Flame resistant of birch plywood according to Main Ingredients of Fire retardant paint

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Abstracts: This study aims to comparative analyze the flame resistant of birch plywood according to using fire retardant paints. As interest in eco-friendly environmental issues has recently increased, wood, an eco-friendly material, is being used when people choose materials for interior design and furniture. Since wood is easily combustible and susceptible to fire, it should be mainly treated with a flame-retardant material to make up for the vulnerability. Bromine-based and chlorine-based materials, a type of halogen-based system with good flame resistant, were used for flame retardant treatment but those substances can cause toxic and harmful gas emissions when a fire occurs. That's why these have been still regulated by rules. Although research to solve such problems has been actively conducted to develop phosphorus compound-based materials, nitrogen compound-based materials, and boron compound-based materials as fire retardant paints by applying different numbers and amount of fire retardant paint depending on each type and characteristic of it, attempts to comparative analyze the performance of each fire retardant paint have been still insufficient. Therefore, in order to analyze how the effect of the flame resistant varies whenever the main components and theoretical application amount of each fire retardant paint are applied differently, this study intends to measure the char length and area of birch plywood according to standard of the Nation Fire Agency in Republic of Korea. In this experiment, we used three types of fire retardant paints, each containing ammonium polyphosphate, emulsion resin, and phosphorus-based mixture as main components. Each fire retardant paint was applied to the birch plywood in 150g/m2, 180g/m2, 180g/m2 based on the theoretical application amount. As a control, a non-flame-retardant treated specimen was added. Based on the experiment, the following conclusions were obtained. First, the after flame time and after glow time satisfied the flame resistant standard of the Nation Fire Agency of Republic Korea regardless of the fire retardant paint for each manufacturer. Second, the flame resistant according to the fire retardant paint of each manufacturer was tested. As a result, when ammonium polyphosphate-based fire retardant paint was treated on birch plywood, the value of char length and char area was the smallest, and the effect of flame resistant was clearly shown to be excellent. Third, one fact was confirmed based on the results of previous studies and this study. When two types of fire retardant paint containing a phosphorus-based mixture were treated on a birch plywood, the flame resistant was different according to the technology development of each manufacturer. Through this study, the effect of the flame resistant was different depending on the fire retardant paint of each manufacturer. In order to secure fire safety of indoor furniture using wood construction and wood in the future, it is necessary to select fire retardant paints with high flame resistant depending on the materials of each type. Also, it is judged that it is necessary to compare and analyze the flame resistant of each manufacturer's fire retardant paint for various tree species. Not only that, The results of this study are expected to be used as basic data for selecting fire retardant paints with high flame resistant for each tree species and used as basic data for the production of semi-non-combustible wood suitable for flame resistant standard of the Nation Fire Agency of Republic Korea in the future.

Keywords: flame-resistant, fire retardant paint, 45° Meckel's burner, char length, char area

1. INTRODUCTION

Wood is used as building materials such as eco-friendly furniture materials, interior materials, and building materials. However, wood is vulnerable to fire due to its easy combustion. In a fire, wood is heated by convective heat and radiant heat and emits decomposition gas. It shows the characteristic of burning for a long time. [20] So fire safety of wood should be secured by supplementing the vulnerability of wood. To solve the problem flame retardant treatment is mainly used. [6], [13]

Genually, fire retardant paint is classified into inorganic, halogen, and phosphorus. This each fire retardant paint is mainly composed of aluminum hydroxide, bromine, and phosphate ester. Previously, bromine and chlorine, a type of halogen, were mainly used because of their excellent flame resistant. [9], [22] However, when a fire occurs, bromin-based and chlorine-based substances generate toxic gases and harmful gases that are fatal to the human body. Therefore, due to this problem, bromine-based and chlorine-based substances are regulated. In order to improve this problem, research has been actively conducted to develop eco-friendly materials for flame-resistant in recent years. A phosphorus compound-based, nitrogen compound-based, and boron compound-based paint are used alone or in combination as an eco-friendly fire retardant paint. [10] In general, many study aims to ensure

flame resistant by treating this paint on wood.

Normally, the number of applications and the amount of application of the flame retardant paint differ according to each type and characteristic. Usually, the number of applications of fire retardant paint is reported to be 2 to 3 times, and the amount of application of fire retardant paint per time is reported to be about 200 to 1,000g/m^2. [11] The flame retardant treatment varies depending on the properties of the combustible material. [5], [6] However, after the construction of the building, when flame retardant treatment was performed on wood and wood products, the fire retardant paint was coated with a spray or painted with a brush. [12] But, looking at the flow of previous studies, various fire retardant paints are being developed to improve flame resistant. On the other hand, attempts to find the flame resistant of wood by tree species according to fire retardant paint were insufficient.

