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MECHANICAL PROPERTIES OF WOODCERAMICS MADE WITH SOLID WOOD

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In this study, we investigated the strength properties of woodceramics made with solid wood. Sapwoods of six species were used as raw materials, impregnated with phenolic resin and then burned in a vacuum furnace at 800℃. Bending tests were made on those specimens. Compression tests were made on the specimens prepared from three species (i.e. softwood, diffuse-porous wood and ring-porous wood), in which load was applied along longitudinal, radial and tangential direction. The effect of phenolic resin loading was examined by changing concentration of phenolic resin solution.

Both bending Young's modulus and bending strength of woodceramics were highest for katsura and lowest for oak. These values tended to increase with increasing density, but were varied with species even at the same density level. Compressive strength increased with increasing phenolic resin loading because the increased phenolic resin loading increased the density. The anisotropy of compressive strength decreased with increasing phenolic resin loading.

Key words : woodceramics, phenolic resin loading, bending Young's modulus, bending strength, compressive strength

1. INTRODUCTION

The long axes of most cells in wood are arranged in parallel to the longitudinal direction, and the values of bending Young's modulus and bending strength in this direction are higher than those of MDF which has been mainly used as raw material for woodceramics. But the values in the transverse direction range from one-tenth to one-twentieth of those in the longitudinal direction. This property can be thought to have the possibility to reflect on woodceramics made with solid wood, and it is expected to get woodceramics that have mechanical property different from woodceramics made with MDF. In this study, we aimed at investigating the bending strength properties of woodceramics made with solid wood, and clarifying the anisotropy of their compressive strength.

2. EXPERIMENTAL METHOD

2.1. Bending test

2.1.1.Specimen

Softwood (Japanese cedar and Japanese cypress) and hardwood (Japanese beech, katsura, Japanese oak and lauan) were used as woody raw material. The sapwood of these species was used so that large amount of phenolic resin might be impregnated into the specimen. The density of these species is shown in Table I . Specimen was 110mm (longitudinal direction) × 10mm (radial direction) × 10mm (tangential direction). The specimens were impregnated with resol-type phenolic resin under a reduced pressure. The concentration of the phenolic resin solution was 70.5%. After the impregnated specimens were dried hardened in an oven, they burned 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.

Table I Density of solid wood

Species	Density (Mg/m^3)
Cedar	0.365
Cypress	0.397
Beech	0.544
Katsura	0.411
Oak	0.574
Lauan	0.343

2.1.2. Bending test method

Bending test was conducted on a testing machine equipped with three point bending system. The span of beam was 90mm, and applied to beam along the tangential direction. The deflection was measured with the dial gauge. The bending Young's modulus and the bending strength were obtained from the load-deflection curve.

2.2. Compressive test

2.2.1. Specimen

Sapwoods of cedar, beech and oak were used as woody materials. The density of these species was the same as that of the specimen for bending test. We prepared specimens for compressive test of longitudinal, radial and tangential direction. The specimen size was 20mm(loading direction) × 10mm × 10mm. These specimens were impregnated with three concentrations (28.2%, 49.4% and 70.5%) of phenolic resin solution. Burning condition was the same as that of bending test. The untreated specimen and impregnated one that was not burned were prepared as comparative objects.

2.2.2.Compressive test method

A universal testing machine was used for compressive test. Load was applied in the longitudinal, radial and tangential directions. The compressive strength was obtained from the maximum load on the load-deflection curve.

3. RESULTS AND DISCUSSION

3.1 Phenolic resin loading

Figure 1 shows the relationship between the phenolic resin loading and the density of solid wood in bending test specimen. The phenolic resin loading decreased with increasing density of wood. However, the phenolic resin loadings in lauan and oak showed lower values than those in other species with almost the same density. And they increased with increasing concentration of resin solution in cedar and beech, but hardly depended on it in oak.

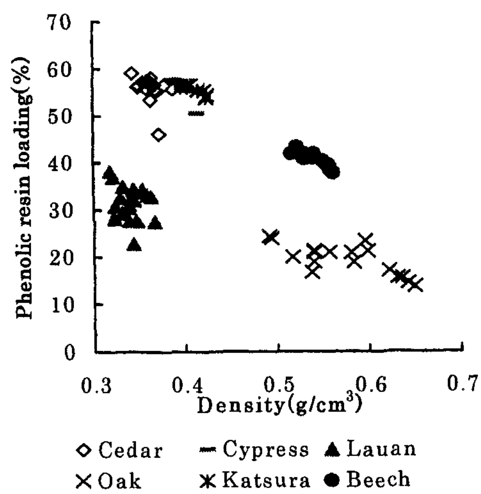

Fig.1 Relationship between phenolic resin loading and density of solid wood.

