韓國林學會誌 79(3) : 255-259. 1990.
Jour. Korean For. Soc. 79(3) : 255-259. 1990.

Oxygen Index for Wood in Burning Test by the Up and Down Method[1]

Young Geun Eom[2], Phil Woo Lee[3] and Hyun Joong Kim[3]

Up and Down法에 依한 木材 燃燒試驗에 있어서의 酸素指數[1]

嚴永根[2] · 李弼宇[3] · 金顯中[3]

ABSTRACT

To investigate relative flammability in flaming combustion among 10 softwoods and 10 hardwoods, oxygen indices were determined for flat-grained sapwoods through Up and Down method following oxygen index test of ASTM D 2863-77.

Oxygen index ranged from 21.0 for *Pinus strobus* to 28.2 for *Larix gmelinii var. principis-ruprechtii* in softwoods and from 20.7 for *Populus davidiana* to 27.6 for *Quercus acutissima in hardwoods*, which indicates *Larix gmelinii var. principis-ruprechtii* and *Quercus acutissima* being ranked first in inflammability and *Pinus strobus* and *Populus davidiana* being the least in fire resistance by softwood and hardwood because highly flammable materials are likely to have a low oxygen index.

Key words : Softwood, hardwood, oxygen index, Up and Down Method.

要 約

10種의 針葉樹材와 10種의 濶葉樹材에 있어서의 相對的 燃燒度를 測定 調査하기 위하여 邊材 板目材의 酸素指數를 *ASTM D 2863-77*에 의거 *Up and Down* 法을 통하여 구하였다.

酸素指數는 針葉樹材의 경우 스트로부스잣나무가 21.0으로 그리고 일갈나무가 28.2로 각각 最小値 및 最大値를 나타냈으며 濶葉樹材의 경우 사시나무가 20.7로 最小値를 그리고 상수리나무가 27.6으로 最大値를 나타냈다. 따라서, 燃燒가 용이한 材料일수록 낮은 酸素指數値를 지닌다는 事實에 근거하여 볼 때 針葉樹材와 濶葉樹材별로 일갈나무와 상수리나무가 燃燒性이 가장 낮으며 스트로부스잣나무와 사시나무가 燃燒性이 가장 큰 素材임을 구명할 수 있었다.

INTRODUCTION

The oxygen index test, which was originally developed to obtain a numerical indication of relative flammability of polymeric materials by Fenimore and Martin 1966a, b), measures the minimum concentration of oxygen in a flowing mixture of oxygen and nitrogen that will just support flaming combustion of a specimen under specified laboratory conditions. The so-called oxygen index is expressed as volume percent of oxygen in the flowing gas mixture and highly flammable materials are likely to have a low oxygen index.

[1] 接受 1990年 4月 11日 Received on April 11, 1990.
[2] 國民大學校 林業大學 College of Forestry, Kookmin University, Seoul 136-702, Korea.
[3] 서울大學校 農科大學 College of Agriculture, Seoul National University, Suwon 441-744, Korea.

This test, referred to as candle test as well, was known to have the advantages of requiring relatively small size specimens(White, 1979) and of producing a single numerical value, indicative of relative flammability among materials(ASTM, 1977 , and also found to be effective method of obtaining an indication of the relative flammability of fire-retardant -treated wood and wood products by White(1979), Yoshimura and Umemura(1980), Yoshimura and Miwa(1980), and Yoshimura and Horii(1980).

White (1979), in the oxygen index tests of untreated and fire-retardant-treated southern pine solid woods and fire-retardant-treated Douglas-fir plywoods, reported that this oxygen index test could be used as an indication of the flammability of a fire-retardant -treated wood sample relative to other fire-retardant -treated and untreated wood products through comparisons with the available data for the fire tube, modified Schlyter, and 8-foot tunnel tests. Yoshimura and Umemura(1980) obtained oxygen indices of 5 softwoods and 5 hardwoods which have commonly been used for building and interior contents in Japan and noted the oxygen index test through Dixon and Massey's Up and Down method(1969) could be a proper testing method of obtaining oxygen index from materials of having uneven flaming combustion characters such as woods. The fact that oxygen index was greatly affected by moisture contents of woods was revealed in the oxygen index determination of 4 softwoods and 6 hardwoods according to JIS K 7201 method by Yoshimura and Miwa(1980). Also, Yoshimura and Horii(1980) indicated that sapwoods of *Cryptomeria japonica* and *Fagus crenata* treated with diammonium phosphate showed higher oxygen indices than with ammonium sulfamate and recommended the oxygen index test employing Up and Down method as a simple and proper method of obtaining relative flammability among materials compared with JIS K 7201 method.

