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Combustion and Mechanical Properties of Fire Retardant Treated Waste Paper-Waste Acrylic Raw Fiber Composite Board*1

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ABSTRACT

Shredded waste newspapers, waste acrylic raw fibers, and urea-formaldehyde (UF) adhesives, at 10% by weight on raw material, were used to produce recycled waste paper-waste acrylic raw fiber composite boards in laboratory scale experiments. The physical and mechanical properties of fire retardant treated recycled waste paper-waste acrylic raw fiber composite boards were examined to investigate the possibility of using the composites as internal finishing materials with specific gravities of 0.8 and 1.0, containing 5, 10, 20, and 30(wt.%) of waste acrylic raw fiber and 10, 15, 20, and 25(wt.%) of fire retardant (inorganic chemical, FR-7®) using the fabricating method used by commercial fiberboard manufacturers. The bending modulus of rupture increased as board density increased, decreased as waste acrylic raw fiber content increased, and also 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 of the fire retardant treated composite board increased on increasing the fire retardant content. The study shows that there is a possibility that composites made of recycled waste paper and waste acrylic raw fiber can be use as fire retardant internal finishing materials.

Keywords : recycled waste paper, waste acrylic raw fiber, fire retardant, inorganic chemical, incombustibility

1. INTRODUCTION

In world wide, environmental pollution resulting from industrial wastes and waste living materials is one of the biggest problem facing the entire human race and it will be more and more serious, thus, much concentrated effort is being put into solving this problem, in advanced and less advanced countries. Waste products that could not be dealt with by the self-

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cleansing action of nature have to be processed by establishing waste processing facilities such as land fills and incinerators, measures are needed for more effective, inexpensive and active waste processing and recycling since various social and economic problems arise during this process of treating waste such as local egotism by local people opposing the building of waste processing facilities and huge amount of investment cost for building of facilities.

Among different wastes produced by ordinary households, the amount of paper collected such as newspaper and corrugated paper as the main source of being discharged and collected separately is increasing every year due to the establishment of the system of collecting waste in which people have to purchase specific size waste bags to place their waste, place waste bags in designated places, and separately throw away those wastes that could be recycled. Nonetheless, not significant amount of waste paper is being utilized until now. If these paper wastes could be used to develop various environmentally friendly composites, not only environmental pollution could be reduced but also a big contribution could be made from the aspect of recycling wastes.

Gypsum boards and ceiling boards are hard to recycle and are fundamentally weak. Accordingly, if a recycled waste paper board were 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 internal finish 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 and lighter weight. Considering the fact that the lumber industry entirely relies on imports for the source of MDF, not only a significant effect could be seen in replacing imports for internal finishing panels and furnitures but also environmentally-friendly materials could be produced while avoiding petrochemical products with the development of functional boards using recycled paper. Another advantage of recycled waste paper board is that it does not require the de-inking of waste paper, can be easily recycled, could use as the source of composite board in more amount compared with recycled paper used in the production of paper, and is expected to contribute significantly from the aspect of effective recycling of wastes inducing environmental pollution, which is a key difference between the waste paper board process and the paper industry. Recycled waste paper board is bio-degradable, 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.

In addition, the development of fire retardant (inorganic chemical, FR-7®) treated recycled waste paper-waste acrylic raw fiber composite board as internal finishing material has the advantage of reducing toxic smoke levels caused by the burning of such finish materials, thus saving life (Kozlowski *et al.*, 1999). 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.

Deppe (1985) 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. Ellis *et al.*(1993) produced a composite from phone books and various wastes vinyl products and reported that although the mechanical properties were superior, the dimensional stability was poor in the composite. Lee and Son (1995) manufactured composite boards made of waste papers (coating paper and old newspaper) and various wood-based 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. These researchers, selected waste paper and other wood-based material as raw materials in a 50/50 mixing ratio (Deppe, 1985 ; Lee *et al.*, 1995), however, we selected waste paper only. The mechanical properties of recycled waste paper board are expected to be inferior to hardboard or medium density fiberboard, but sufficiently superior to insulation board or gypsum board (International Organization For Standardization, 1972, 1980). Stokke and Liang (1991) tested a wood based composite produced by mixing waste paper and wood based raw material (flake, particle, TMP, wood fiber) at 50:50 ratio and reported that although this board showed the similar bending strength was commercial boards, it showed a low internal bonding strength with more than 25% increase in thickness swelling. In order to reduce this thickness swelling, they added foamed polystyrene. Past research has established the production of composite board from waste paper through a dry-process (Krzysik *et al.*, 1993 ; Laundrie *et al.*, 1975 ; Okino *et al.*, 2000 ; Lee *et al.*, 1995 ; Raghupathy *et al.*, 2002), 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 materials, and it is easily recycled, thus contributing to the enhanced recycling of waste materials and having a major impact on environmentally friendly effect according to pioneering in the recycle field.