Chung(2013, 2015) treated two types of fire retardant paint on *Pinus rigida* to develop eco-friendly fire retardant paint. The paint is a fire retardant paint based on alkylenediaminoalkyl-bis-phosphonic acid, and a fire retardant paint in which a nitrogen compound and a hydroxyl group are introduced into a phosphorus compound. Afterwards, as a result of analyzing the combustion characteristics of Pinus rigida, type 2 experimental medicine partially improved the fire safety of Pinus rigida. [18], [19]

Choi(2011) conducted an experiment on *Pinus koraiensis* and *Pinus densiflora* to analyze whether there is a difference in flame resistant by tree species using the same fire retardant paint. After treating *Pinus koraiensis* and *Pinus densiflora* with water-soluble fire retardant paint for wood, combustion characteristics were compared. As a result, *Pinus densiflora* were measured to have a char length of 11.0cm, a char area of 43.3cm^2, and *Pinus koraiensis* to have a char length of 10.5cm, and a char area of 47.5cm^2, improving fire safety of fire retardant wood. [7]

Park(2020) conducted an experiment to analyze the flame resistant according to the coating amount of the fire retardant paint. In the experiment, fire retardant paint developed was treated on pine plywood, larch plywood, cypress plywood, and perforated birch plywood. After that, as a result of analyzing the flame resistant of each plywood, the char length and char area generally decreased as the coating amount of the fire retardant paint increased. In other words, the flame resistant tended to increase. (Except for larch plywood.) [11]

In the experiment of Seo (2017), after applying 300g/m2 of commercial fire retardant paint to Pinus densiflora, the flame resistant was measured, and the char length was 74 to 93mm and the char area was 2,650 to 3,970mm^2, satisfying the flame resistant standard of the Nation Fire Agency in Republic of Korea. [4] According to previous studies, two conclusions can be drawn. First, the developed fire retardant paint was effective in flame resistant. Second, as the coating amount of the fire retardant paint increased, the effect of the flame resistant was also improved. However, there was a difference in flame resistant by fire retardant paint and tree species. Until now, various fire retardant paints have been developed rapidly. Nevertheless, attempts to analyze how different the flame resistant differs by fire retardant paint and tree species are insufficient. Therefore, there is a need for additional research to analyze the effect of flame resistant according to fire retardant paint and tree species.

In this study, three types of fire retardant paint were selected and fire retardant paint was treated on birch plywood. The fire retardant paint was treated based on each theoretical coating amount. The reason why birch plywood was selected is that it is widely used as interior and furniture. Through this experiment, the author aims to analyze the flame resistant according to the fire retardant paint.

2. SPECIMENS AND EXPERIMENTAL METHODS

2.1 Specimens

The standard of living of the people has risen and an emotional society has arrived. [17] Due to this influence, the trend of luxury and diversification of interior design has become stronger. Recently, interest in eco-friendly well-being issues has increased. For this reason, eco-friendly materials are selected as materials for interior decoration and storage. [14] According to this trend, birch plywood was selected as an experimental material in this study. This is because birch plywood is not only mainly used as a high-quality finishing material [21], but also is widely used as

an interior material. In addition, three types of fire retardant paints in this study were selected because of frequently using in the current field. The main components of each fire retardant paint are ammonium polyphosphate, emulsion resin, and phosphorus mixture. [3], [8], [15]

2.2 Experimental Environments and Methods

The flame resistant was measured in accordance with Article 20 (2) of the Fire Prevention, 「Act On Fire Prevention and Installation, Maintencance, and Safety control of Firefighting Systems」 (Fire Protection Agency Notice No. 2021-7). [1] First, birch plywood was prepared 190mm transvers, 290mm length, and 12mm thickness. Second, the selected three types of fire retardant paints were applied three times, 150g/m^2, 180g/m^2, and 180g/m^2, based on the theoretical application amount, according to the technical data of each manufacturer. After that, it was naturally dried at room temperature for 24 hours. Finally, birch plywood, which was not used fire retardant paint, was treated as a control group. The detailed flame retardant treatment methods for the experiment specimen are summarized in Table 1.

