# Combustion and Mechanical Properties of Fire Retardant Treated Waste Paper Board for Interior Finishing Material

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(Received May 2, 2002)

**ABSTRACT:** The physical and mechanical properties of fire retardant treated composites made of recycled waste paper were examined to investigate the possibility of using the composites as interior finishing materials. With specific gravities of 0.8 and 1.0, and containing 10, 15, and 20(wt.%) of fire retardant (inorganic chemical, FR-7®) using the fabricating method used by commercial fiberboard manufacturers. Shredded waste newspapers and urea-formaldehyde (UF) adhesives, at 10% by weight on raw material, were used to produce recycled waste paper boards in laboratory scale experiments. The bending modulus of rupture increased as board density increased, and decreased as the fire retardant content increased. Mechanical properties were a little inferior to medium density fiberboard (MDF) or hardboard (HB), but significantly superior to gypsum board (GB) and insulation board (IB). The incombustibility per JIS A 1321-1994 [Japanese Standards Association (1994). Testing method for incombustibility of interior finish material and procedure of buildings, JIS A 1321–1994] of the fire retardant treated board increased on increasing the fire retardant content. The

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0734-9041/02/06 0505–13 $10.00/0 DOI: 10.1106/073490402031471

study shows that there is a possibility that composites made of recycled waste paper can be used as fire retardant treated interior finishing materials.

**KEY WORDS:** recycled waste paper, fire retardant, inorganic chemical, incombustibility.

## INTRODUCTION

ENVIRONMENTAL POLLUTION RESULTING from industrial wastes and waste living materials is one of the biggest problems facing the human race and much concentrated effort is being put into solving this problem on a world wide basis, in advanced and less advanced countries. To solve this problem effectively, we need to establish proper solutions for the recycling of waste materials safely at low cost.

Waste paper is one of the major waste materials and yet comparatively little is recycled. Therefore, the development of composites made of waste paper as raw materials with fire retardant or other desirable properties will contribute to waste recycling and reduce environmental pollution.

If a recycled waste paper board was developed through a dry-process, it would reduce environmental pollution. In addition, not only would such a board be able to substitute for a gypsum board or a ceiling board as an interior finishing material, but it could also substitute for medium density fiberboard and particleboard as a raw material for furniture, if used in combination with a fire retardant treatment. Recycled waste paper boards have the advantages of improved mechanical properties, lighter weight. Another advantage of recycled waste paper board is that it does not require the de-inking of waste paper, and it can be easily recycled, which is a key difference between the waste paper board process and the paper industry. Recycled waste paper board is biodegradable, which in turn reduces the secondary environmental pollution concerning its disposal. Moreover, as a material that is used within building, it will contribute significantly to the effective recycling of waste materials. Gypsum boards and ceiling boards are very hard to recycle and to strengthen. Typical gypsum boards have very high densities and are relatively weak, but recycled waste paper boards are of relatively low density and have significantly higher strengths than gypsum boards.

Today, the major part of the paper recycling process is a wet-process that produces recycled paper by disintegrating waste papers or by producing paper boards gain through a wet-process, which also means that such products are easily disintegrated in water. Due to the wet paper recycling process, secondary environmental pollution associated with the use of water occur. Increased numbers of short fibers as produced by repeated recycling cause strength reductions, and this necessitates the mixing of waste paper and virgin pulp as a raw material. However, if a dry-process was developed with water-soluble adhesives, these problems will be substantially solved, and new goods beyond the current paper industry's abilities would become available. In addition, the development of fire retardant (FR-7®) treated recycled paper board as interior finishing material has the advantage of reducing toxic smoke levels caused by the burning of such finish materials, thus saving life [9]. In particular, the new fire retardant (FR-7®) used in this research, is known to be effective and to have the advantage of low cost compared to other fire retardants.

Several researchers have succeeded in the recycling and the utilization of waste paper. Deppe manufactured medium density fiberboard made of waste paper and wood fibers using a dry-process, and reported that physical and mechanical properties decreased as waste paper content increased, and suggested to obtain an adequate product, that the specific gravity should be higher than 0.8 or increase resin content [4]. Lee and Son manufactured composite boards made of waste papers (coating paper and old newspaper) and various wood-based raw materials (flake, particle, fiber) using a dry-process, and used PMDI, UF- and PF-resins as composite binders. Composite boards were tested and examined for mechanical properties in the fundamental research of waste paper-wood based composite [13]. These researchers, selected waste paper and other wood-based raw materials in a 50/50 mixing ratio [4,13], however, we selected waste paper only. The mechanical properties of recycled waste paper boards are expected to be inferior to hardboard or medium density fiberboard, but sufficiently superior to insulation board [6] or gypsum board [7]. Past research has established the production of composite board from waste paper through a dry-process [10,11,13,16,17], but some additional research upon issues such as improved water resistance, fire retardancy, and others are necessary.

