Crushed Mussel Shell Powder and Optional Borax in Surface Char Layers to Protect Four Wood Species against Fire

Hüseyin Tan

The goal is to protect semi-finished/finished wood components from burning/fires in a variety of settings (wooden buildings, historical sites, restoration, *etc*.). Natural (organic) sea mussel shells (*Chamelea gallina*) were crushed and prepared with water in various solution concentrations (10%, 15%) after the pyrolysis process, either alone or together with boron compounds (borax). The limiting oxygen index value (LOI) was determined by making retention calculations. Coatings were applied to the wood as a double treatment, with boron compounds (borax) used for comparison purposes. Eastern spruce (*Picea orientalis* (L.) Link.), Anatolian chestnut (*Castanea sativa* Mill.), eastern beech (*Fagus orientalis* Lipsky), and locust (*Robinia pseudoacacia*) were chosen for this research. When the pyrolysis-treated impregnated samples were compared to the pyrolysis-treated control sample, the limiting oxygen index value (LOI) was found to be significantly higher in the impregnated samples. After impregnation, 15% borax (0.89%) in acacia wood had the highest retention value, whereas 10 percent mussel shell (0.22%) in spruce wood had the lowest. The maximum limiting oxygen index value (LOI) was found in acacia wood (42.8%), while the lowest value was found in acacia wood (28.9%) impregnated with 10% mussel shell powder after the pyrolysis process.

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Contact information: Department of Forest, Recep Tayyip Erdoğan University, 48800 Rize, Turkey; Email: gakkomtan@hotmail.com

INTRODUCTION

The term biomass refers to all organic wastes from agriculture, forestry, and fishery, as well as sewage and black liquor pulp, excluding fossil fuels. Biomass is useful as an energy source in two ways. First, biomass is the only renewable and abundant resource available. Second, biomass fixes carbon dioxide in the atmosphere through photosynthesis. Wood, as a major biomass material, has been employed as an energy source in the production of charcoal (Demirbaş 2000). Wood is the world's oldest and most commonly utilized raw material (Hastaoğlu and Berruti 1989). It is also reported that wood contains up to 85 percent volatile content and produces the most gas among solid fuels (Bruch *et al.* 2003). Increased use of renewable energy sources like wood will help to alleviate the CO_2 problem, which is one of the major causes of greenhouse gas effects. As a result of this advantage, biomass has been considered to be the primary replacement for fossil fuels today.

To prevent combustion in wood and cellulosic materials, a variety of fire-retardant compounds have been utilized. Because of their smoke-suppressing capabilities, products based on boron compounds as a fire retardant are employed alone or in combination. Because of their structural qualities, fire retardants either inhibit or prevent combustion. They may facilitate the process of carbonization. It is known that fire retardants create a char layer after the impregnated wood material is exposed to high heat, and this prevents flaming. Therefore, preventing or preventing the flaming feature of the wood material used in the building saves time for people to leave the building during a fire.

It has been claimed that the amount of heat conveyed to the interior portions as a result of carbonization on the surface of the wood substance is insufficient to allow the combustible gases in the material to escape, and that this prevents the surface from igniting (Baysal 2002).

The range of applications for charcoal produced by pyrolysis of wood is quite extensive. Charcoal, a popular fuel, is also utilized in metallurgy. Much research has recently been conducted on the utilization of compressed biomass, particularly in the form of pellets (Obenberger and Thek 2004; Öhman *et al*. 2004). The ecosystem's health, the acquisition and development of new organic preservatives/top surface treatment chemicals in the wood business, and the creation of novel impregnation processes are all critical for humanity's future. Wood may provide valuable services in a variety of sectors under the correct conditions of use. However, unfavorable usage environments and fire can easily damage the wood. Therefore, treating wood with fire retardants is a vital process. The proper application of fire-retardant chemicals protects the wood from burning and, as a result, it increases the wood's service life. The use of fire-retardant chemicals does not guarantee that the wood will be fully non-flammable. However, they can make it difficult for wood to ignite and delay the rapid spread of fire after the combustion event has started (Dubey *et al*. 2012).

The initial step in any gasification process is pyrolysis. Solid fuels are transformed to the intermediate product char in this step. The processing parameters have a significant impact on the reactivity and yield of the solid product (char) created as a result of the pyrolysis of a solid fuel. Therefore, the gasification kinetics of the solid product is very important among the researched topics. Rates of various reactions occurring during pyrolysis will determine the size of the gasifier and the operating conditions (Bryden *et al.* 2002).

Wood is a valuable raw material that has been employed in numerous fields since the dawn of time. Even without the use of chemicals, wood can last a long time. However, chemical operations are also necessary due to the variety and continuity of dangers (Kartal and Unamura 2004). The combustion of wood occurs with the pyrolysis of cellulose and its reaction with oxygen, and this pyrolysis begins with an increase in temperature (İlhan 1988; Pabelina *et al*. 2012). After the wood is ignited, for the next 8 minutes, the depth of carbonization increases at a rate of about 0.8 mm/min. Later, the charred part forms an insulating layer, and it has therefore been reported that the charring depth decreases at a rate of 0.6 mm/min (Anonymous 1969). The presence of less extractive material in the leafy woods compared to the coniferous woods reduces the variability in the flame spread and heat spread rates.