On the other hand, Lee, Kim, and Eom(1989a) reported oxygen indices of untreated lauan solid wood, plywood, particleboard, and medium density fiberboard and Lee and Chung(1989), in test of plywood, particleboard, and medium density fiberboard, noted that the oxygen index was not affected by total gas flow rate in the test column of an Oxygen Index Test Apparatus. The meranti plywoods which were press-dried after treatment with fire-retardant -chemicals were tested for investigating of relative effectiveness of chemicals in fire resistance through comparisons of oxygen indices by Lee, Eom, and Kim (1989) and the oxygen indices of plywood, particleboard, and medium density fiberboard coated with fire-retardant-coating of chlorinated rubber system were obtained and compared with non-coated one by Lee, Kim, and Eom(1989b).

This study was conducted to obtain oxygen indices and to compare relative flammabilities of 10 softwoods and 10 hardwoods that grow in Korea.

MATERIALS AND METHODS

Wood Specimens

The solid woods of 10 softwoods and 10 hardwoods were obtained from collections in Wood Anatomy

Table 1. Character of wood specimens.

Species	Moisture* content(%)	Specific* gravity
Softwoods		
Larix gmelinii var. principis-ruprechtii	16.1	0.57
Cryptomeria japonica	15.6	0.43
Chamaecyparis obtusa	12.6	0.44
Pinus rigida	11.5	0.47
Abies holophylla	12.3	0.42
Pinus thunbergii	12.0	0.58
Taxodium distichum	14.2	0.44
Picea jezoensis	12.3	0.41
Pinus strobus	14.4	0.40
Pinus densiflora	15.1	0.53
Hardwoods		
Alnus hirsuta	15.5	0.49
Prunus sargentii	14.1	0.61
Rhus chinensis	16.6	0.53
Corylus sieboldiana var. mandshurica	13.6	0.64
Quercus acutissima	15.8	0.86
Magnolia kobus	15.7	0.50
Acer negundo	17.2	0.53
Populus davidiana	19.4	0.39
Quercus grosseserrata	13.2	0.66
Fraxinus mandshurica	14.5	0.56

*Moisture content and specific gravity of specimens after air drying in a laboratory of ca. 60% RH and 15℃ for one month.

Laboratory, Department of Forest Products, College of Agriculture, Seoul National University, Suwon 441-744, Korea and cut into the size of ca. 3.5mm thick, 15x15cm² sections. The sections with visible defects such as reaction wood, knot, cross grain, etc. were excluded and clear sections only were left in a laboratory of about 65% RH and 15℃ for one month.

The flat-grained specimens of sapwoods were prepared by resawing the sections into 6.5±0.5mm wide, 3.0±0.5mm thick, and 70 to 150mm long according to ASTM D 2863-77(1977) and 20 specimens per species were used. The characters of wood species tested in this experiment were listed in Table 1.

Oxygen Index Test

The oxygen index was determined, through large N technique of Up and Down method by Dixon and Massey(1969), for sapwood of each species with the aid of an Oxygen Index Test Apparatus, Model FTA Serial No. 945, Stanton Redcroft Co., at the gas flow rate of 4.20cm/sec. in the test column following ASTM D 2863-77(1977).

The oxygen concentration interval of 1.0% was used in up-and-down sequences of trials. In an oxygen concentration, the specimen burned for at least 3 minutes after removal of igniter or burned down 50 mm was marked with X sign(success) and the specimen extinguished before the satisfaction with the criterion of 3 minutes or 50mm was marked with O sign(fail). If a test at an oxygen concentration was marked with O or X sign, the next test was made at the higher or lower oxygen concentration by its interval of 1.0%, respectively.

