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Decay Resistance of Fire-Retardant Treated Wood*1

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ABSTRACT

In this study, the Korean pine wood (*Pinus densiflora Sieb. et Zucc*) and Italian poplar wood *(Populus euramericana Guinier*) was treated with a mixture of monoammonium phosphate (MAP) and boric acid. Their usability as fire retardant and as decay-resistant construction and interior materials were evaluated by testing of chemicals, corrosion rate and absorption rate, weight loss and chemical contents.

An experiment was performed to compare treated pine wood and Italian poplar wood. According to the results, Italian poplar wood had higher specific gravity and retention of chemicals than pine wood, and treated wood showed higher decay-resistance than untreated one. Weight loss was less in treated wood than untreated one because the degree of decay was lower in the former than the latter. Corrosion rate and absorption rate met the KS standard for wood preservative performance. The chemical contents analysis was carried out to determine the degree of decay and it was found that the preservative effect of chemical treatment was lower in Italian poplar wood than in pine wood.

Keywords : monoammonium phosphate (MAP), boric acid, fire retardant, decay-resistant, corrosion rate, absorption rate

1. INTRODUCTION

Wood is highly vulnerable to biological degradation and combustive degradation due to its nature as an environment-friendly material and a high-molecular organic matter. The two most important types of wood degradation can be categorized into biological degradation that include decay by microbes and eating by insects and vermin, and combustive degradation, that is burning. There are wood-decaying microbes such as white rot fungi, brown rot fungi and soft rot fungi, but their patten of decay is rather different. White rot fungi attack wood cells from inside to outside and decompose lignin and the decayed part would turn white. Brown decay fungi attack woods by infiltrating chemical diffused from hyphae into cell walls at the beginning of decay, cutting the rings of cellulose in and finally decompose the lignin. The part decayed by brown rot fungi would then turn to brown colour (Proctor 1941). In order to prevent wood from being decayed and burned, preservatives and fire-retardants are used.

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For the efficient use of pine and Italian poplar that have a substantial presence in Korea, this study treated these woods with a mixture of boric acid and MAP and applied to them standard strains of representative wood rot fungi including *Trametes versicolor*, white rot fungi, and *Tyromyces palustris*, brown rot fungi. There are fire retardants such as ammonium sulfate, monoammonium phosphate, diammonium phosphate, Borax-Boric acid, minalith, etc. (Kim 1986). In conclusion more researches are necessary in this area. Treated wood has longer life and could reduces wood consumption and in turn, generate economic benefits.

This purposed study is to identify the effects of the treatment of pine wood and Italian poplar wood with chemical mixture on their usability as decay-resistant and fire-retardant materials.

2. MATERIALS and METHODS

2.1. Standard Materials

2.1.1. Standard Wood Materials

Standard pine wood used in this experiment was 20～25 year old raw lumber cut down at Panmun-dong, Jinju-si, Gyeongsangnam-do, and Italian poplar wood was 20～25 year old lumber purchased from Singaemyeong Lumbermill at Dopyeong-ri, Jusang-myeon, Geochang-gun, Gyeongsangnam-do.

2.1.2. Standard Strains

Strains used in this experiment were *Trametes versicolor* (FRI 20251), white rot fungi, and *Tyromyces palustris* (FRI 21055), brown rot fungi, which were distributed by the Korea Forest Research Institute.

2.1.3. Standard Media

A liquid medium was prepared using 25 g of glucose, 10 g of malt extract, 5 g of pepton, 0.3 g of KH_2PO_4 and 2 g of $MgSO_4$ in distilled water,which summed up to the total quantity becomes 1000 ㎖.

A quartz sand incubator was prepared by putting 300 g of well-dried quartz sand in a 800 ㎖ glass container with an open mouth on the top, adding 80 ㎖ of the liquid medium above for *T. palustris* and 82 ㎖ for *T. versicolor*, covering the mouth with a lid, and sterilizing with high-pressure steam.