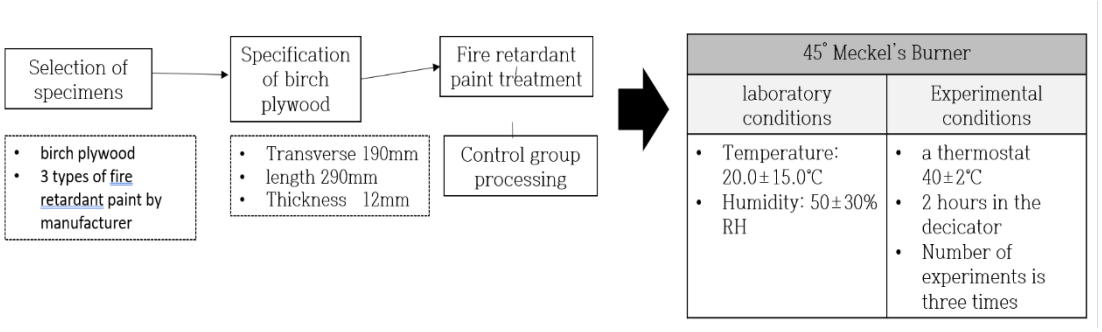

Figure 1. The overall process of an experiment.

The combustion properties of the material can be evaluated in various ways. Representatively, there are flame resistant using a 45° Meckel's buner, a heat dissipation rate test method using a corn calorimeter, and a gas harmful test method. The flame resistant test using a 45° Meckel's burner is to determine flame resistant to wood and wood plywood. The heat dissipation rate test using a corn calorimeter evaluates combustion behavior and mass loss when the material receives constant radiant heat in a fire situation. The gas harmful test is to investigate the harmfulness of combustion gas generated during a fire. [7]

In this study, in order to compare the flame resistant of birch plywood according to the fire retardant paint, the flame resistant was analyzed using a 45° Meckel's burner. The birch plywood was dried for 1 hour in a thermostat at 40±2℃. After that, the birch plywood was placed in a decicator containing silica gel for 2 hours and then taken out. The experiment was conducted three times in the same way. The environmental temperature of the laboratory was 20.0±15.0°C and the humidity was 50±30% RH. The overall process for the experiment is summarized in Figure 1.

2.3 Standard for Flame Resistant Using 45° Meckel's Burner

In order to test the flame resistant of the fire retardant paint, the method of testing the flame resistant of plywood was applied in accordance with Article 20 (2) of 「Act On Fire Prevention and Installation, Maintencance, and Safety control of Firefighting Systems」 (Fire Protection Agency Notice No. 2021-7). [1] The wood combustion test device used in this study is a 45° Meckel's burner. The order of the experiments is as follows. First, fix the birch plywood to a pedestal in a 45° Meckel's burner. Second, with a length of 65 mm, the flame of the heating device is brought into contact with the lower end of the center of the birch plywood.

Table 1. List of specimens used in this study.

Specimen[1)]	Samples		Fire reatardant condition[2)]	Treatment method
	Plywood	Main components of fire retardant paint		
A	birch plywood	-	-	brush painting
B		ammonium polyphosphate	150g/m^2	brush painting
C		emulsion resin	180g/m^2	brush painting
D		a phosphorus-based mixture	180g/m^2	brush painting

[1)] A is unprocessed, B is a fire retardant paint with ammonium polyphosphate as the main ingredient, C is a fire retardant paint mainly composed of emulsion resin, D is a birch plywood treated with a fire retardant paint containing a phosphorus-based mixture as the main component.
[2)] The theoretical application amount is derived based on the technical data of the fire retardant paint provided by the manufacturer of each fire retardant paint.

Third, heat treatment is performed for 2 minutes for each specimen. Finally, after flame time, after glow time, char length, and char area are measured according to the flame resistant standard. According to Standard of the Nation Fire Agency in Republic of Korea (Fire Protection Agency No. 2021-7) [1], the flame resistant of wood and plywood must meet after flame time within 10 seconds, after glow time within 30 seconds, char length within 200mm, and char area within 5,000mm^2. Figure 2 are schematic diagrams of test devices and test devices.