Waste paper was selected as a raw material in this research. Due to the fact that recycled waste paper board does not require de-inked waste paper as a raw material, and it is easily recycled, thus contributing to the enhanced recycling of waste materials. In addition, because waste papers are bio-degradable, it should reduce secondary environmental pollution and thus reduce overall costs. In the present study, physical and mechanical tests, an oxygen index test, and an incombustibility test of the fire retardant treated recycled waste paper boards were undertaken. In the future, environmental policies will change more so in all countries, and the value of such recycled products will increase. Moreover, we believe that this waste paper board adequately substitutes for gypsum board, ceiling board, and insulation board as a interior finishing material for the construction industry.

## METHODS

### Materials

Old newspapers were used as the raw material. Waste papers were subjected to a primary and secondary cutting by machine to $1 \times 1$(cm) in size, milled in order to obtain short fibers, and oven-dried to a target moisture content of 4 wt.%. Commercial urea-formaldehyde (UF) resin adhesive (65 wt.% solids content) was used (10% by weight of the oven-dried weight of raw material) as a binder and 10 wt.% of $NH_4Cl$ solution was used as a hardener, based on 10 wt.% of the oven-dried weight of adhesive. The FR-7® (Recytech Co., Ltd., S.KOREA.) was used as fire retardant. This FR-7® was composed of potassium hydroxide, an ammonium phosphate, ammonia, and glycerine (Korean Patent No. 1020020045218, 2002.06.19).

### Sample Preparation

Fire retardant treated and nontreated recycled waste paper boards were manufactured using the method currently used in the fiberboard industry. Fire retardant was added to the waste papers before adding the adhesives.

Control boards were manufactured to target specific gravities of 0.8 and 1.0 with target thicknesses of 6, 9, and 12 (mm), and then tested. Subsequently, fire retardant treated recycled waste paper boards were manufactured to a target S.G. 1.0 and to a thickness of 9 mm containing 10, 15, and 20(wt.%) of fire retardant, and then tested.

A mixture of recycled waste paper (and fire retardant) was placed into a rotary drum mixer, and then the mixture was slowly sprayed with commercial UF adhesive, at 10% by weight on the oven-dried weight of the raw materials while rotating the mixer. The mixture of recycled waste paper (with fire retardant) and adhesives was then cold pressed at 30 psi and left for 2 min before hot pressing.

The mixture was then hot pressed, to form a composite board at a peak pressure of 650 psi and a temperature of 150°C. Total pressing time

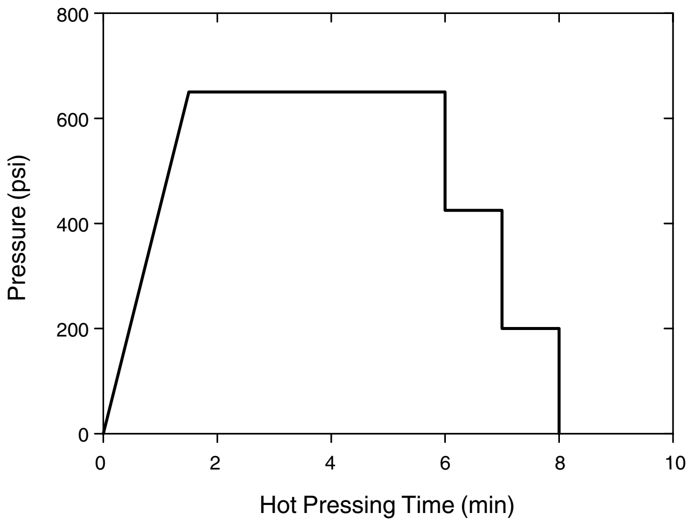


*Figure 1.* Schematic plot of multi–hot press schedule (at 9 mm thickness).

was 8 min at a thickness of 9 mm (6.5 min at 6 mm thickness and 9.5 min at 12 mm thickness). The schematic plot of the multi-hot press schedule at a thickness of 9 mm is shown in Figure 1. Board samples were preconditioned at 25°C and 65% RH for 1 week before testing.

**Physical and Mechanical Properties**

Moisture content, specific gravity, and 3-point bending strength were determined using ASTM D 1037-99 [1]. Each value obtained represented the average of five samples.