2.2. Liquid Chemical Treatment

Wood materials were treated with boric acid, a common preservative, and MAP, a fire-retardant. The liquid chemical was 20% boric acid-MAP mixture, which is prepared by heating the 1:1 (W/W) mixture of boric acid and MAP in a circulating water bath at 60°C, adding distilled water, and dissolving the chemicals.

The chemical was infiltrated using the Bethell method. For infiltration, pressure was lowered down to 10 kgf/cm^2 through vacuum decompression at a pressure of 500 mmHg for 30 min and left at the pressure for 60 min. Then, wood sample pieces were separated.

The retention of chemicals in the treated sample pieces was computed as follows.

$$Sa(\%) = \frac{Wb\text{-}Wa}{Wa} \times 100$$

where, Sa(%) : the retention of chemicals
Wa : Weight before chemical treatment
Wb : Weight after chemical treatment

2.3. Decay Experiment

This experiment used as standard woods 20～25 old pine wood (*P. densiflora*) and Italian poplar wood (*P. euramericana*). Sample pieces were all sapwood. The dimensions of those

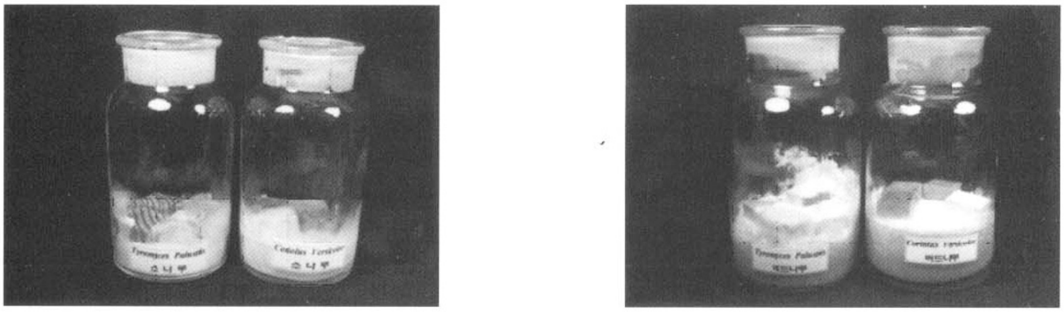

Photo 1. Wood block attacked by wood-rotting fungi.

pieces used in testing weight loss and absorption was 2×2×1 (T×R×L, cm) and their average moisture content was 9.4~10.3%. The size of pieces for testing corrosion loss was 2×2×4.5 (cm) and their average moisture content was 9.6~9.8% (한국산업규격 1999).

Liquid cultivation and quartz sand cultivation were used as standard cultivation, and 20% boric acid-MAP mixture was prepared by heating 1:1 (W/W) mixture of boric acid and MAP in a circulating water bath at 60°C, adding distilled water, and dissolving the chemicals. The chemical treatment was performed according to the Bethell method, lowering pressure down to 10 kgf/cm^2 through vacuum decompression at a pressure of 500 mmHg for 30 min, maintaining the pressure for 60 min, and then separating wood sample pieces.

2.4. Wood Chemical Contents Analysis

For analysis, standard woods were powdered at a size of 40~60 mesh using Willey Mill. As for alcohol-benzene extraction, the mixture of ethanol (95%)-benzene (1:2 v/v) was extracted for 8 h on a heating mantle. To prepare holocellulose, the sample wood powder was treated repeatedly by applying 1 g of sodium chlorite and 0.2 mℓ of glacial acetic acid and washed in succession with cold water (approximately 500 mℓ) and acetone (approximately 50 mℓ). For extracting alkali, 100 mℓ of 1% NaOH solution was added to the sample wood powder, the mixture was boiled in a water bath for 1 h with occasional stirring and washed in succession with hot water (300 mℓ), 10% acetic acid solution (50 mℓ) and hot water (300 mℓ). For measuring the weight of lignin, 1g of defatted sample and 20 mℓ of 72% sulfuric acid solution were well stirred and washed with 500 mℓ of hot distilled water.

