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Effect of Density and Phenolic Resin Loading on the Bending Strength Performance of Woodceramics

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Woodceramics, a new porous carbon material, is composed of wood-originating soft carbon reinforced with hard glassy carbon formed from phenolic resin. For manufacture of woodceramics, medium density fiberboard (MDF) was impregnated with phenolic resin and then sintered in a vacuum furnace at 800 °C. We used different densities of MDF and different concentrations of phenolic resin to make wide range of density of woodceramics. The phenolic resin loading ranged from 30 to 60 %, and the density of woodceramics ranged from 0.55 to 0.95 Mg/m^3.

The effects of density and phenolic resin loading on the Young's modulus and bending strength of woodceramics were investigated. The Young's modulus increased quadratically as the density of woodceramics increased, and increased with increasing phenolic resin-originating carbon content. The bending strength was also improved as the density of woodceramics increased. But the bending strength had little relationship with the phenolic resin-originating carbon content.

Key Words : woodceramics, carbon material, phenolic resin loading, bending Young's modulus, bending strength

1. INTRODUCTION

Many kinds of carbon materials have been developed since early times and have been used for various purposes.

Woodceramics is a new porous carbon material which is made by sintering woody material impregnated with phenolic resin. It is expected to be used for many purposes different from those of wood. The degree of the requirement for mechanical performances of materials depends on the purpose for which materials are used, but it is necessary to improve them in order to make the range of its use increase. There have been some researches in the effects of sintering temperature and phenolic resin loading on its mechanical properties [1, 2, 3].

Woodceramics is a porous material and a kind of composite material which is composed of wood-originating soft carbon reinforced with hard glassy carbon formed from phenolic resin. The mechanical properties of this material can be controlled by changing its density and component ratio of both carbons.

In this study, we made woodceramics with different densities and different contents of carbon from phenolic resin by sintering medium-density fiberboards (MDFs) which had different densities and were impregnated with different concentrations of phenolic resin solution. We investigated the effects of density and phenolic resin-originating carbon content on the bending strength properties of woodceramics.

2. EXPERIMENTAL METHOD

2.1 Specimens

The MDFs which were made with wood fibers of softwood or hardwood and had different densities were used as woody raw materials. Table I shows the properties of MDFs used. The specimens (thickness × 20 mm × 150 mm) which were cut from MDF were impregnated with resol-type phenolic resin under a reduced pressure. The concentrations of the phenolic resin solution were 70.5 %, 49.4 %, and 28.2 %, respectively. The impregnated specimens were dried and hardened in an oven at 60 °C for 10 hours, at 80 °C for 10 hours and then at 130 °C for 20 hours. They were sintered in a vacuum furnace by raising the temperature at a heating rate of 1 °C/min and holding the maximum temperature of 800 °C for 4 hours.

2.2 Bending test

Bending test was conducted on a testing

machine equipped with three point bending system. The span of beam was 90 mm and the load was applied to the beam along the thickness direction. The deflection was measured with a dial gauge.

Table I Properties of MDFs used

	Density (Mg/m^3)	Thickness (mm)
Softwood	0.53	14.2
	0.58	11.4
	0.73	11.6
Hardwood	0.46	14.6
	0.54	14.3
	0.67	14.6

2.3 Phenolic resin loading

The oven-dry masses of unimpregnated specimen (M_0) and impregnated specimen (M_1) were measured. Phenolic resin loading (L) was expressed by the following equation :

$$L = \{(M_1 - M_0) / M_1\} \times 100\ (\%) \qquad (1)$$

2.4 Phenolic resin-originating carbon content

The oven-dry mass of sintered specimen (M_{TC}) was measured and the rate of total carbon residue for the sintered specimen (R_T) was given by the equation (2).

$$R_T = (M_{TC} / M_1) \times 100\ (\%) \qquad (2)$$

Phenolic resin-originating carbon content (C_P) can be calculated by the following equation :

$$C_P = (M_{PC} / M_{TC}) \times 100 = \{ R_P (M_1 - M_0) / R_T M_1\} \times 100\ (\%) \qquad (3)$$

where M_{PC} is the oven-dry mass of phenolic resin-originating carbon, and R_P is the rate of carbon residue of phenolic resin. R_P value was obtained from the regression line between the rate of total carbon residue and the phenolic resin loading (L) as shown in Fig.3.