A Universal Testing Machine (Zwick Co., NICEM at Seoul National University) was used for the 3-point bending test.

**Incombustibility**

Incombustibility testing of fire retardant treated and nontreated recycled waste paper boards was performed using JIS A 1321-1994 [8]. The Building Material Combustibility Tester (Toyoseiki Co., at Korea Forest Research Institute) was used and each value represents the average of three samples. As for the brief explanation of the building material combustibility tester, the light intensity is measured for the calculation of smoke concentration by irradiating light on smoke from the opposite side of smoke collected in a square container that comes out when a test sample is combusted. The light intensity is measured weak in the presence of thick smoke. Using this light intensity value, smoke coefficient is calculated.

The smoke coefficient ($C_A$) is defined by the equation in JIS A 1321-1994 [8], and is proportional to the amount of smoke; light intensity increases as smoke concentration decreases.

$$C_A = 240 \log_{10}(I_0/I)$$

$I_0$ is the light intensity at the beginning of the incombustibility test (lx); $I$ is the minimum light intensity during the incombustibility test (lx).

According to the smoke coefficient ($C_A$), materials are classified in to three classes. The smoke coefficient ($C_A$) of incombustibility first class materials is $\leq$30, second class is $\leq$60, and third class is $\leq$120 [8].

The $td\theta$ ($^\circ$C min) is defined as the area between the ventilated air temperature curve and the standard temperature curve. According to the $td\theta$ ($^\circ$C min), materials are classified as belonging to 2 classes. The $td\theta$ ($^\circ$C min) of incombustibility second class materials is $\leq$100 and of third class materials is $\leq$350 [8].

The weight loss (%) was evaluated by weighing before and after the incombustibility test, and the ignition time (s) was measured from the start of the test to the ignition point. The residual flame time (s) was measured from the end of the test to the time the flame was extinguished.

### Oxygen Index

Oxygen index of the composite board specimen was measured using ASTM D 2863-97 [2], and is the minimum concentration of oxygen required for flaming combustion in a flowing mixture of oxygen and nitrogen [2]. Basically, if the test specimen is hard to burn, it requires more oxygen to cause flaming combustion and this increases its oxygen index.

## RESULTS AND DISCUSSION

### Physical Properties

The moisture content and specific gravity of composite boards are listed in Table 1. The moisture content of specimen was 5.40–7.70 wt.%, and S.G. was 0.96–1.02.

*Table 1. Moisture content and specific gravity of composite boards.*

| Fire Retardant Content (wt.%) | Moisture Content (wt.%) | Specific Gravity |
|---|---|---|
| 0 | 5.40 (0.05) | 0.96 (0.01)[a] |
| 10 | 6.26 (0.08) | 1.02 (0.02) |
| 15 | 6.86 (0.12) | 0.98 (0.01) |
| 20 | 7.70 (0.12) | 1.01 (0.02) |

[a]Standard deviation; Target Sp.Gr.: 1.0; Thickness : 9 mm.

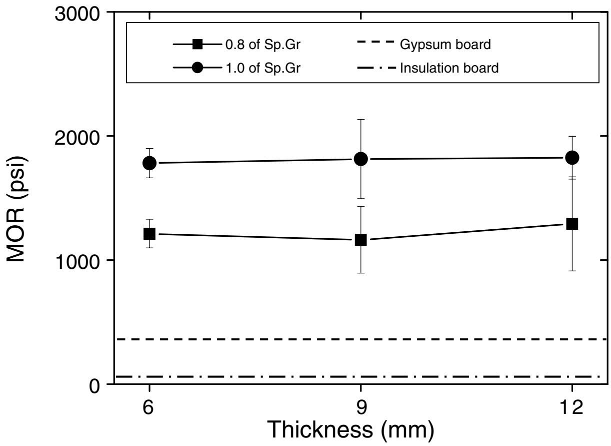


*Figure 2. Bending MOR of control board vs. specific gravity and thickness.*

## Mechanical Properties

The bending modulus of rupture (MOR) of the control board at different densities and thicknesses is shown in Figure 2. The bending MOR was found to be higher at an S.G. of 1.0 than at 0.8, but not affected at board thickness. Board samples were prepared with S.G.s of 1.0 and 0.8, because it has been reported that at S.G.s lower than 0.8 properties deteriorate [4].