3.2. Bending Young's modulus and bending strength

Figure 2 shows the relationship between bending Young's modulus and the density of the woodceramics. The bending Young's modulus was highest in katsura (14.4GPa) and lowest in oak (1.83GPa). Bending Young's modulus tended to increase with increasing density, but there was a marked difference in it between katsura and cypress having almost the same densities. The specific bending Young's modulus increased with an increase in phenolic resin loading. Figure 3 shows the relationship between the bending strength and the density of woodceramics. The bending strength depended more strongly on the kinds of species than the bending Young's modulus. As for bending strength, it had highest value

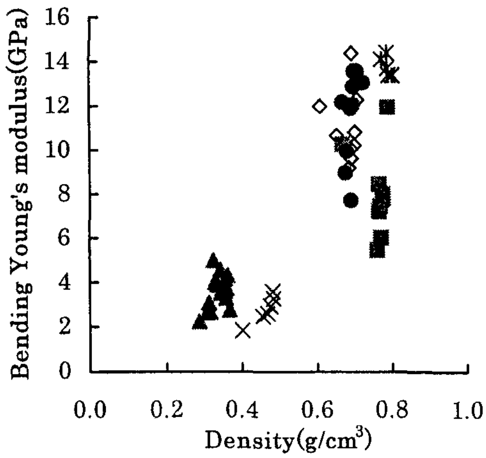

Fig.2 Relationship between bending Young's modulus and density of woodceramics.
Legend: See Fig1.

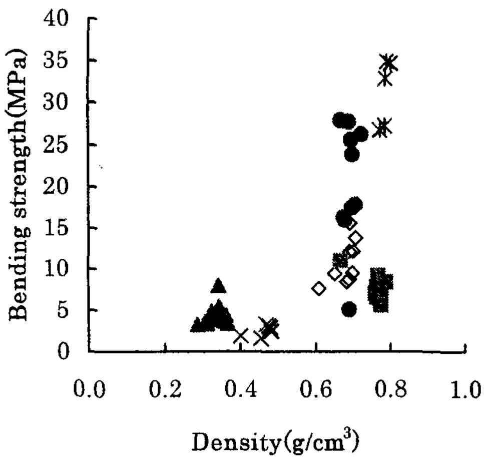

Fig.3 Relationship between bending strength and density of woodceramics.
Legend : See Fig.1.

(34.9MPa) in katsura, and lowest one (1.58MPa) in oak. The bending strength of softwood showed low value for its density. Cracks were observed in cedar, cypress, oak and lauan with a scanning electron microscope. It was thought that these cracks were connected with lowering strength. They may be ascribed to from the ununiform shrinking during the burning process because of ununiform resin impregnation into wood tissues. The structure composed of different tissues was apt to make resin be impregnated into wood ununiformly. When woodceramics is made with solid wood, it is needed to consider not only the resin loading, but also the uniform resin impregnation. The values of bending Young's modulus and bending strength for woodceramics made with katsura and beech were higher than those (10GPa and 17MPa) for woodceramics made with MDF and having a density of 0.7g/cm^3[1].

3.3. Compressive strength

Table II shows the relationship between phenolic resin loading and the concentration of impregnated phenolic resin solution in compression test specimen. The phenolic resin loading in cedar and beech increased with increasing concentration of phenolic resin solution, but that in oak was hardly varied with the concentration of phenolic resin solution.

Table II Phenolic resin loading in compression test specimen.

	Phenolic resin loading (%)		
Species	40%	50%	70%
Cedar	47.62	53.50	61.42
	~52.45	~58.49	~66.49
Beech	27.03	37.37	39.61
	~37.50	~44.33	~50.47
Oak	22.52	25.52	26.11
	~31,91	~35.06	~38.82

Note : 40%, 50%, 70% are concentrations of phenolic resin solution.