Furthermore, since waste materials are used as the raw material, compared with previous panel product, it could reduce production cost and could induce value addedness through the development of composites with added functionality.

In the present study, physical and mechanical tests, an oxygen index test, and an incombustibility test of the fire retardant treated recycled waste paper-waste acrylic raw fiber composite 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 composite board adequately substitutes for gypsum board, ceiling board, and insulation board as a internal finishing material for the construction industry.

2. METHODS

2.1. Materials

Old newspapers and waste acrylic raw fibers were used as the raw material. 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 of inorganic chemical.

Table 1. Manufacturing parameters for control board

Specific gravity	Thickness (mm)
0.8	6
	9
	12
1.0	6
	9
	12

2.2. Raw Material Preparation

Waste papers were subjected to a primary and secondary cutting by machine to 1 cm×1 cm in size, milled in order to obtain short fibers, and oven-dried to a target moisture content of 4 wt.%. Waste acrylic raw fibers (North Japan Spinning Factory Co., Ltd, JAPAN) were cut in length of 1 cm.

2.3. Sample Preparation

Fire retardant treated and non-treated recycled waste paper-waste acrylic raw fiber composite boards were manufactured using the method currently used in the fiberboard industry. Fire retardant was added to the waste papers before adding the adhesives. The manufacturing parameters are listed in Tables 1, 2, 3, and 4. 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, 20, and 25 (wt.%) of fire retardant. Waste acrylic raw fiber mixed boards were manufactured to a target S.G. 1.0 and to a thickness of 9 mm containing 5, 10, 20, and 30 (wt.%) of waste acrylic raw fiber. Fire retardant treated recycled waste paper-waste acrylic raw fiber composite boards were manufactured to a target S.G. 1.0 and to a thickness of 9 mm containing 10 wt.% of fire retardant, containing 5, 10, 20, and 30 wt.% of waste acrylic raw fiber, and then tested.

A mixture of recycled waste paper (and fire retardant) was placed into a rotary drum mixer,

Table 2. Manufacturing parameters for fire retardant treated waste paper board

Specific gravity	Thickness (mm)	Fire retardant content (wt.%)
1.0	9	10
		15
		20
		25

Table 3. Manufacturing parameters for waste paper-waste acrylic raw fiber mixed board

Specific gravity	Thickness (mm)	Waste acrylic raw fiber content (wt.%)
1.0	9	5
		10
		20
		30

Table 4. Manufacturing parameters for fire retardant treated waste paper-waste acrylic raw fiber mixed board

Specific gravity	Thickness (mm)	Fire retardant content (wt.%)	Waste acrylic raw fiber content (wt.%)
1.0	9	10	5
			10
			20
			30

and then the mixture was slowly sprayed with commercial urea-formaldehyde 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 2 kgf/cm^2 and left for 2 min before hot pressing. The mixture was then hot pressed, to form a composite boards at a peak pressure of 45 kgf/cm^2 and a temperature of 150°C. Total pressing time 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 Fig. 1. Board samples were pre-conditioned at 25°C and 65% RH for 1 week before testing.

2.4. Physical and Mechanical Properties

Moisture content, specific gravity, and 3-point bending strength were determined using ASTM D 1037-99 (1999). 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.

2.5. Incombustibility

Incombustibility testing of fire retardant treated and non-treated composite boards was performed using JIS A 1321-1994 (1994). The Building Material Combustibility Tester (Toyo-seiki Co., at Korea Forest Research Institute) was used and each value represents the average of three samples.

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

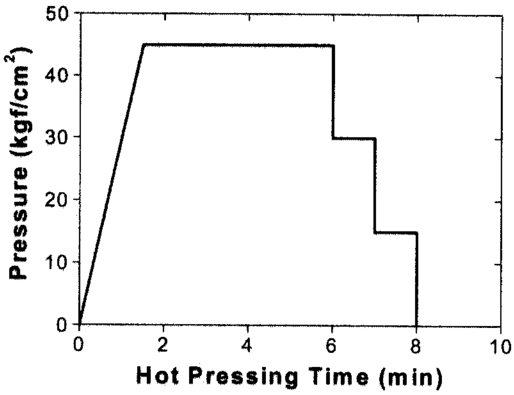

Fig. 1. Schematic plot of multi-hot press schedule (at 9 mm thickness).

decreases.

$$C_A = 240 \log10(I_O/I)$$

I_O : Light intensity at the beginning of the incombustibility test (lx)

I : Minimum light intensity during the incombustibility test (lx)

According to the smoke coefficient, materials are classified in three classes. The smoke coefficient of incombustibility first class materials is $\leq$ 30, second class is $\leq$ 60, and third class is $\leq$ 120 (Japanese Standards Association, 1994).