The bending MOR of fire retardant treated board is shown in Figure 3, and the effect of fire retardant content was examined. The target S.G. in this case was 1.0 and the thickness was 9 mm. The bending MOR of fire retardant treated board decreased as the fire retardant content increased, but was nevertheless superior to gypsum [7] and insulation boards [6]. Therefore, these results demonstrate the possibility of fire

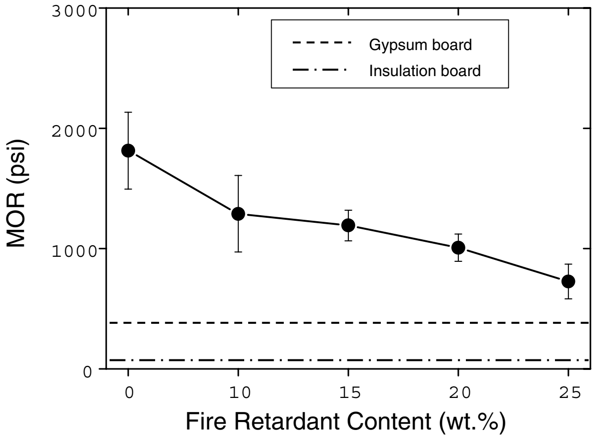


*Figure 3.* *Bending MOR of fire retardant treated board vs. fire retardant content.*

retardant treatments of recycled waste paper board as an interior finishing material or as an insulation board with acceptable strength.

## INCOMBUSTIBILITY

### Smoke Coefficient ($C_A$)

The smoke coefficient ($C_A$) of fire retardant treated board is shown in Figure 4. The smoke coefficient ($C_A$) of the fire retardant treated board decreased as the fire retardant content increased. All of the fire retardant treated board samples were of incombustibility 1st class [8]. Thus, fire retardant treated waste paper boards have excellent incombustibility for smoke when tested per JIS A 1321-1994 [8].

### $td\theta$ (°C min)

The $td\theta$ (°C min) of fire retardant treated board is shown in Figure 5. The effect of fire retardant content was examined, and the $td\theta$ (°C min) of the fire retardant treated board was found to decrease on increasing the fire retardant content. Board samples containing 10% by weight of fire retardant were found to be of 3rd class incombustibility, and board samples with 15 and 20(%) by weight of fire retardant were in 2nd class incombustibility per JIS A 1321-1994 [8].

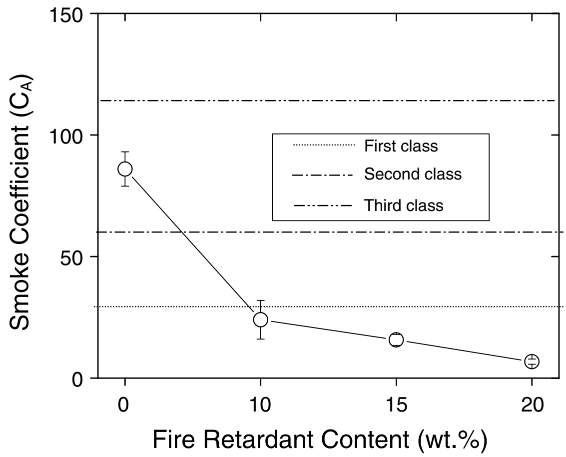


*Figure 4.* *Smoke coefficient ($C_A$) of fire retardant treated board vs. fire retardant content.*

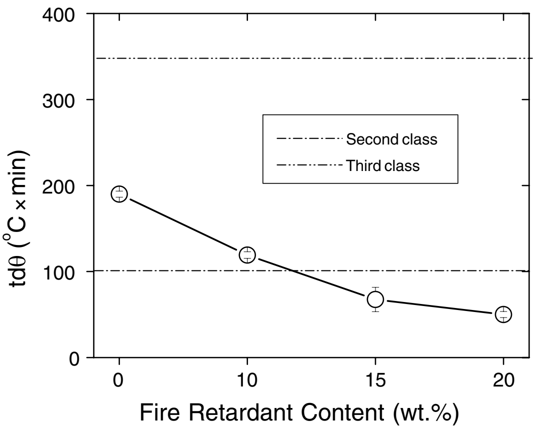


*Figure 5.* *tdθ (°C × min) of fire retardant treated board vs. fire retardant content.*

## Weight Loss (%)

The weight loss (%) of fire retardant treated board is shown in Figure 6. The effect of fire retardant content was examined, and the weight loss (%) of the fire retardant treated board decreased as the fire retardant content increased, which is in agreement with the incombustibility results.