Threats to human/environmental health include synthetic and chemical substances, rapid reduction of forest resources, global climate change, and the use of materials found in the ecosystem (nature). A way of ensuring the use of a new protective material in extinguishing fires, on the other hand, after the pyrolysis process, is to use organic (mussel shell powder) and inorganic (borax) impregnation materials. These materials are applied separately and, in a mixture, (borax + mussel shell powder) and the Limiting Oxygen Index

(LOI) is determined. It is aimed to determine the usability effect.

The average live weight of white sand mussel (*Chamelea gallina* L., 1758) was determined as 3.464±0.075 g, shell weight of 2.307 ± 0.052 g, and edible meat weight of 1.157±0.029 g. Edible meat was found. Its shell consists mainly of $CaCO_3$. Although $CaCO_3$ crystallizes in different ways, it generally crystallizes in calcite and aragonite structures (Şentürk 1990).

Borax is a hydrated sodium borate, a salt with the elemental formula $Na_2H_{20}B_4O_{17}$, often written as $Na_2B_4O_7{\cdot}10H_2O$. It is a colorless crystalline solid that dissolves in water to form a basic solution. It has a melting point of 743 °C, a boiling point of 1.575 °C, and a specific gravity of 1.73 g/cm^3. Borax is a salt, a hydrated borate of sodium, with elemental formula $Na_2H_{20}B_4O_{17}$ often written $Na_2B_4O_7{\cdot}10H_2O$. It is a colorless crystalline solid, that dissolves in water to make a basic solution.

Eastern Spruce (*Picea orientalis* (L.) Link) (coniferous tree), chestnut (*Castanea sativa*), black locust (*Robinia pseudo-acacia* L.) and beech (*Fagus orientalis*) (leafy trees) in the Eastern Black Sea Region of Turkey make up most of the forests. Especially, false locusts are also found in abundance at the riverbanks and park-recreation areas. Chestnut and locust are ringed trachelia, and beech is scattered trachelia. Spruce has resin channels. The specific gravity of eastern beech is 0.57 to 0.66 g/cm^3, the specific gravity of acacia is 0.67 to 0.90 g/cm^3, the specific gravity of Anatolian chestnut is 0.40 to 0.750 g/cm^3, and the specific gravity of oriental spruce is 0.420 g/cm^3.

EXPERIMENTAL

Materials

Wood and plant

Within the scope of the investigation, chestnut (*Castanea sativa* Mill.), spruce (*Picea orientalis* (L.) Link), oriental beech (*Fagus orientalis* Lipsky), and locust (*Robinia pseudoacacia*) woods were preferred. Mussel shell (*Chamelea gallina*) and borax were preferred as natural impregnation material. The mussel shell was bought from a company that produces and exports seafood in Sakarya/Turkey, while the borax was obtained from several medical sources.

While preparing wood test specimens, radial cross-sections were obtained and 110x20x20 mm dimensions were prepared for all tree species. After drying in the oven at 103±2 °C for 24 h, the pyrolysis process was carried out according to ASTM D 1102-84 (2021). Tree species were applied separately in groups in a steel cage by using a torch to 1300 °C light blue flame burning, and a charcoal layer was formed on their outer surfaces. The charcoal part of all samples was scraped with a hand planer and brought to the dimensions of 100x10x10 mm. Afterwards, an aqueous mixture (solution) prepared from mussel shell was used as a natural impregnation material. To prepare the solution from the mussel shell samples, first the shell samples were ground with the aid of a ring mill and then passed through a 63-micron sieve to ensure particle size homogeneity. Then, 10 and 15 g weights were made, respectively, to prepare a 10% and 15% solution of 100 mL from the mussel powder samples that were sieved. Weighed samples were sequentially placed in a 200 mL beaker on a magnetic stirrer. To dissolve the mussel powder, 15 to 20 mL of ultrapure 32% HCl and 10 mL of distilled water were added to the beaker; 500 rpm and 200 °C temperature were applied to dissolve the samples of white sand mussel shells.

Then, the solution obtained from the thawed bark samples was made up to a final volume of 100 mL with the help of distilled water.

Preparation of borax solution: A volumetric dissolution method was applied wherein 1 g borax was dissolved in 100 mL of water. The aqueous mixture (solution) was prepared at the level of 10% and 15% in the mussel shell aqueous mixture, and both the aqueous mussel shell mixture and the borax aqueous mixture were mixed at 1/1 scale. In this way, it was used in the impregnation process. When borax and mussel shell mixture solutions were used together, an equal amount of mixture was prepared on a one-to-one scale. In other words, 10% Borax shell slurry + 10% mussel shell slurry or 15% Borax shell slurry + 15% mussel shell slurry was mixed in equal proportions and impregnated.

Methods

Preparation of experimental samples

Wood samples measuring 110x20x20 mm were manufactured for the pyrolysis process. The sample sizes were scraped off in a hand planer machine after the flame burning procedure, and 100x10x10 mm wood samples were prepared for LOI analysis. Afterwards, each wood sample was kept in an oven at 103±2 °C for 24 h (Yılgın *et al*. 2005).