3. RESULTS AND DISCUSSION

3.1 Phenolic resin loading

Figure 1 shows the relationship between the phenolic resin loading and the density of MDF. The phenolic resin loading of impregnated specimens decreased with increasing density of MDF. The correlation coefficient between them showed a high value for every concentration of resin solution in the softwood and hardwood MDFs. The phenolic resin loading was slightly higher in the softwood MDF than in the hardwood one at the same density. The increased concentration of resin solution caused the reduction in the amount of impregnated solution because of higher viscosity, but gave the higher resin loading after drying.

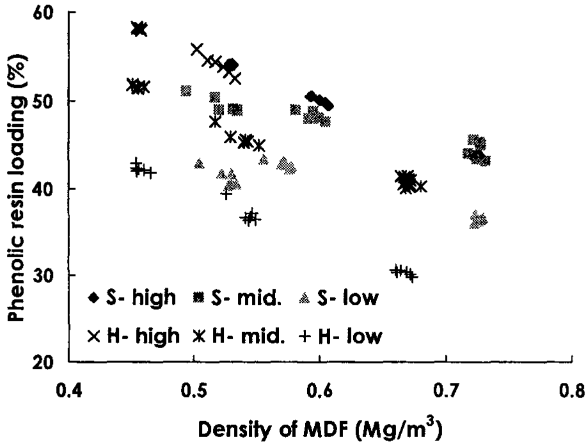

Fig.1 Relationship between phenolic resin loading and density of MDF

Legend : S : Woodceramics made with softwood MDF.
H : Woodceramics made with hardwood MDF.
high, mid., low : 70.5%, 49.4% and 28.2% phenolic resin solutions, respectively.

3.2 Density of woodceramics

Figure 2 shows the relationship between the density of woodceramics and the phenolic resin loading. The density of woodceramics tended to increase with an increase in phenolic resin loading and ranged from 0.55 to 0.95 Mg/m^3.

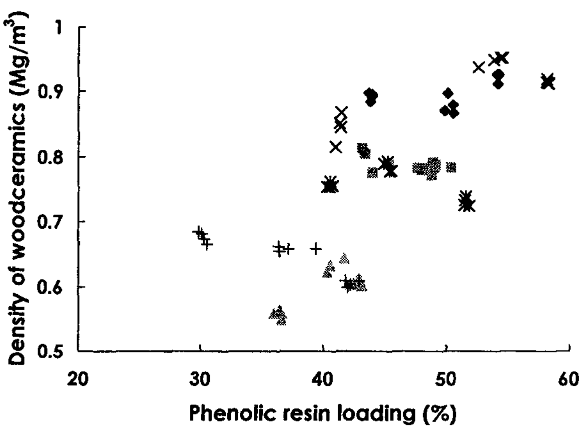

Fig.2 Relationship between density of woodceramics and phenolic resin loading.

Legend : See Fig.1.

However, its density varied widely even at the same phenolic resin loading because the density of woodceramics is affected by the density of impregnated specimen before sintering and the volume change by sintering as well as the rate of carbon residue.

3.3 Phenolic resin-originating carbon content

The relationships between the rate of the total carbon residue of the specimen and the phenolic resin loading were shown in Fig.3 and expressed by the following regression lines :

For softwood MDF,

$$R_T = 0.406\,L + 23.34 \quad r = 0.992,$$

and for hardwood MDF,

$$R_T = 0.410\,L + 24.41 \quad r = 0.993.$$

From these equations, the rates of carbon residue of MDF (R_M) at L = 0% and phenolic resin (R_P) at L = 100% were 23.3 % and 63.9 % for the softwood MDF, 24.4 % and 65.4 % for the hardwood one, respectively. Phenolic resins have very high rates of carbon residue [4], and the rate of carbon residue of woodceramics increased markedly in proportion to phenolic resin loading.