The oxygen index($\bar{x}$) and standard deviation(s) were calculated, based on only O's or X's depending on which has the smaller total, by using below equations:

$$\bar{x}=\bar{y}_i \pm d/2, \qquad \bar{y}_i=\Sigma y_i n_i/\Sigma n_i$$

$$s=1.620d(s_y^2/d^2+0.029), \qquad s_y^2=\frac{\Sigma y_i^2 n_i-(\Sigma y_i n_i)^2/n}{n-1}$$

where, y_i : oxygen concentration value

n_i : frequency of O's or X's at y_i level

d : interval of oxygen concentration

+ or - : used when the analysis is based on the O's or X's, respectively

$n=n_i$

RESULTS AND DISCUSSION

Results of 20 tests for flat-grained sapwood of each species by up-and-down sequences of trials are obtained and the oxygen indices and standard deviations calculated from the test results using large N technique of Dixon and Massey's Up and Down method(1969) are tabulated in Table 2.

Table 2 indicates that oxygen index ranges from 21.0 for *Pinus strobus* to 28.2 for *Larix gmelinii var. principis-ruprechtii* in softwoods and from 20.7 for *Populus davidiana* to 27.6 for *Quercus acutissima* in hardwoods, and *Larix gmelinii var. principis-ruprechtii* and *Quercus acutissima*, therefore, appear to be ranked first in inflammability but *Pinus strobus* and *Populus davidiana* appear to be the least in fire resistance, judging from the fact that highly flammable materials are likely to have a low oxygen index.

The oxygen indices of woods reported previously by some investigators were as follows: 20.5 for cabinet birch and 22.7 for red oak by Isaacs(1970), 20.9 for white pine and 21.2 for sugar maple by Tsuchiya and Sumi(1974), and 22.4 for French pine, 22.5 for French poplar, and 24.6 for French oak by Hilado(1974), respectively. Yoshimura and Umemura(1980) in 5 softwoods and 5 hardwoods noted that edge-grained inner heartwood of *Acer mono* was ranked first as 25.3 and flat-grained sapwood of *Pinus thunbergii* the lowest as 19.8 in oxygen index values and also Yoshimura and Miwa(1980) reported that *Paulownia tomentosa* showed the lowest oxygen index value as 19 to 20 for the dry specimens at moisture content 4% and 21 to 22 for the air-dry ones at moisture content 12%.

CONCLUSION

The oxygen indices in flat-grained sapwoods of 10 softwoods and 10 hardwoods were as follows: 21.5 for *Cryptomeria japonica*, 28.2 for *Larix gmelinii var. principis-ruprechtii*, 25.9 for *Chamaecyparis obtusa*, 25.3 for *Pinus rigida*, 24.2 for *Abies holophylla*, 23.4 for *Pinus thunbergii*, 26.0 for *Taxodium distichum*, 22.8 for *Picea jezoensis*, 21.0 for *Pinus strobus*, and 23.5 for *Pinus densiflora* in softwoods and 24.6 for

Table 2. The oxygen indices and standard deviations for flat-grained sapwoods.

Species	Flow rate (cm/sec.)	No. of specimen	Frequency*		Average oxygen index	Standard deviation
			O's	X's		
Softwood						
Larix gmelinii var. principis-ruprechtii	4.20	20	10	10	28.2	0.79
Cryptomeria japonica	4.20	20	11	9	21.5	0.45
Chamaecyparis obtusa	4.20	20	10	10	25.9	0.84
Pinus rigida	4.20	20	10	10	25.3	0.69
Abies holophylla	4.20	20	11	9	24.2	1.26
Pinus thunbergii	4.20	20	10	10	23.4	0.56
Taxodium distichum	4.20	20	11	9	26.0	0.78
Picea jezoensis	4.20	20	10	10	22.8	0.46
Pinus strobus	4.20	20	10	10	21.0	0.86
Pinus densiflora	4.20	20	10	10	23.5	0.76
Hardwood						
Alnus hirsuta	4.20	20	10	10	24.6	0.93
Prunus sargentii	4.20	20	11	9	24.6	0.63
Rhus chinensis	4.20	20	11	9	26.9	0.50
Corylus sieboldiana var. mandshurica	4.20	20	10	10	25.5	0.77
Quercus acutissima	4.20	20	11	9	27.6	0.63
Magnolia kobus	4.20	20	10	10	23.1	0.48
Acer negundo	4.20	20	11	9	26.2	1.26
Populus davidiana	4.20	20	9	11	20.7	0.36
Quercus grosseserrata	4.20	20	9	11	23.4	0.63
Fraxinus mandshurica	4.20	20	11	9	25.1	0.50