Solution preparation

The mussel shell was ground as a natural impregnation material and then dissolved in HCl ($CaCO_3$) and diluted with water to make solutions at various concentrations (10%, 15%). Mussel shells were ground using a ring grinder, and mussel powder samples were prepared by passing them through a 63-micron sieve to guarantee particle size homogeneity. To dissolve the mussel powder, 15 to 20 mL of ultrapure 32% HCl and 10 mL of double-distilled water were added to the beaker. The bark samples were dissolved at 500 rpm and 200 °C, and the solution obtained from the thawed bark samples was distilled to a final volume of 100 mL using distilled water. Borax was prepared by dissolving it with normal distilled water (Peker and Atılgan 2015).

Pyrolysis process

The pyrolysis was performed in accordance with ASTM D 1102-84 (2021). Wood samples were constructed in (110x20x20 mm) a steel wire cage and exposed to a 1300 °C light blue flame using a torch. For flame combustion, 5 min were used for spruce samples and an average of 8 min for beech-acacia and chestnut samples. Since the flame propagation velocities of coniferous (spruce) and leafy (chestnut, beech, acacia) wood samples prepared in the same dimensions and at the same initial humidity vary according to their density and due to their anatomical structure, the pyrolysis process applied for spruce wood samples with lower density was applied for 5 minutes. For the other leafy wood samples, it was applied for 8 min because of their high specific gravity. Since the flame propagation rate is also higher in coniferous trees in terms of anatomical structure, the pyrolysis time was kept short for those samples. Following that, the carbonized portions of the surfaces were scraped with a planer, and 100x10x10 mm samples were prepared.

Impregnation process

A vacuum impregnation method is preferred according to ASTMD 1413 76 standard. Thirty minutes of vacuum and 30 min of diffusion were applied. The adhesion process of the samples was measured before and after impregnation, when they were completely dry (0 %). To prepare the solution from the mussel shell samples, first the shell samples were ground with the aid of a ring mill and then passed through a 63-micron sieve to ensure particle size homogeneity; 10 and 15 g weights were made, respectively, to prepare a 10% and 15% solution of 100 mL from the mussel powder samples that were sieved. Weighed samples were sequentially placed in a 200 mL beaker on a magnetic stirrer. To dissolve the mussel powder, 15 to 20 mL of ultrapure 32% HCl and 10 mL of double-distilled water were added to the beaker, and 500 rpm and 200 °C temperature were applied to dissolve the samples of white sand mussel shells. Then, the solution obtained from the thawed bark samples was made up to a final volume of 100 mL with the help of double-distilled water. Preparation of borax solution: A volumetric dissolution method was applied, such that 1 g borax was dissolved in 100 mL of water. The aqueous mixture (solution) was prepared at the level of 10% and 15% in the mussel shell aqueous mixture, and both the aqueous mussel shell mixture and the borax aqueous mixture were mixed at 1/1 scale. In this way, it was used in the impregnation process.

Afterwards, vacuum impregnation method was preferred according to ASTMD 1413 76 standard. After 24 h at a temperature of 103±2 °C (0%), the weight (M_1) and size measurements were carried out. After 30 min of vacuum and 30 min of diffusion, the weight (M_2) and sample dimensions are taken again at 103±2 °C for 24 h, and the % retention amount was calculated as:

$$\% \text{ Retention} = [(M_2 - M_1) / M_1] \times 100 \quad (1)$$

where M_1 is the full dry weight before impregnation, and M_2 is the full dry weight after impregnation.

Limiting oxygen index test (LOI)

The flammability of combustible materials that ignite is determined by the limiting oxygen index test. This value expresses the amount of oxygen that must be present in the environment in order for the combustion to continue. This allows for the precise determination of the combustion event, as well as the amount of carbon in post-combustion residues and decomposable organic compounds according to ASTM 2863-09 (2006). For the LOI test, control groups exposed to pyrolysis and 10% and 15% impregnated wood material groups after pyrolysis were formed.

RESULTS AND DISCUSSION

Solution Properties

Solution properties are given in Table 1.

Table 1. Solution Properties (Density/pH Values)

Material	Solution (w/w) Extract	Solvent	Temperature (°C)	pH		Density (g/mL)	
				Bİ	Aİ	Bİ	Aİ
Mussel shell	10%	Distilled water	22 °C	0.88	0.88	1.010	1.010
	15%			1.00	1.00	0.999	0.999
Borax	10%			10.02	10.02	1.020	1.020
	15%			11.15	11.15	1.015	1.015
Mussel Shell+ Borax	10%			8.89	8.89	1.080	1.080
	15%			7.65	7.65	1.0.90	1.090

Bİ: Before impregnation **Aİ**: After impregnation **W/W**: Weight/weight

During the impregnation processes, the solution characteristics remained unchanged. The pH of the solution properties may be acidic or basic, which may negatively affect the cellulose chain structure of the wood.

% Retention Value

Table 2 shows the quantity of adhesion in several wood species, with a graph of variation in Fig. 1.

