4.1% in Scots pine samples to which NB was applied.

CONCLUSIONS

The study aimed to determine the combustion properties of wood species impregnated with nano hexagonal boron nitride (NB). The selected species were Scots pine (*Pinus sylvestris* L.), Eastern spruce (*Picea orientalis* Link), and Anatolian chestnut (*Castanea sativa* Mill.).

1. The application of NB significantly increased the flame-induced combustion (FIC) temperatures across all wood species. The highest FIC temperature recorded was in Anatolian chestnut, which was likely due to its high extractive content.
2. Scots pine exhibited the highest self-combustion (SC) temperatures, which may be attributed to its resin content. NB-treated samples showed increased SC temperatures compared to control samples, with chestnut showing the most significant increase.
3. The NB treatment resulted in lower glowing combustion (GC) temperatures across all wood species, suggesting that the higher temperatures in the FIC and SC stages led to a cooling effect during GC. However, it led to reduced GC temperatures, which could be beneficial in certain fire retardant applications. Future studies should explore the long-term effects of NB treatment and its implications for various industrial applications.

In conclusion, nano hexagonal boron nitride impregnation improved the fire resistance of wood materials, making it a promising treatment for enhancing the safety and durability of wood used in construction and other industries. Further research is needed to fully understand its potential and optimize its application methods.

ACKNOWLEDGEMENTS

This study was conducted from the Master's Thesis prepared by Eyup Cicek under the supervision of Dr. Sekip Sadiye Yasar in Gumushane University, Institute of Science and Technology, Department of Forestry and Environment. This study was supported by Gumushane University - BAP Coordination Unit within the scope of GUBAP2907: Graduate Student Support Program projects.

REFERENCES CITED

Archer, K., and Lebow, S. (2006). "Wood preservation," in: *Primary Wood Processing: Principles and Practice*, J. C. F. Walker (ed.), Springer, Amsterdam, The Netherlands, pp. 297–338.

ASTM D1413-76 (1976). "Standard test methods of testing wood preservatives by laboratory soil block cultures," ASTM International, West Conshohocken, PA, USA.

ASTM E160-50 (1975). "Standard test method for combustible properties of treated wood by the crib test," ASTM International, West Conshohocken, PA, USA.

Bozkurt, A. Y., Goker, Y., and Erdin, N. (1993). *Impregnate Technique*, Istanbul University, Press N: 71, Publication N: 3879, Publication Faculty of Forestry: 4135, Istanbul, Turkey, pp. 106-107.

Deng, C., Liu, Y., Xu, J. X., Li, X. Y., Wen, M. Y., Dua, X. X., and Park, H. (2022). "Fire retardant performance of sugi and hinoki treated with phosphorus and nitrogen fire retardant," *Wood Research* 67(6), 941-952. DOI: 10.37763/wr.1336-4561/67.6.941952

Ebin, B. (2007). "Hexagonal boron nitride," Hard Metal Compounds Lecture, Istanbul Technical University. Istanbul, Turkey.

Environmental Protection Agency (EPA) (2006). *Solid Waste Management and Greenhouse Gases a Life Cycle Assessment of Emissions and Sinks*, 3rd Ed., Environmental Protection Agency, Washington, D.C., USA.

Esteves, B. M., and Pereira, H. M. (2009). "Wood modification by heat treatment: A review," *BioResources* 4(1), 370-404. DOI: 10.15376/biores.4.1.Esteves

Fidan, M. S., Yasar, S. S., Yasar, M., Atar, M., and Alkan, E. (2016a). "Effect of seasonal changes on the combustion characteristics of impregnated cedar (*Cedrus libani* A. Rich .) wood," *Constr Build Mater* 106, 711-720. DOI: 10.1016/j.conbuildmat.2015.12.133

Fidan, M. S., Yasar, S. S., Yasar, M., Atar, M., and Alkan, E. (2016b). "Combustion characteristics of impregnated and surface-treated chestnut (*Castanea sativa* M.) wood left outdoors for one year," *BioResources* 11(1), 2083-2095. DOI: 10.15376/biores.11.1.2083-2095

Gan, W., Chen, C., Wang, Z., Pei, Y., Ping, W., Xiao, S., Sunderland, P. B., and Hu, L. (2020). "Fire-resistant structural material enabled by an anisotropic thermally conductive hexagonal boron nitride coating," *Advanced Functional Materials* 30(10), article 1909196. DOI: 10.1002/adfm.201909196

Godovčin, P., Martinka, J., Rantuch, P., Hladova, M., Kopúnek, J., Otajovičová, M. Á. R. I. A., and Bednáriková, M. Z. (2022). "Impact of temperature and ultraviolet radiation on changes of colour of fir and spruce wood," *Wood Research* 67(6), 894-907. DOI: 10.37763/wr.1336-4561/67.6.894907

Haubner, R., Wilhelm, M., Weissenbacher, R. and Lux, B. (2002). "Boron nitrides-properties, synthesis and applications," in: *High Performance Non- Oxide Ceramics II*, M. Jansen (ed), Springer Verlag, Berlin, Germany.