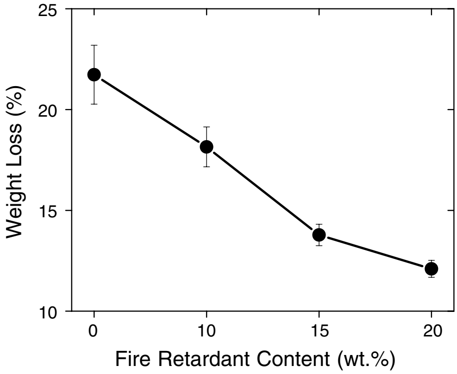


*Figure 6.* *Weight loss (%) of fire retardant treated board vs. fire retardant content.*

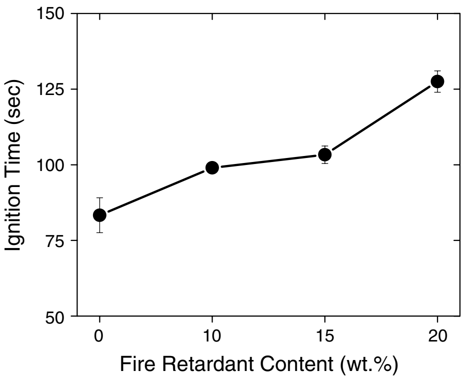


*Figure 7.* *Ignition time (s) of fire retardant treated board vs. fire retardant content.*

## Ignition Time (s)

The ignition time (s) of the fire retardant treated board is shown in Figure 7, and the effect of fire retardant content on the ignition time examined, and as expected the ignition time (s) increased as the fire retardant content increased. Meaning that it is more difficult to ignite a board with a higher fire retardant content, which is in line with our incombustibility test results.

## Residual Flame Time (s)

The residual flame time (s) of the fire retardant treated boards are shown in Figure 8. It can be seen that the residual flame time (s) of fire

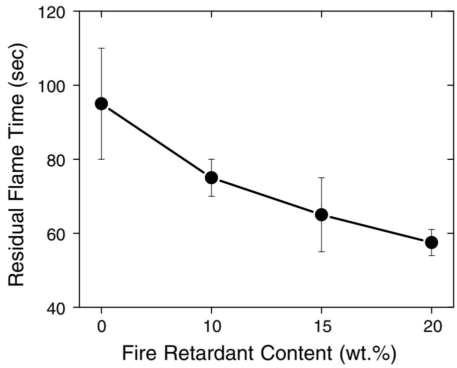


*Figure 8. Residual flame time (s) of fire retardant treated board vs. fire retardant content.*

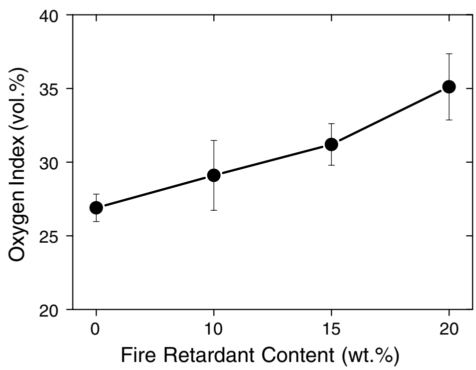


*Figure 9. Oxygen index (vol.%) of fire retardant treated board vs. fire retardant content.*

retardant treated board decreased as the fire retardant content was increased. Meaning that it is more difficult to maintain combustion in boards with higher fire retardant content, which is in agreement with previously obtained incombustibility test results.

## Oxygen Index

The oxygen index (vol.%) of the fire retardant treated boards is shown in Figure 9. If a specimen is difficult to burn, it requires more oxygen to maintain combustion and this increases its oxygen index value. In the control board, the oxygen index value was about 27 vol.% and this increased as the fire retardant content was increased. Moreover, the oxygen index of the fire retardant treated waste paper board was higher than 21 vol.%, which is the mean value of oxygen concentration in the air, and also higher than particleboard, paper sludge-wood particle mixed board, paper sludgeboard and solid wood [13,19]. Stated another way, the oxygen index is the minimum concentration of oxygen required to support combustion in a flowing mixture of oxygen and nitrogen [2]. These results show that combustion becomes more difficult to sustain as the fire retardant content is increased, which is again in agreement with our incombustibility test results.

## CONCLUSIONS

Bending strength of nontreated board, is independent of board thickness, and the higher the board density, the higher its bending strength. The bending strength of fire retardant treated board decreased as the fire retardant content increased, but this was nevertheless superior to gypsum boards [7] and insulation boards [6]. As expected, the incombustibility of fire retardant treated board increased as the fire retardant content increased. Fire retardant treated waste paper boards had very good incombustibility, which is imparted by the new fire retardant (FR-7®). Fire retardant treated recycled waste paper board is suitable for use as an interior finishing material or as insulation board.

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