Table 2. Amount of Adhesion (Remaining amount of solid matter in proportion to the dry wood weight)

Treatment Materials	% Retention			
	Spruce Wood	Beech Wood	Black Locust Wood	Chestnut Wood
%10 Borax	0.42	0.59	0.58	0.45
%15 Borax	0.74	0.80	0.89	0.58
%10 Mussel shell	0.22	0.55	0.25	0.26
%15 Mussel shell	0.28	0.40	0.27	0.39
%10 Borax+ Mussel shell	0.35	0.32	0.39	0.44
%15 Borax+ Mussel shell	0.38	0.42	0.46	0.53

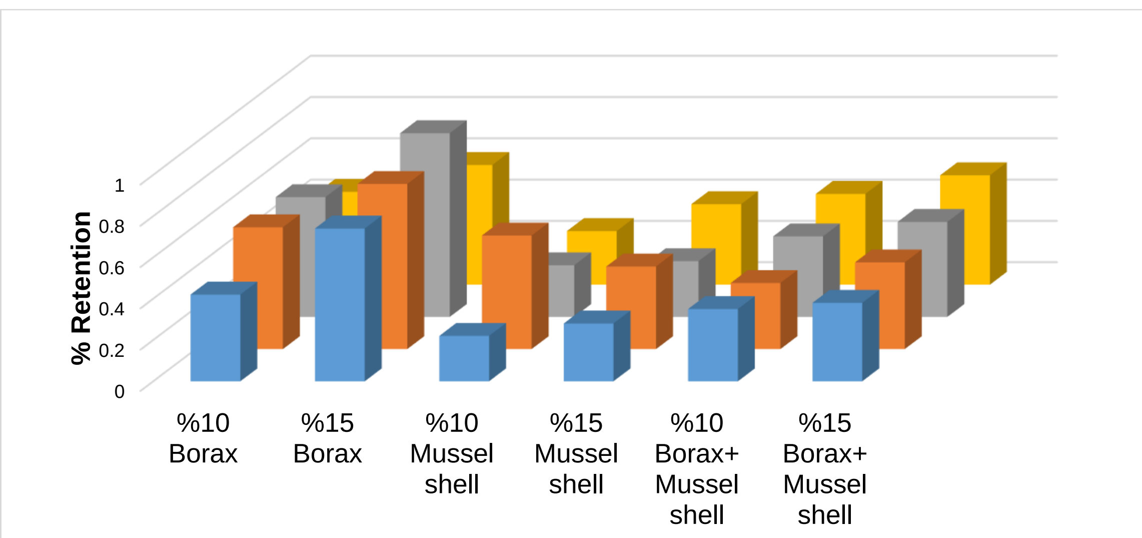

Fig. 1. Retention amount and variation

The maximum retention percentage was found in 15% borax solution (0.89%) in acacia wood, and the lowest in 10% mussel shell solution (0.22%) in spruce wood. The wood type, anatomical structure of the wood, humidity, solution concentration and solvent, and the pyrolysis process could all have contributed to these findings.

Anatomical properties of wood can be listed as the conditions of the impregnation process, as well as the properties of the impregnation material, the physical properties of the wood, and the chemical properties of the wood. It has been reported that the trachea/tracheid arrangement of the wood, its diameter, and the areas in mm^2 have a great effect on the impregnation of the wood (Bozkurt and Erdin 1990). Therefore, knowing the structure of the wood to be impregnated is a very important element in terms of impregnation. The importance levels of the sub-criteria of the anatomical features of the wood can be listed as gauze/passage aspiration, permeability, sapwood heartwood, annual ring width, and spring wood-summer wood ratio. Therefore, the effect of the passage membranes on the impregnability of the wood is enormous. It has been reported that the flow rate of the liquids in the wood is directly proportional to the 4^{th} power of the radius of the passage opening (Yıldız 2003). The expression of the passage of a certain liquid through a certain volume under an atmospheric pressure as cm^3/sec is called permeability. Therefore, the impregnability of wood is directly proportional to its permeability. Tree species are classified in four groups according to their permeability as easy, medium, hard, and very hard. It has been reported that heartwood is more difficult to impregnate than sapwood, due to the formation of aspiration and the ability of extractive substances to accumulate on the passage membrane surfaces. In the light of this information, it is seen that the heterogeneous structure of different wood species samples and the above-mentioned anatomical, physical, and chemical properties cause differences in terms of impregnation.

Pyrolysis Process and (LOI) Results in Wood Species (Spruce Wood)

Table 3 shows the results of the limit oxygen index (LOI) test in spruce wood, and a graph of their variation is shown in Fig. 2.

Table 3. Results after Pyrolysis Treatment (LOI) in Spruce Wood (%)

Treatment Materials	(W/W) Extract	LOI Values (%)		
		Average	Std. Dev.	HG
Control	-	27.5	2.03	E
Borax	10%	40.4	1.98	A
Borax	15%	40.7	3.89	A
Mussel shell	10%	29.5	4.73	D
Mussel shell	15%	30.5	5.71	C
Borax+ Mussel shell	10%	35.0	3.75	B
Borax+ Mussel shell	15%	35.2	2.37	B