Figures 4 and 5 show the relationships between the compressive strengths in the longitudinal and radial directions and the density of woodceramics. The compressive strength in all directions of beech increased with increasing density. The compressive strengths in all directions of beech were the highest of three species. Those maximum values were 125MPa in the longitudinal direction, 48.0MPa in the radial direction and 28.0MPa in the tangential direction. Okabe et al. reported that the compressive strength in the longitudinal direction of woodceramics made with beech was much higher than that in the radial and in the tangential directions.

The anisotropy of compressive strength for solid wood reflected on that of woodceramics, but its anisotropy of woodceramics was lower than that for solid wood. Figure 6 shows the relationship between the anisotropy of compressive strength for woodceramics and the concentration of impregnated resin solution. It is found that the anisotropy of L/T and L/R decreases with an increase in the concentration of impregnated resin solution. The result shows that the reinforcing effect of carbonization residure formed from phenolic resin on the compressive strength of woodceramics is greater in transverse direction than in the longitudinal direction. This can be attributed to the reason that since the compressive force is applied perpendicular to fiber axis (radial and tangential direction), cells are crushed, and the bending deformation and fracture of cells are suppressed by impregnating cell walls and lumina with resin.

On the other hand, the anisotropy of R/T in the transverse direction of woodceramics was hardly affected by the concentration of impregnated resin solution. Moreover, the anisotropies of L/T and L/R for woodceramics (resin solution : 70%) showed values nearly equal to those for the impregnated and unburned specimen. This suggests that the anisotropy of compressive strength for the impregnated and unburned wood is reflected on that for woodceramics.

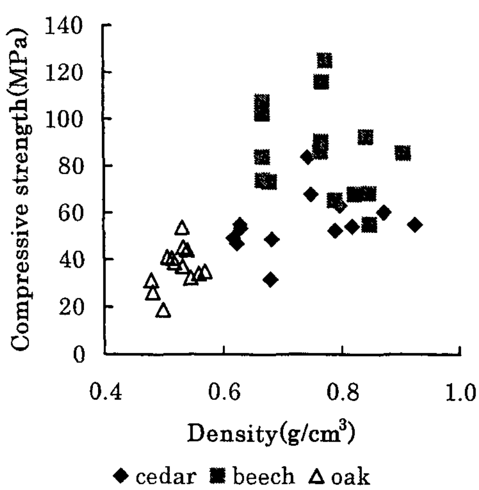

Fig.4 Relationship between compressive strength in longitudinal direction and density of woodceramics.

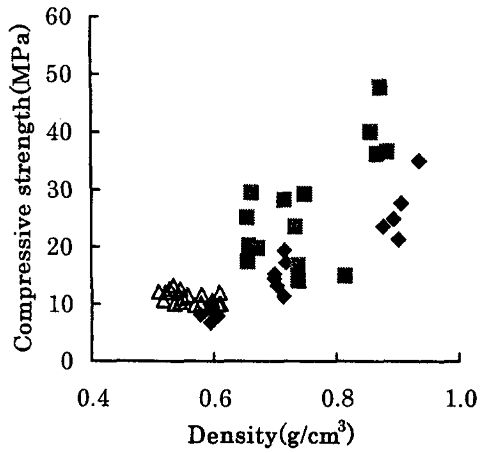

Fig.5 Relationship between compressive strength in radial direction and density of woodceramics.

Legend: See Fig.4.

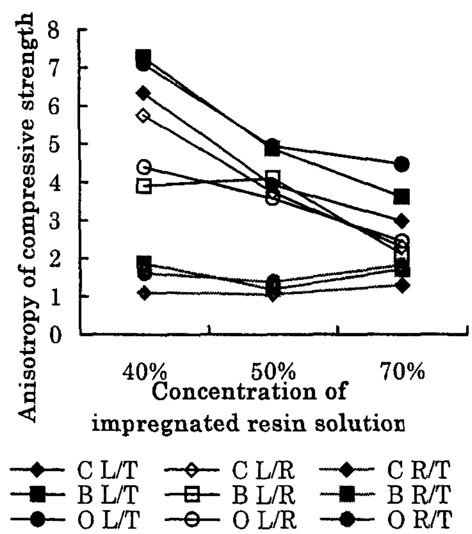

Fig.6 Relationships between anisotropy of compressive strength and concentration of impregnated resin solution.

Legend: C: Cedar, B: Beech, O: Oak

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