3. RESULTS and DISCUSSION

3.1. Retention of Chemicals

This study took samples from the sapwood of Italian poplar (*P. euramericana*) and pine (*P. densiflora*), the air-dry condition of which was identical, and used 1:1 (W/W) mixture of boric acid and MAP, which are commonly used as a preservative and a fire-retardant respectively. The retention of chemicals obtained from the experiment is as in Table 1.

The retention of chemicals was 1.52 kg/(30 cm^3) for pine (2×2×1 cm) and 2.24 kg/(30 cm^3) for Italian poplar (2×2×1 cm), which is 0.72 kg/(30 cm^3) higher than that of pine. The result exceeded 1.125~2.250 kg/(30 cm^3), the minimum retention of chemicals suggested by the American Forest Product Research Institute (1974) and Koch (1972). Thus the chemical is

Table 1. Chemical retention obtained by pressure treatment

Species	Thickness (cm)	Retention of chemicals (kg/(30 cm)^3)
P. densiflora	(2×1×1)	1.52
P. euramericana	(2×1×1)	2.24

Table 2. Weight loss of wood block attacked by *T. palustris* and *T. versicolor*

Fungi species	Species	Treatment	Weight loss (%)
T. versicolor	*P. densiflora*	Control	11.32
		Boric acid · monoamonium phosphate	3.07
	P. euramericana	Control	16.42
		Boric acid · monoamonium phosphate	4.51
T. palustris	*P. densiflora*	Control	13.96
		Boric acid · monoamonium phosphate	4.05
	P. euramericana	Control	20.23
		Boric acid · monoamonium phosphate	5.60

regarded as appropriate as a fire-retardant. In addition, Because of the differences in specific gravity and chemical contents, the Italian poplar contains more chemicals than pine wood.

3.2. Weight Loss of Decayed Wood

If wood is decayed, its components are decomposed and the weight decreases. Table 2 shows differences in weight loss between Italian poplar (*P. euramericana*) and pine (*P. densiflora*) decayed by white rot fungi *T. versicolor* and brown rot fungi *T. palustris*.

The weight loss of untreated pine wood was 11.32% when the wood was decayed by white rot fungi *T. versicolor* and 13.96% when it was decayed by brown rot fungi *T. palustris*. The correlation (R^2) between the two strains was 0.18. In addition, the weight loss of treated pine wood was 3.07% when the wood was decayed by white rot fungi *T. versicolor* and 4.04% when it was decayed by brown rot fungi *T. palustris*. The correlation (R^2) between the two strains was 0.33. Thus, decay was lessened when pine wood was treated with the chemical.

The weight loss of untreated Italian poplar wood was 16.42% when the wood decayed by white rot fungi *T. versicolor* and 20.23% when it was decayed by brown rot fungi *T. palustris*. In addition, the weight loss of treated Italian poplar wood was 4.51% when the wood was decayed by white rot fungi *T. versicolor* and 5.6% when it was decayed by brown rot fungi *T. palustris*. The correlation (R^2) between the two strains was 0.33 for untreated wood and 0.81 for treated wood. Significance was acknowledged at a significance level less than 1%.

Yalinkilic *et al.* reported that the mixture of boric acid and other chemicals affects decay-resistance, reduces weight loss against white rot fungi *T. versicolor* and brown rot fungi *T. palustris*, and makes sample wood pieces fully resistant against decay. Thus the treatment of Italian poplar with the chemical appeared to be greatly effective against weight loss by decay.

Table 3. Corrosion loss rate and absorption rate in the wood treated with preservation and fire-retardant agents after mixed treatment

(unit : %)

Species	Corrosion of iron	Absorbent
P. densiflora	1.02	1.25
P. euramericana	0.90	1.45

3.3. Corrosion Rate and Absorption Rate

Because many metal parts are used in order to join wood materials, the corrosion of metal such as nails should be considered in selecting preservatives. The corrosion rate of wood preservatives should be 2.0 or less, and the absorption rate should be 1.2 or less. As shown in Table 3, corrosion rate for pine wood was 1.02%, slightly higher than that of Italian poplar. Absorption rate was higher in broadleaf trees (1.45).