The soft carbon with the framework of porous structure was reinforced with hard glassy carbon from phenolic resin. The phenolic resin-originating carbon content (C_P) were calculated by using the equation (3) and the average R_P value (64.65 %) for softwood and hardwood MDFs.

Figure 4 shows the relationship between the calculated phenolic resin-originating carbon content (C_P) and the phenolic resin loading (L). The phenolic resin-originating carbon content of impregnated specimen ranged from 50 to 80 %.

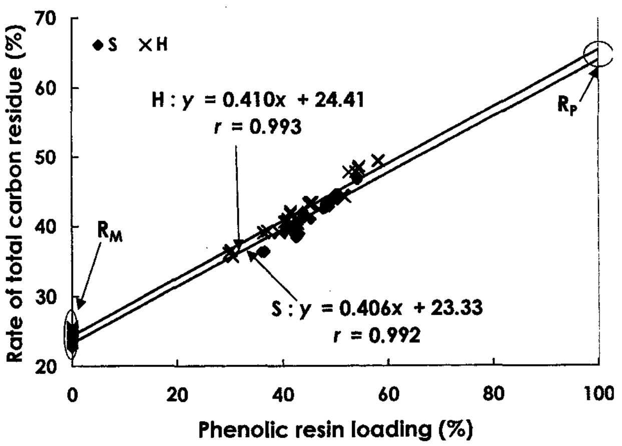

Fig.3 Relationship between rate of total carbon residue and phenolic resin loading.

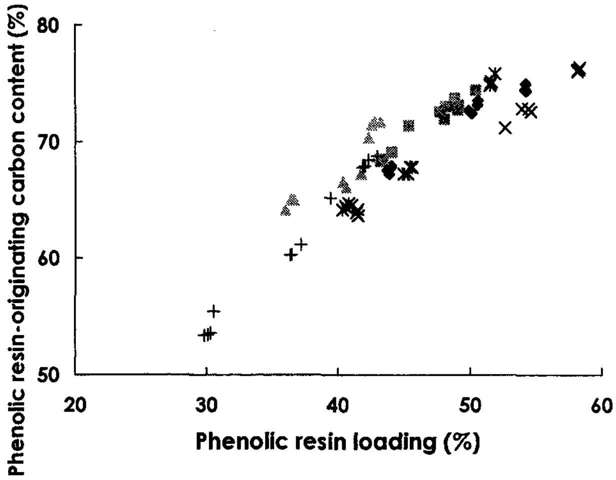

Fig.4 Relationship between phenolic resin-originating carbon content.

Legend : See Fig.1.

3.4 Bending Young's modulus

Figure 5 shows relationship between the bending Young's modulus and the density of woodceramics. The bending Young's modulus ranged from 1.7 to 17.7 GPa and the maximum value was 10.4 times larger than the minimum one. The bending Young's modulus of the woodceramics made with the softwood MDF showed slightly higher values than that with the hardwood one.

In the exponential regression equations between the bending Young's modulus and the density, the fitted values of exponent were 1.60 in the softwood MDF and 1.86 in the hardwood

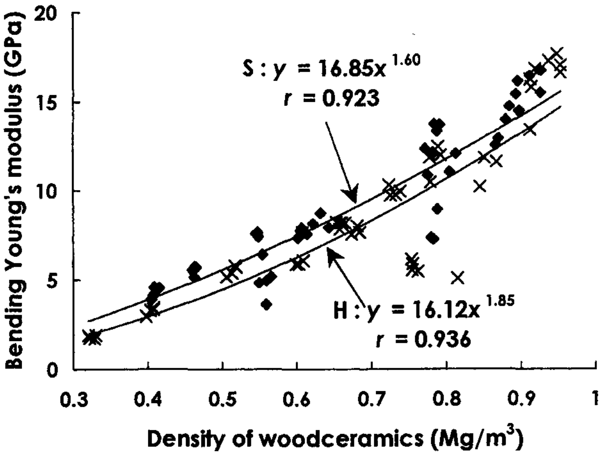

Fig.5 Relationship between bending Young's modulus and density of woodceramics.