Ibach, R. E. (2013). "Biological properties of wood," in: *Handbook of Wood Chemistry and Wood Composites*, R. Rowell (ed.), CRC Press, Boca Raton, FL, USA, pp. 99-126. DOI: 10.1201/b12487-8

ISO 3129 (2019). "Wood – Sampling methods and general requirements for physical and mechanical testing of small clear wood specimens," International Organization for Standardization, Geneva, Switzerland.

Kurtoglu, A. (2000). *Wood Material Surface Treatments*, Istanbul University, Faculty of Forestry, Department of Forest Industry Engineering, Istanbul, Turkey.

Lelonis, D. A., Thereshko, J. W., and Anderson, C. M. (2003). *Boron Nitride Powder – A High Performance Alternative for Solid Lubrication*, General Electric Advanced Ceramics (Pub. No. 81506 (9/03)), Cleveland, OH, USA.

Mai, C., and Militz, H. (2023). "Wood modification," in: *Springer Handbook of Wood Science and Technology*, Springer International Publishing, Cham, Switzerland, pp. 873-910.

Nanografi (2024). "Nano grafit Nano Tek. Bil. İmalat ve Dan. Ltd Şti [Nano graphite. Nano tech know Manufacturing and Dan. LLC]," Nano Grafi, (https://www.nanografi.com.tr/), Accessed 28 May 2024.

Ors, Y., Atar, M., and Peker, H. (1999). "The effect of some boron compounds and water repellents on the fire resistance properties of scotch pine wood," *Turkish Journal of Agriculture and Forestry* 23, 501-509,

Oz, M. (2016). "Thermal behavior of hexagonal boron nitride in the open atmosphere," *Cumhuriyet University Faculty of Science Journal (CSJ)* 37(1), 57-64. DOI: 10.17776/csj.38616

Paine, R., and Narula, C. K. (1990). "Synthetic routes to boron nitride," *Chemistry Reviews* 90, 73-91. DOI: 10.1021/cr00099a004

Park, H. J., Wen, M. Y., Kang, C. W., and Sun, Y. X. (2017). "Development of physical pretreatment method for wood fire retardant impregnation," *BioResources* 12(2), 3778-3789. DOI: 10.15376/biores.12.2.3778-3789

Percin, O., Sofuoglu, S. D., and Uzun, O. (2015). "Effects of boron impregnation and heat treatment on some mechanical properties of oak (*Quercus petraea* L.) wood," *BioResources* 10(3), 3963-3978. DOI: 10.15376/biores.10.3.3963-3978

Reinprecht, L. (2016). "Wood durability and lifetime of wooden products," in: *Wood Deterioration, Protection and Maintenance*, John Wiley & Sons, Ltd., Hoboken, NJ, USA, pp. 1-27. DOI: 10.1002/9781119106500.ch1

Rowell, R. M., and Dietenberger, M. A. (2005). "Thermal properties, combustion, and fire retardancy of wood," in: *Handbook of Wood Chemistry and Wood Composites,* CRC Press, Boca Raton, FL, USA, pp. 128-147. DOI: 10.1201/b12487

Sandberg, D., Kutnar, A., and Mantanis, G. (2017). "Wood modification technologies - A review," *iForest- Biogeosciences and Forestry* 10(6), 895-908. DOI: 10.3832/ifor2380-010

Siegel, D. S. (1999). "Skill-biased technological change: Evidence from a firm-level survey," *Upjohn Press Collection*, Upjohn Institute for Employment Research, Kalamazoo, MI, USA. DOI: 10.17848/9780585341651

Temiz, A., Gezer, E. D., Yildiz, U. C., Yildiz, S. (2008). "Combustion properties of alder (*Alnus glutinosa* L.) Gaertn. Subsp. Barbata (C.A. Mey) Yalt.) and southern pine (*Pinus sylvestris* L.) wood treated with boron compounds," *Constr. Build. Mater*. 22, 2165-2169.

Xing, D., and Li, J. (2014). "Effects of heat treatment on thermal decomposition and combustion performance of *Larix* spp. Wood," *BioResources* 9(3), 4274-4287. DOI: 10.15376/biores.9.3.4274-4287

Yasar, S. S., Fidan, M. S., Yasar, M., Atar, M., and Alkan, E. (2016). "Influences of seasonal alterations on the burning characteristics of impregnated and surface treated chestnut (*Castanea sativa* M.) wood," *Wood Research* 61(3), 399-412.

Yildiz, S., Gezer, E. D., and Yildiz, U. C. (2006). "Mechanical and chemical behavior of spruce wood modified by heat," *Building and Environment* 41(12), 1762-1766. DOI: 10.1016/j.buildenv.2005.07.017

Article submitted: June 6, 2024; Peer review completed: August 6, 2024; Revised version received and accepted: August 11, 2024; Published: October 15, 2024.
DOI: 10.15376/biores.19.4.9158-9168