This is because broadleaf trees have pipes for the passage of air, which facilitates the infiltration of liquid.

Corrosion rates and absorption rates are in Table 3.

3.4. Chemical Contents

It is necessary to examine changes in the chemical contents of wood when the wood is treated with a preservative or a fire-retardant and decayed by fungi. It is for investigating changes in wood components resulting from preservative treatment. In addition, changes in chemical contents by rot fungi give clues to the understanding of the effects of preservative treatment.

Figs. 1~4 show the chemical contents of wood treated with boric acid · MAP, one treated with white rot fungi *T. versicolor* and the other

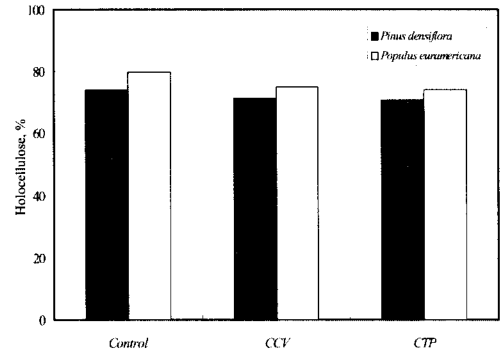

Fig. 1. Changes of holocellulose content in the various treated wood.

Legend ; **Control** : Non-treated wood
CTV : Chemical treated wood decayed by *T. versicolor*
CTP : Chemical treated wood decayed by *T. palustris*

treated with brown rot fungi *T. palustris*. White rot fungi decompose not only cellulose and hemicellulose but also lignin. Brown rot fungi are known to decompose both cellulose and hemicellulose, which compose cell walls, at the same rate. The content of holocellulose in each type of treated wood is as in Fig. 1.

There was little difference in the content of holocellulose between untreated wood and one treated with boric acid · MAP. This shows that cellulose and hemicellulose, which are wood carbohydrate, are not much affected physically and chemically by the treatment of boric acid · MAP.

Furthermore, when wood is treated with boric acid MAP and white rot fungi *T. versicolor* and brown rot fungi *T. palustris*, holocellulose decreased slightly only in Italian poplar. This shows that boric acid · MAP treatment for pine wood has the effect of decay-resistance against white rot fungi and brown rot fungi. Decay-resistance of Italian poplar was lower than that of treated with boric acid·MAP (Yalinkilic *et al.* 1998).

Previous researches reported that, because *T.*

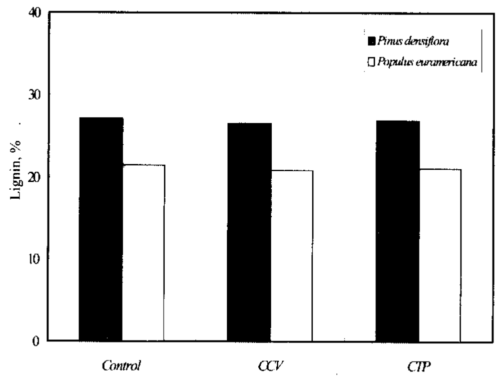

Fig. 2. Changes of lignin content in the various treated wood.

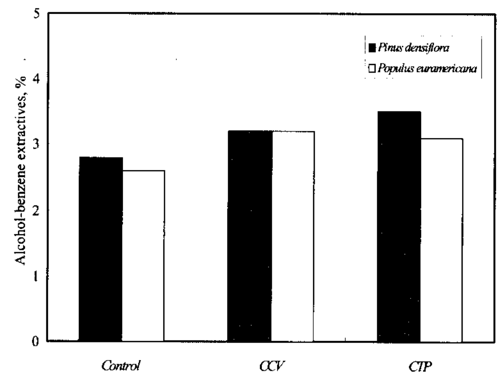

Fig. 3. Changes of organic solvent extractives content in the various treated wood.

versicolor decomposes cellulose, hemicellulose and lignin in almost the same rate, the weight loss of cellulose and hemicellulose are nearly identical. In this experiment as well, the decomposition rate of the components by *T. versicolor* was almost identical (高橋 1989).