HG:Homogeneous groups

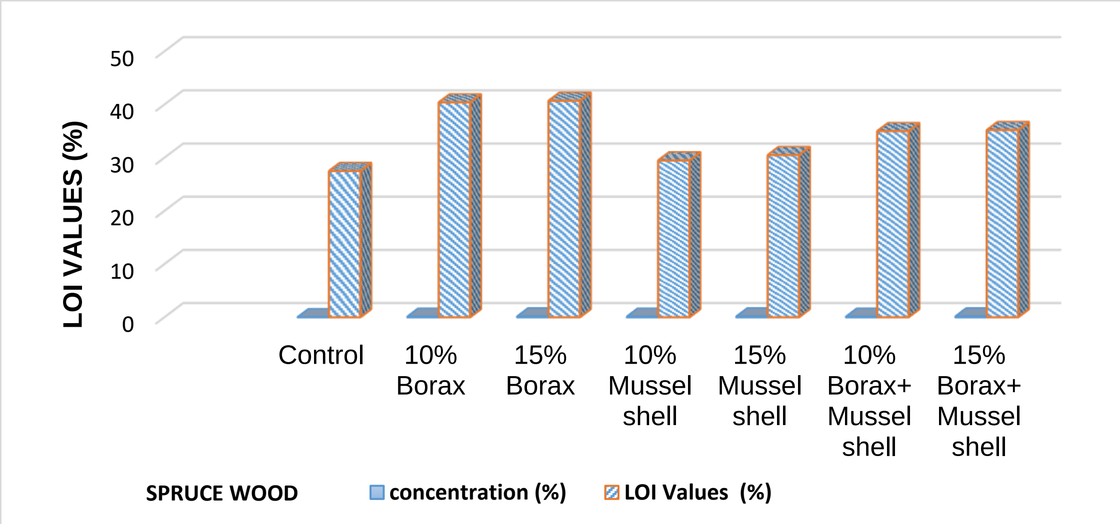

Fig. 2. Retention amount variation

In comparison to the control sample, 15% Borax (40.7%) in spruce wood had the greatest LOI value, while the control sample had the lowest (27.5%). The LOI values for both the mussel shell and borax impregnation methods were significantly positive. This could be caused by the impregnation substance, the wood's anatomical structure, the impregnation procedure, or the concentration.

With regards to retention, the amount of adhered matter (%) is given in tables and figures in proportion to the weight of the dry wood. In other words, the rate of penetration of the water mixture is expressed in terms of completely dry wood material.

Pyrolysis Process and (LOI) Results in Wood Species (Beech Wood)

Table 4 shows the results of the limiting oxygen index test (LOI) in beech wood, and Fig. 3 shows the graph of their change.

Table 4. Results after Pyrolysis Treatment (LOI) in Beech Wood (%)

Treatment Materials	(w/w) Extract	LOI Values (%)		
		Average	Std. Dev.	HG
Control	-	29.4	6.32	D
Borax	10%	40.8	1.34	B
Borax	15%	41.7	2.43	A
Mussel shell	10%	29.5	9.19	D
Mussel shell	15%	29.7	6.72	D
Borax+ Mussel shell	10%	33.2	1.09	C
Borax+ Mussel shell	15%	33.3	4.13	C

HG: Homogeneous groups

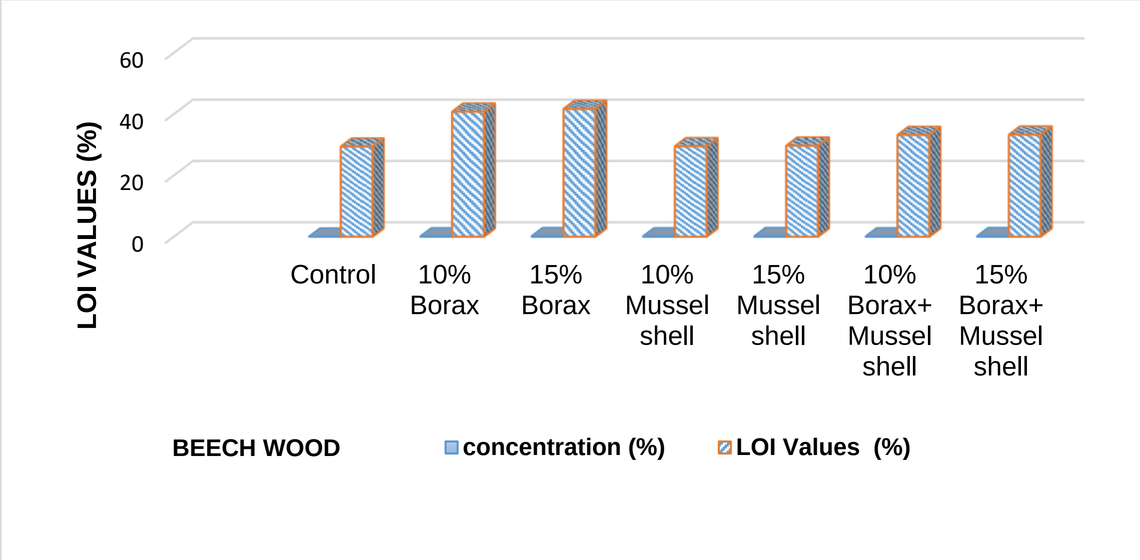

Fig. 3. Retention amount variation

In comparison to the control sample, the 15% Borax (41.7%) in beech wood had the greatest LOI value, while the control sample and both concentrations of mussel shell solution had the lowest. Both using borax alone and mixing borax mussel shell solutions yielded positive outcomes. The type of wood, the impregnation material, and the anatomical structure of the wood could all contributed to this.

Pyrolysis Process and (LOI) Results in Wood Species (Locust Wood)

Table 5 shows the results of the limiting oxygen index test (LOI) in locust wood, and Fig. 4 shows the graph of their change.