$td\theta$ (°C × min) is defined as the area between the ventilated air temperature curve from sample plate and the ventilated air temperature curve from standard plate. According to the $td\theta$, materials are classified as belonging to 2 classes. The $td\theta$ of incombustibility second class materials is $\leq$ 100 and of third class materials is $\leq$ 350 (Japanese Standards Association, 1994).

Weight loss was evaluated by weighing before and after the incombustibility test, and the ignition time was measured from the start of the test to the ignition point. Residual flame

Table 5. Moisture content and specific gravity of fire retardant treated waste paper boards (target Sp.Gr : 1.0, thickness : 9 mm)

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

time was measured from the end of the test to the time the flame was extinguished.

2.6. Oxygen Index

Oxygen index of the composite board specimen was measured using ASTM D 2863-97 (1997), and is the minimum concentration of oxygen required for flaming combustion in a flowing mixture of oxygen and nitrogen. Basically, if the test specimen is hard to burn, it requires more oxygen to cause flaming combustion and this increases its oxygen index.

3. RESULTS and DISCUSSION

3.1. Physical Properties

The moisture content and specific gravity of composite boards (target Sp.Gr : 1.0) are listed in Table 5. The moisture content of specimen was 5.40~7.70 wt.%, and S.G. was 0.96~1.02.

3.2. Mechanical Properties

The bending modulus of rupture (MOR) of the control board at different densities and thicknesses is shown in Fig. 2. The bending MOR was found to be higher at an S.G. of 1.0

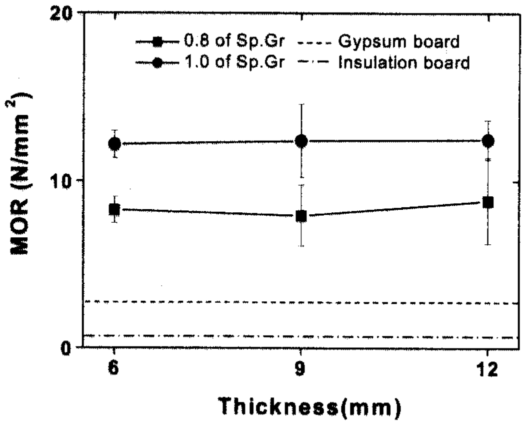

Fig. 2. Bending MOR of control board versus specific gravity and thickness.

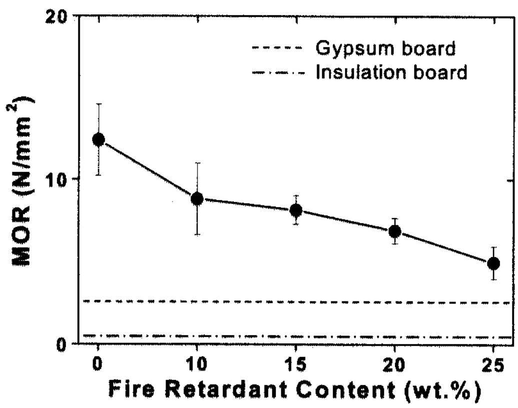

Fig. 3. Bending MOR of fire retardant treated waste paper board versus fire retardant content.

than at 0.8, but not affected at board thickness. Board samples were prepared with S.G. of 1.0 and 0.8, because it has been reported that at S.G. lower than 0.8 properties deteriorate (Deppe, 1985).

The bending MOR of fire retardant treated board is shown in Fig. 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

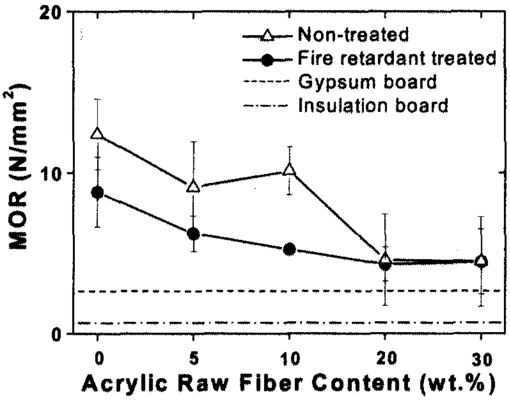

Fig. 4. Bending MOR of fire retardant treated (10 wt.%) and non-treated waste paper-waste acrylic raw fiber mixed board versus waste acrylic raw fiber content.