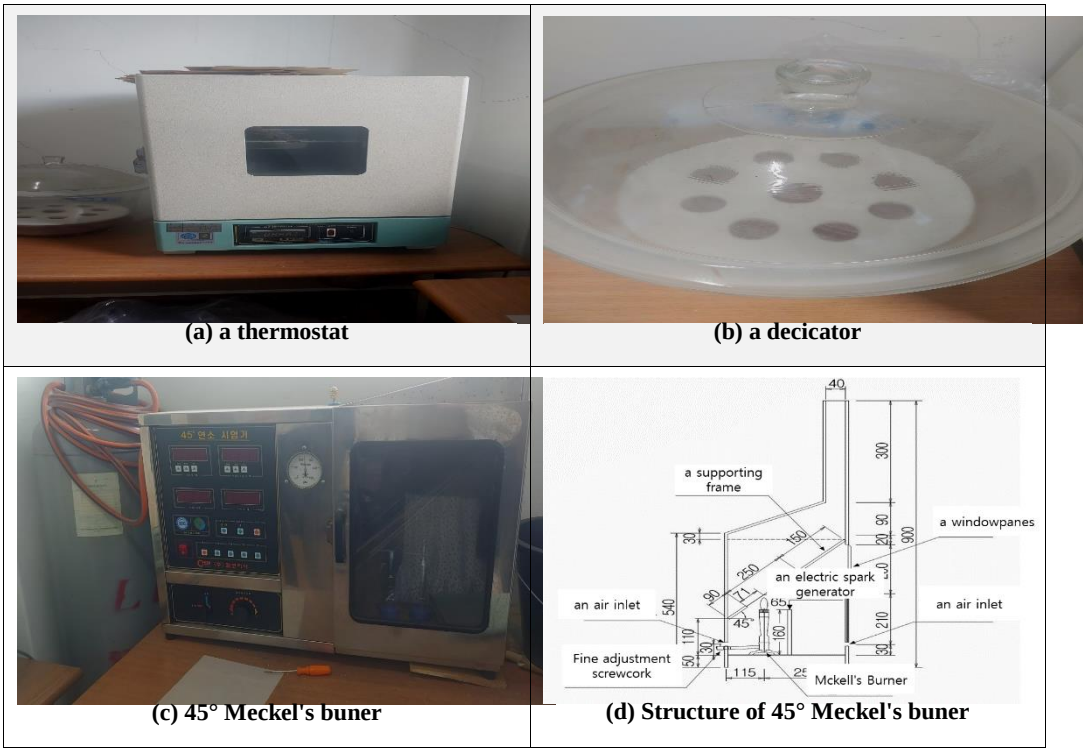

Figure 2. Test apparatus and schematic diagram.

3. EXPERIMENTAL RESULTS AND CONSIDERATIONS

The flame resistant of fire retardant paints by manufacturer was compared and analyzed for birch plywood. For the experiment, after flame time, after glow time, char length, and char area were measured using a 45° meckel's burner. The experimental results are presented in Table 3 below.

Specimen[1)]	Before the experiment	after the experiment
A		
	(a) Control group (no processing)	
B		
	(b) Ammonium polyphosphate treatment	
C		
	(c) emulsion resin treatment	
D		
	(d) phosphorus mixture treatment	

Figure 3. Before and after the experiment of the specimen.

The after flame time occurred as 0.0 seconds for 'B', 2.3 seconds for 'C', and 0.8 seconds for 'D'. However, based on the occurrence of after flame time of 'A' in 22.1 seconds, after flame time decreased 'C' reduced to 89.6% and 'D' reduced to 96.4%. In other words, it satisfied the flame resistant standard of the Nation Fire Agency of Repulic of Korea. after glow time was measured to be 0 seconds regardless of the type of fire retardant paint.

Table 2. Flame resistant according to fire retardant paint by manufacturer.

Sortation		specimen			
		A	B	C	D
after flame time (second)	One-time	0.0	0.0	0.0	2.4
	Twice	0.0	0.0	6.8	0.0
	Three-times	**66.2**	0.0	0.0	0.0
	Average	**22.1**	0.0	2.3	0.8
after glow time (second)	One-time	0.0	0.0	0.0	0.0
	Twice	0.0	0.0	0.0	0.0
	Three-times	0.0	0.0	0.0	0.0
	Average	0.0	0.0	0.0	0.0
char length (mm)	One-time	102.0	50.0	91.0	89.0
	Twice	106.0	48.0	87.0	78.0
	Three-times	156.0	51.0	85.0	92.0
	Average	121.3	49.7	87.7	86.3
char area (mm^2)	One-time	**5410.0**	1200.0	3750.0	3450.0
	Twice	4690.0	1180.0	3890.0	2990.0
	Three-times	**7260.0**	1490.0	3260.0	3340.0
	Average	**5786.7**	1290.0	3633.3	3260.0
Judged of Suitability [1),2)]		Inadequate	Suitable	Suitable	Suitable

[1)] Pursuant to Article 20 (2) of 「ACT ON FIRE PREVENTION AND INSTALLATION, MAINTENCANCE, AND SAFETY CONTROL OF FIREFIGHTING SYSTEMS」 (Fire Protection Agency Notice No. 2021-7), In the case of plywood, after flame time shall be within 10 seconds, after glow time shall be within 30 seconds, char length shall be within 200 mm, and char area shall be within 5,000 mm^2.
[2)] The experiment was repeated three times, and suitability was evaluated based on the average value of the results.
[3)] The bold text expressed the value that did not satisfy the "standard of flame resistant of the flame-retardant object (Fire Protection Agency Notice No. 2021-7)".