Table 5. Results after Pyrolysis Treatment (LOI) in Locust Wood (%)

Treatment Materials	(w/w) Extract	LOI Values (%)		
		Average	Std. Dev.	HG
Control	-	28.8	3.48	E
Borax	10%	42.4	9.46	A
Borax	15%	42.8	5.78	A
Mussel shell	10%	28.9	3.72	E
Mussel shell	15%	30.0	6.49	D
Borax+ Mussel shell	10%	34.8	2.07	C
Borax+ Mussel shell	15%	35.5	1.97	B

HG: Homogeneous groups

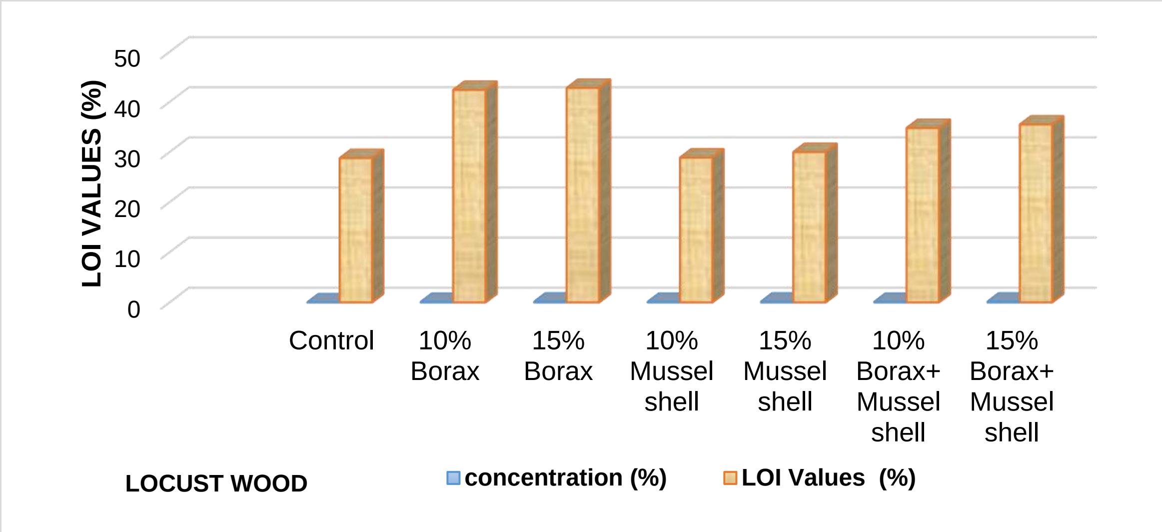

Fig. 4. Retention amount variation

In comparison to the control sample, the highest LOI value was found in 15% Borax (42.8 %) in acacia wood, and the lowest in the control sample (28.8%). It was discovered that the mixture of mussel shell solution and borax had a positive structure. Solution concentration, anatomical structure, and wood type may all play a role in this condition.

Pyrolysis Process and (LOI) Results in Wood Species (Chestnut Wood)

Table 6 shows the results of the limiting oxygen index test (LOI) in chestnut wood, and Fig. 5 shows the graph of their change.

Table 6. Results after Pyrolysis Treatment (LOI) in Chestnut Wood (%)

Treatment Materials	(w/w) Extract	LOI Values (%)		
		Average	Std. Dev.	HG
Control	-	30.5	2.19	E
Borax	% 10	39.0	1.91	B
Borax	% 15	42.0	3.56	A
Mussel shell	% 10	31.5	4.18	D
Mussel shell	% 15	31.8	2.67	D
Borax+ Mussel shell	% 10	36.5	3.61	C
Borax+ Mussel shell	% 15	36.8	8.12	C

HG:Homogeneous groups

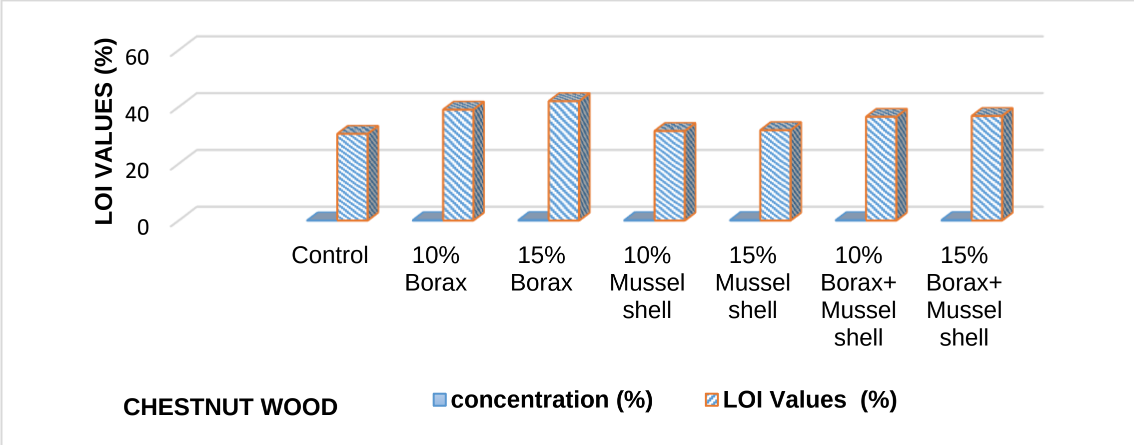

Fig. 5. Retention amount variation

The greatest LOI value in chestnut wood was found in 15% borax (42%), which was also the lowest in the control sample, while the next highest value was found in the usage of mussel shell alone and in borax combinations. While the mussel shell solution provides the intended results, we can attribute this to the solution's characteristics.