Legend : See Fig.3.

one.

Figure 6 shows the relationship between the specific bending Young's modulus and the phenolic resin-originating carbon content. It was found that there was a positive correlation between them. The specific bending Young's modulus ranged from 5.2 to 18.7 GPa and the maximum value was 3.6 times larger than the minimum one. Therefore, the bending Young's modulus of woodceramics is affected by not only its density but also its phenolic resin-originating carbon content.

3.5 Bending strength

Figure 7 shows the relationship between the bending strength and the density of woodceramics. The bending strength increased with increasing density. The bending strength ranged from 4.8 to 36.8 MPa and the maximum value was 7.7 times larger than the minimum one. However, in the exponential regression equations between the bending strength and the density, the fitted values of exponent were smaller than those for bending Young's modulus as shown in Fig.5. It was found there was no correlation between the specific bending strength and the phenolic resin-originating carbon content. This was due to the fact that its bending Young's modulus increased with an increase in phenolic resin-originating carbon content, whereas its breaking strain decreased with it.

The bending strength of the woodceramics made from the softwood MDF had higher values than that from the hardwood one. This may result mainly from that the softwood MDF was composed almost all of long and strong tracheids, while the hardwood MDF was composed of some woody tissues.

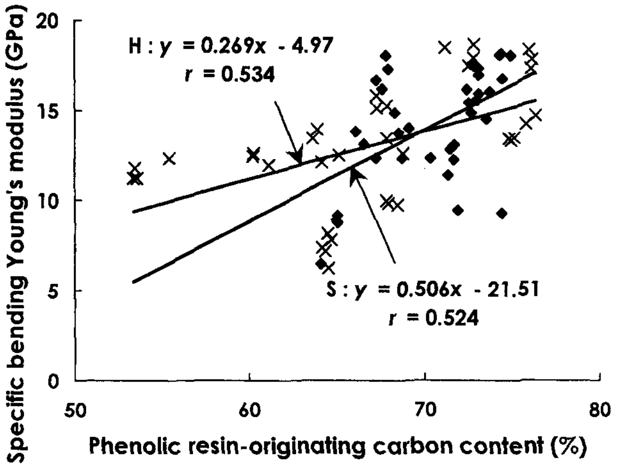

Fig.6 Relationship between specific bending Young's modulus and phenolic resin-originating carbon content.

Legend : See Fig.3.

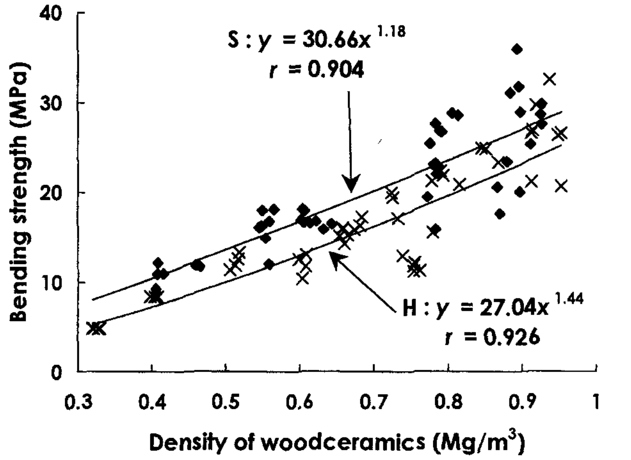

Fig.7 Relationship between bending strength and density of woodceramics.

Legend : See Fig.3.

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