* Results of 20 tests for each species by up-and-down sequences of trials. X and O represent the specimen burned for at least 3 minutes after removal of igniter or burned down 50mm and the specimen extinguished before satisfaction with the criterion of 3 minutes or 50mm, respectively.

Alnus hirsuta, 24.6 for *Prunus sargentii*, 26.9 for *Rhus chinensis*, 25.5 for *Corylus sieboldiana var. mandshurica*, 27.6 for *Quercus acutissima*, 23.1 for *Magnolia kobus*, 26.2 for *Acer negundo*, 20.7 for *Populus davidiana*, 23.4 for *Quercus grosseserrata*, and 25.1 for *Fraxinus mandshurica* in hardwoods, respectively. Because highly flammable materials are likely to have a low oxygen index, *Larix gmelinii var. principis-ruprechtii* and *Quercus acutissima* appeared to be ranked first in inflammability but *Pinus strobus* and *Populus davidiana* appeared to be the least in fire resistance by softwood and hardwood.

LITERATURE CITED

1. ASTM. 1977. Standard method for measuring the minimum oxygen concentration to support candle-like combustion of plastics(oxygen index). Stand. Desig. ASTM D 2863-77.
2. Dixon, W. J. and F. J. Massey, Jr. 1969. Introduction to statistical analysis. 3rd ed., McGraw-Hill, New York, 638pp.
3. Fenimore, C. P. and F. J. Martin. 1966a. Candle-type test for flammability of polymers. Mod. Plast. 44(3) : 141-148, 192.
4. Fenimore, C. P. and F. J. Martin. 1966b. Flammability of polymers. Combust. and Flame 10 : 135-139.
5. Hilado, C. J. 1974. Flammability handbook for plastics. 2nd ed., Technomic Publ. Co., Westport, Conn.
6. Isaacs, J. L. 1970. The oxygen index flammability test. J. Fire and Flammability 1(Jan.) : 36-47.
7. Lee, P. W., H. J. Kim, and Y. G. Eom. 1989a. Preliminary studies on combustion properties of lauan solid wood and some wood-based materials by oxygen index method. J. Kor. Wood Sci. and

Tech. 17(4) : 77-82.

8. Lee, P. W., H. J. Kim, and Y. G. Eom. 1989b. Study on combustion properties of some wood-based materials treated with fire-retarding coating by oxygen index method. Agr. Res. of Seoul Nat'l Univ. 14(2) : 205-210.
9. Lee, P. W. and I. J. Chung. 1989. Oxygen index evaluation of wood-based materials. J. Kor. For. Soc. 78(4) : 396-400.
10. Lee, P. W., Y. G. Eom, and H. J. Kim. 1989. Oxygen index of fire-retardant-treated plywood in burning test. J. Kor. For. Soc. 78(4) : 419-423.
11. White, R. H. 1979. Oxygen index evaluation of fire-retardant-treated wood. Wood Sci. 12(2) : 113-121.
12. Tsuchiya, Y. and K. Sumi. 1974. Smoke-producing characteristics of materials. J. Fire and Flammability 5(Jan.) : 64-75.
13. Yoshimura, M. and K. Umemura. 1980. Oxygen index for wood in burning test. I. Determination in Up and Down method. Mokuzai Gakkaishi 26(3) : 209-214.
14. Yoshimura, M. and A. Miwa. 1980. Ibid. II. Determination in JIS K 7201 method. Mokuzai Gakkaishi 26(4) : 287-292.
15. Yoshimura, M. and H. Horii. 1980. Ibid. III. Fire-retarding effect of diammonium phosphate and ammonium sulfamate. Mokuzai Gakkaishi 26(7) : 476-481.