Fig. 2 shows the content of lignin in untreated wood and its decayed sample. The content of lignin, which is the main component of wood, did not change significantly in wood decayed by *T. versicolor* and that by *T. palustris*. This is probably because chemically treated wood chemically in the treated wood influence in the decay patten of specimens and the fungi used in this study decay carbohydrates first and then lignin, a phenolic compound, later.

Fig. 3 shows the content of alcohol-benzene extract. According to the result, when *T. versicolor* and *T. palustris* infiltrated, the content of alcohol-benzene (organic solvent extract) increased. The content rose more in pine wood, coniferous tree, than Italian poplar wood, a broadleaf tree. A possible reason is that the coniferous trees contain a larger quantity of organic solvents such as oil, fat and resin than broadleaf trees.

Fig. 4 shows the content of alkali extract in untreated wood and decayed sample pieces. The content of alkali extract was higher in decayed

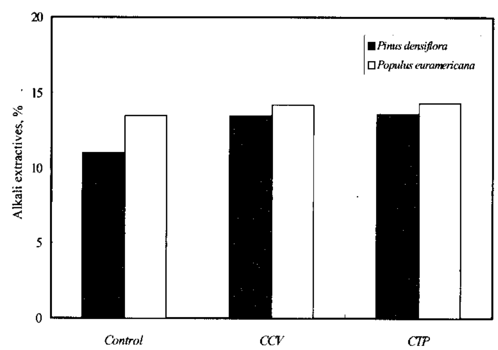

Fig. 4. Changes of alkali extractives content in the various treated wood.

sample pieces than in untreated wood. This is probably because a lot of soluble components and some resin, refined oil, lignin, etc. are eluted by alkali extract and the content of alkali extract rises as *T. palustris* decomposes cellulose and *T. versicolor* decomposes lignin.

In addition, when decayed by *T. versicolor* and *T. palustris*, Italian poplar wood showed a higher content of alkali extract than pine wood. This may be because of the increase of low molecular materials generated when rot fungi decompose hemicellulose in wood. What is more, Italian poplar wood was found to be less decay-resistant against *T. versicolor* and *T. palustris* than pine wood.

4. CONCLUSIONS

This study performed an experiment in order to examine the decay-resistance of Korean pine wood (*P. densiflora*) and Italian poplar wood (*P. euramericana*) treated with a chemical mixture containing fire-retardant. The results are summarized as follows.

1. The retention of chemicals in pine wood (2 ×2×1 cm) and Italian poplar wood (2×2×1 cm) was 1.52 kg/(30 cm^3) and 2.24 kg/(30 cm^3) respectively, higher in Italian poplar wood. That the retention of chemicals was higher in Italian poplar wood is may be because of difference in specific gravity and chemical components.

2. Weight loss by *T. versicolor* and *T. palustris* for 12 weeks was 11.31% and 13.96% respectively for untreated pine wood, and 3.07% and 4.05% respectively for treated pine wood. It was 16.42% and 20.23% for untreated Italian poplar wood and 4.51% and 5.60% for treated Italian poplar wood. Accordingly, weight loss was high both in untreated and treated wood, and somewhat higher in Italian poplar wood than in pine wood.

3. The corrosion rate of pine wood and Italian poplar wood was 1.02% and 0.90% respectively, so it was slightly higher in pine wood, and the absorption rate of pine wood and Italian poplar wood was 1.25% and 1.45% respectively, so it was slightly higher in Italian poplar wood. The corrosion rate and absorption rate met the KS standard for wood preservative performance.

4. According to the result of decaying chemically treated wood with white rot fungi and brown rot fungi, the content of holocellulose in pine wood decreased at a small rate and in Italian poplar wood at a somewhat large rate, but the content of lignin did not change much regardless of the kind of wood and fungi.

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