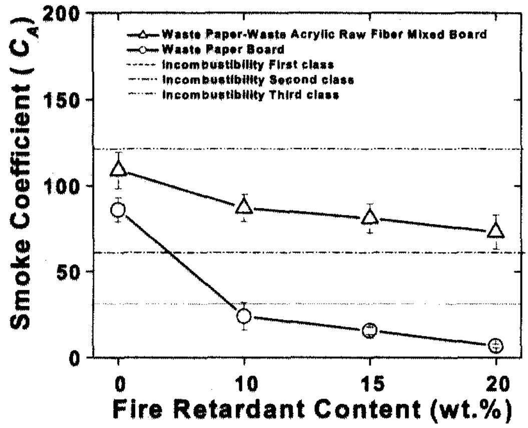

Fig. 5. Smoke coefficient of fire retardant treated waste paper board and waste paper-waste acrylic raw fiber (5 wt.%) mixed board versus fire retardant content.

gypsum and insulation boards (International Organization For Standardization, 1972, 1980), even at a fire retardant loading of 25 wt.%. The bending MOR of fire retardant non-treated and treated waste paper-waste acrylic raw fiber mixed board is shown in Fig. 4, and the effect of waste acrylic raw fiber content was examined. The target S.G. in this case was also 1.0 and the thickness was 9 mm. The bending MOR of waste paper-waste acrylic raw fiber mixed board decreased as the waste acrylic raw fiber content increased, but was nevertheless superior to gypsum and insulation boards (International Organization For Standardization, 1972, 1980). Therefore, these results demonstrate the possibility of fire retardant treatments of recycled waste paper board as an internal finish material or as an insulation board without decreasing strength.

3.3. Incombustibility

3.3.1. Smoke Coefficient

The smoke coefficients of fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards are shown in Fig. 5. The smoke coefficients of the fire retardant treated boards decreased as the fire retardant content increased. All of the fire retardant treated waste paper board samples (at 10, 15, and 20 wt.% of fire retardant content) were of 1st class incombustibility and fire retardant treated waste paper-waste acrylic raw fiber mixed board samples were of 3rd class incombustibility (Japanese Standards Association, 1994). Thus, fire retardant treated waste paper boards have excellent incombustibility.

3.3.2. *td*θ

The *td*θ of fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards is shown in Fig. 6. The effects of fire retardant content were examined, and the *td*θ of the fire retardant treated boards was found to decrease on increasing the fire retardant content. Waste paper board samples containing 10% by weight of fire retardant and all of the waste paper-waste acrylic raw fiber mixed boards were found to be of 3rd class

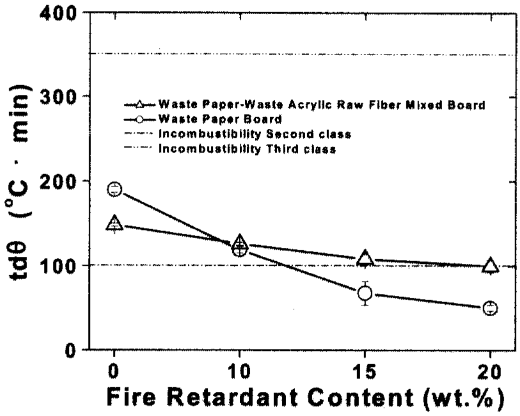

Fig. 6. *tdθ* of fire retardant treated waste paper board and waste paper-waste acrylic raw fiber (5 wt.%) mixed board versus fire retardant content.

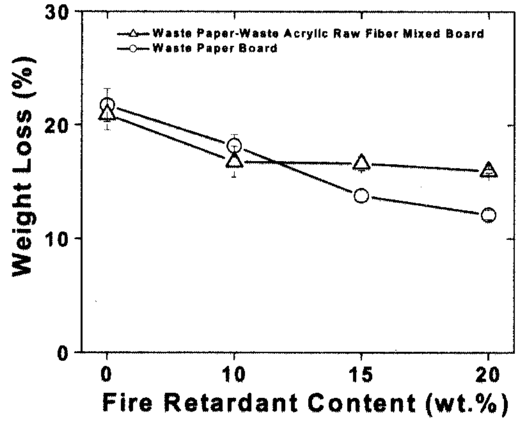

Fig. 7. Weight loss of fire retardant treated waste paper board and waste paper-waste acrylic raw fiber (5 wt.%) mixed board versus fire retardant content.

incombustibility, and waste paper board samples with 15 and 20% by weight of fire retardant were in 2nd class incombustibility (Japanese Standards Association, 1994).