Limiting Oxygen Index Test (LOI) Results by Wood Types

Table 7 shows the results of the limiting oxygen index test (LOI) following pyrolysis for all wood species. Figure 6 shows the change graph for these.

Table 7. LOI Results after Pyrolysis in Wood Species (%)

Treatment Materials	Wood Type / LOI Values (%)			
	Spruce Wood	Beech Wood	Locust Wood	Chestnut Wood
Control	27.5	29.4	28.8	30.5
10% Borax	40.4	40.8	42.4	39.0
15% Borax	40.7	41.7	42.8	42.0
10% Mussel shell	29.5	29.5	28.9	31.5
15% Mussel shell	30.5	29.7	30.0	31.8
10% Borax+ Mussel shell	35.0	33.2	34.8	36.5
15% Borax+ Mussel shell	35.2	33.3	35.5	36.8

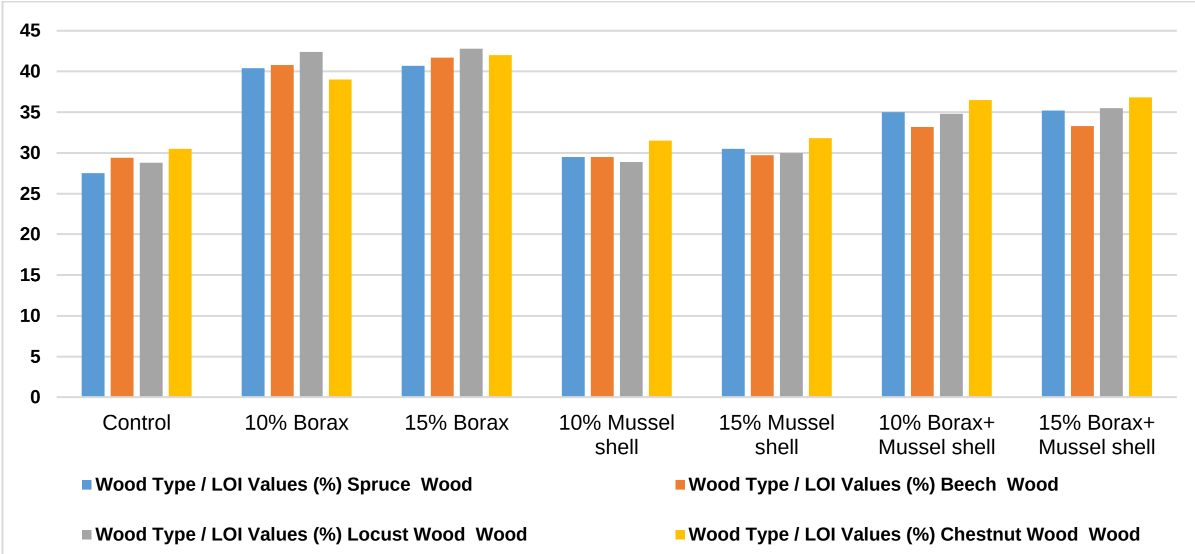

Fig. 6. LOI values of spruce, beech, acacia, and chestnut woods after pyrolysis process

The percent LOI of wood samples exposed to the pyrolysis process, including control samples, surpassed 25%. Pyrolysis process was applied and impregnation process was carried out; in all of the spruce, beech, acacia and chestnut wood sample groups, in order from large to small; 15% borax > 10% borax > 15% borax and mussel shell powder mixture > 10% borax and mussel shell powder mixture > 15% mussel shell powder > 10% mussel shell powder > control groups.

The limiting oxygen index percentages increased as the solution percentages increased in all wood species. The samples of acacia wood that had been pyrolyzed with 15 percent borax impregnated materials had the highest LOI percentage (42.8%); the results were similar to retention values. The amount of substance penetrating the wood material has been determined to be greater than the amount of fire protection and oxygen required by wood. After pyrolysis, even the control groups had positive outcomes. A mixture of 15% borax and mussel shell powder had a LOI value in the range of 33.3% to 36.8% in terms of being more cost-effective, especially when the impregnated groups were compared within themselves. This technology and impregnation mixture can be studied and commercialized in the industry. TGA and LOI studies both showed positive effects in terms of fire retardation as the retention quantity was raised. When the variations in retention are compared to spruce and chestnut trees, as described in the literature, there is a difficulty in the impregnation of spruce wood in terms of its anatomical structure. In addition to the literature, the industry should bring in ecologically beneficial mussel shells, which we have tested in combustion experiments and shown to be effective as a fire retardant, and which are plentiful in nature but cannot be completely utilized. The goal of this research is to remove the surface layer of charcoal and improve the LOI results of the impregnation process after pyrolysis.