The after flame time and after glow time satisfied both the flame resistant standards regardless of the presence or absence of flame retardant treatment and the type of fire retardant paint. However, the generation of smoke can be a bigger problem than the continuous combustion of fuel when a fire occurs. Therefore, it is judged that further research is needed. [16]

In the case of char length, 'A' was measured in 121.3mm, and the plywood of birch treated with fire retardant paint for each main component was measured in the range of 49.7 to 87.7mm. In other words, regardless of the presence or absence of flame retardant treatment, the flame resistant standard of the Nation Fire Agency of Repulic Korea were satisfied.

In the case of char area, it was measured at 5,786.7mm^2 in the birch plywood that did not treat a fire retardant paint, exceeding 5,000mm^2, the flame resistant standard of the Nation Fire Agency of Repulic Korea. In other words, it did not satisfy the flame resistant standard of the Nation Fire Agency of Repulbic Korea. However, the birch plywood treated with fire retardant paint met the flame resistant standard of the Nation Fire Agency of Republic Korea in the range of 1,290.0 to 3,633.3mm^2.

The performance of the fire retardant paint used in this study met the Article 20 (2) of 「Act On Fire Prevention and Installation, Maintencance, and Safety control of Firefighting Systems」 (Fire Protection Agency Notice No. 2021-7). However, there was a difference in flame resistant depending on the main ingredient of the fire retardant paint. As a result, 'B' had a better flame resistant than 'C' and 'D'.

In previous studies, flame resistant was measured after using 150g/m^2 of phosphorus-based compounds in perforated birch plywood. As a result, the char length and char area did not satisfy the flame resistant standard of the Nation Fire Agency of Repulbic Korea. When the coating amount increased to 300g/m^2, it was reported that the flame resistant standard of the Nation Fire Agency of Republic Korea was satisfied. [11] On the other hand, as a result of treating 180g/m^2 of the fire retardant paint consisting of the phosphorus-based mixture used in this study on birch plywood, the char length was 86.3mm and the char area was 3,260.0mm^2, satisfying the flame resistant standard of the Nation Fire Agency of Republic Korea. Even if the main components of the fire retardant paint were composed of the same phosphorus, the performance of the fire retardant paint by manufacturer was different. [11] Accordingly, it is believed that there is a deviation in flame resistant due to the technology development of fire retardant paints by manufacturers.

In addition, when the same fire retardant paint was treated with various wood and wood products, it was found that there was a difference in flame resistant depending on the type of tree species. Therefore, additional studies should be conducted to compare and analyze the effects of flame resistant when treating fire retardant paints by manufacturer for various species. Based on the results, it is judged that it is necessary to select fire retardant paint for each manufacturer that shows high flame resistant for each tree species type in the future and prepare basic data for flame retardant treatment.

4. CONCLUSION

In this study, the flame resistant according to three types of fire retardant paint by manufacturer was analyzed for birch plywood. The reason why birch plywood was selected is that it is used as interior decoration and high-quality finishing materials. In addition, after flame time, after glow time, char length, and char area of birch plywood were measured in accordance with Article 20 (2) of 「Act On Fire Prevention and Installation, Maintencance, and Safety control of Firefighting Systems」 (Fire Protection Agency Notice No. 2021-7). Based on the results, the following conclusions were obtained.

(1) The after flame time and after glow time satisfied the flame resistant standard of the Nation Fire Agency of Republic Korea regardless of the fire retardant paint for each manufacturer.

(2) The flame resistant according to the fire retardant paint of each manufacturer was tested. As a result, when ammonium polyphosphate-based fire retardant paint was treated on birch plywood, the value of char length and char area was the smallest, and the effect of flame resistant was clearly shown to be excellent.

(3) One fact was confirmed based on the results of previous studies and this study. When two types of fire retardant paint containing a phosphorus-based mixture were treated on a birch plywood, the flame resistant was different according to the technology development of each manufacturer.

Through this study, the flame resistant of the fire retardant paint by manufacturer was confirmed for birch plywood. As a result, it was found that the effect of the flame resistant was different depending on the fire retardant paint of each manufacturer. In order to secure fire safety of indoor furniture using wood construction and wood in the future, it is necessary to select fire retardant paints with high flame resistant depending on the materials of each type. Therefore, it is judged that additional research needs to be conducted to analyze the flame resistant of fire retardant paints by manufacturer according to materials of each tree species.

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