3.3.3. Weight Loss

Weight loss of fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards are shown in Fig. 7. The effects of fire retardant contents were examined, and the weight loss of the fire retardant treated boards decreased as the fire retardant contents increased.

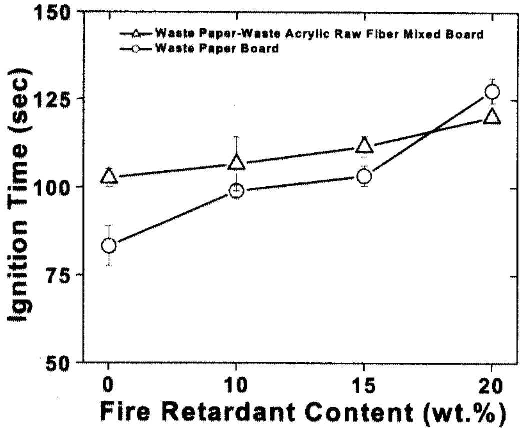

Fig. 8. Ignition time of fire retardant treated waste paper board and waste paper-waste acrylic raw fiber (5 wt.%) mixed board versus fire retardant content.

3.3.4. Ignition Time

The ignition time of the fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards are shown in Fig. 8, and the effects of fire retardant contents on ignition time examined, and as expected ignition time 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.

3.3.5. Residual Flame Time

Residual flame times of the fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards

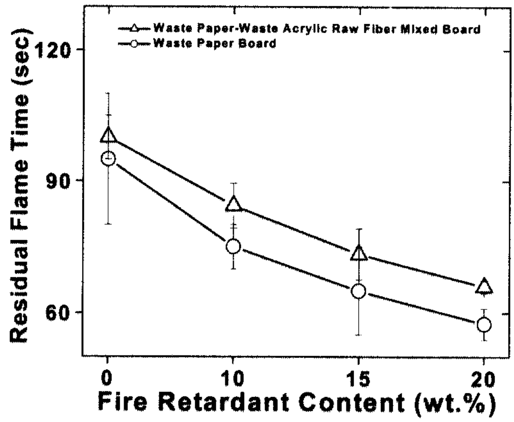

Fig. 9. Residual flame time of fire retardant treated waste paper board and waste paper-waste acrylic raw fiber (5 wt.%) mixed board versus fire retardant content.

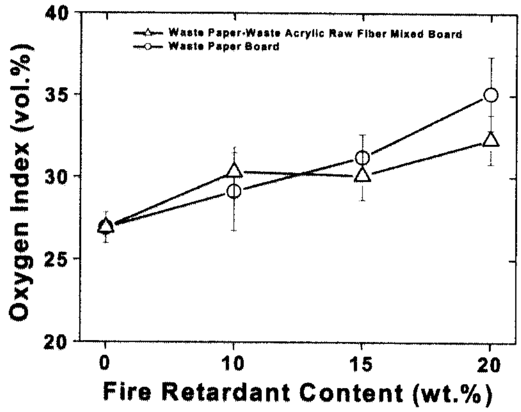

Fig. 10. Oxygen index of fire retardant treated waste paper board and waste paper-waste acrylic raw fiber (5 wt.%) mixed board versus fire retardant content.

are shown in Fig. 9. It can be seen that the residual flame time of fire 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.

3.4. Oxygen Index

The oxygen indices of the fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards are shown in Fig. 10. 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 boards and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards were higher than 25~30 vol.%, which is the mean value of oxygen concentration in the air. Stated another way the oxygen index is the minimum concentration of oxygen required to support combustion in a flowing mixture of oxygen and nitrogen (American Society for Testing and Materials, 1997). 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.

4. CONCLUSION

In bending strength of fire retardant non-treated waste paper board, is independent of board thickness, and the higher the board density, the higher its bending strength. The bending strength of fire retardant treated waste paper board and waste paper-waste acrylic raw fiber (5 wt.%) mixed boards decreased as the fire retardant contents increased, and the bending strength of fire retardant treated and non-treated waste paper-waste acrylic raw fiber mixed boards decreased as the waste acrylic raw fiber content increased, but this was nevertheless superior to gypsum board and to insulation board (International Organization For Standardization, 1972, 1980). As expected the incombustibility of fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber mixed boards increased as the fire retardant content increased. Fire retardant treated waste paper boards and waste paper-waste acrylic raw fiber mixed boards had very good incombustibility, which is imparted by the new fire retardant (FR-7®). Fire retardant treated recycled waste paper board and waste paper-waste acrylic raw fiber mixed boards are suitable for use as an internal finishing material.

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