Yılgin *et al.* (2005) evaluated the flash pyrolysis of wood species such as oak, pine, and poplar at various temperatures in their research. The effects of temperature (400, 500, and 600 °C), grain size (8, 10, and 12 mm), and wood type on the yield of liquid and other products produced by flash pyrolysis of wood, a sustainable energy and chemical raw material source, were studied. They reported that while the liquid product yield grew as the pyrolysis temperature climbed, it reduced as the grain size increased, and that the wood type had an influence on the pyrolysis product yields. Uysal *et al.* (2011) reported that it should be taken into account that wood materials impregnated and varnished in areas where there is a risk of fire, have the effect of raising the temperature and increasing the gases released by the combustion product, so it is preferable not to apply varnish after impregnation of wood materials to be used in areas where there is a risk of fire. They also suggested applying borax as an impregnation agent and water-based varnish as a varnish (Rowell 2005). The rate of lignin charcoal production during burning is greater than that of cellulose and hemicellulose, indicating that lignin has a more heat-resistant structure. According to study, lignin's high charcoal production rate decreases the generation of flammable gas, preventing further thermal degradation in wood. Peker and Atılgan (2015) applied waste tea plant extract as impregnation material. The lowest % retention value in iroko wood (1.58%), the highest % retention rate in beech wood (6.75%), the lowest total retention in iroko (31.27 kg/m^3), and the highest total retention value in beech wood (100.65 kg/m^3)) were determined.

Flynn (1995) thought that the differences in retention percentages might be due to the wood species, the anatomical structure of the trees, and therefore the physical properties of the impregnation process and solution. They determined that permeability is affected by a variety of elements connected to the anatomical structure, including heartwood sapwood, spring wood, summer wood, density, sapwood, tracheid, and resin in the wood (Ozdemir *et al.* 2013). Polymer chemical structures have a considerable impact on LOI values. It has been reported that materials with an LOI value of less than 25% can burn very easily in air, while those with an LOI value of more than 25% are self-extinguishing in air. In the present research it was found that as the solution percentages grew, the LOI values increased in both tree species. Therefore, the amount of CO_2 released by $CaCO_3$ into the environment during combustion leaves the environment without oxygen. As a result, they concluded that the LOI values increased (Göker and Ayrılmış 2003). When wood is exposed to high temperature, its structure deteriorates to form an insulating layer (the carbonized part), which delays further deterioration, and this layer prevents oxygen from entering the burning material (Tan *et al.* 2022) In their study, they determined that a fire retardant effect occurred at various concentrations obtained from mussel shell in both chestnut and spruce wood.

The load-bearing capacity of structural wood elements depends on their cross-sectional dimensions. As a result, the carbonization rate of the cross-section, among other things, is an essential component in the resistance of structural wood parts. It prevents the rapid chemical degradation of the material and the diffusion of oxygen from the charred surface into the interior. The fire resistance of structural wood elements is intimately connected to the rate of carbonization of wood and wood-based products. In the present study, carbonization and the pyrolysis (thermal decomposition) took place in a layer immediately after it charred in the impregnated spruce, chestnut, acacia, and beech trees and formed the pyrolysis layer. Therefore, it is possible to prevent oxygen from entering the part whose structure is deteriorated. The LOI value increased due to the lack of oxygen in the environment.

CONCLUSIONS

1. In this study, the limiting oxygen index (LOI) values of wood samples exposed to pyrolysis in all impregnated groups including the control group, the percentage of oxygen in the air was determined to be above 21% and after impregnation with nature-specific inorganic-organic materials, fire retardant properties were determined in the range of 28.9 to 42.8 %. The fact that the process and impregnation materials employed are both environmentally safe and do not impair human health emphasizes their suitability for usage in living areas.
2. In this study, mussel shells ($CaCO_3$), which are found inert in nature and presently have very little other usage (poultry feed, *etc*.), were ground and treated with HCl acid and as a result of concentration with water in certain percentages, an impregnation substance was obtained. Since the impregnation material used in the present work has not been tested before, it can be sprayed on the surface as a solution with borax, especially in stratified forest products. Important properties such as burning and adhesion resistance of the materials obtained by mixing certain percentages with particle board mortar can be investigated.
3. Forest fires destroyed 139,500 hectares throughout the world and in Turkey in 2021. During the extinguishing actions, it was discovered that some of the trees were burnt on their outsides, leaving a layer of charcoal. But the interior parts of the cross-sections were not burnt. In the present work, after the charred part had been scraped and separated to the pyrolysis layer with environmental milling machines, it is proposed that boutique hotels or camping areas can be built with nature-identical bungalow-style interlocking log constructions in tourism regions by using the impregnation materials and rates used in the present study. It may be assessed in the region's recreation and landscape regions. In this way, besides the forest assets that are used and lost on-site as recycling, the superficially deformed forest assets will be evaluated and their economic losses will be reduced. This technique may have been used to assess the forest assets protected from fires induced by global warming and irresponsibility in several nations throughout the world.
4. The environmentally flame burning process of wood materials and the subsequent polishing and scraping process darkens the natural color feature of the wood and changes it negatively. It can definitely be recommended in terms of fire retardancy in wooden materials that will be used in building materials and will likely be applied mainly in invisible places. However, in obvious areas and places where an attractive wood look is needed, the necessary aesthetics may not be reached.
5. A planer was specifically employed in the study to scrape the burned section. If this approach is adopted and applied, machines that are suited for the method's development can be constructed, allowing for more speedy and safe manufacturing. Obtaining mussel shell wastes from aquaculture enterprises, diluting them using the methods we mentioned in the study, turning them into a solution in water either alone or with borax, and using them in forest fire extinguishing activities can result in an effective and long-lasting extinguishing process.

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