

Bending Strength Properties and Hardness of Woodceramics

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This paper describes the effects of burning temperature and phenolic resin loading on the bending strength properties and hardness of Woodceramics in the burning temperature range of 300°C to 2500°C. MDF (medium-density fiberboard) was used as woody raw material.

The bending Young's modulus, bending strength and Brinell hardness of Woodceramics increased remarkably with increasing burning temperature between 500°C and 800°C, and they had maximum values at about 1500°C. This marked increase in strength properties can be explained in terms of rising density and improvement in crystallinity. The strength properties, especially Brinell hardness were greatly improved by phenolic resin loading.

1. INTRODUCTION

When substance is used as material, various kinds of external force generally exert on it. The degree of the requirement for mechanical performances of materials depends on the purpose for which materials are used, but their mechanical properties are important as basic properties. Therefore, it is necessary to clarify the mechanical properties of Woodceramics, and to improve them in order to make the range of its use increase.

Woodceramics is a porous carbon 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 the component ratio of both carbons.

In this study, we investigated the effects of burning temperature and phenolic resin loading on the bending strength properties and the hardness of Woodceramics made by using medium-density

fiberboard as woody raw material.

2. EXPERIMENTAL METHOD

2.1. Specimens

MDF which was a homogeneous material and had medium density (0.66Mg/m^3) was used as woody raw material. The MDF (12mm × 20mm × 100mm) was impregnated with resol-type phenolic resin by using an ultrasonic impregnation system. The phenolic resin loading was varied by impregnating different concentrations of phenolic resin solution. The impregnated specimens were dried and hardened in an oven at 135°C. And then they were burned in a vacuum furnace at the burning temperature from 300°C to 800°C. In addition, after some specimens were burned at 800°C, they were burned in a high-frequency induction furnace at 1500°C, 2000°C and 2500°C.

2.2. Bending and hardness tests

Bending test was conducted on an Instron

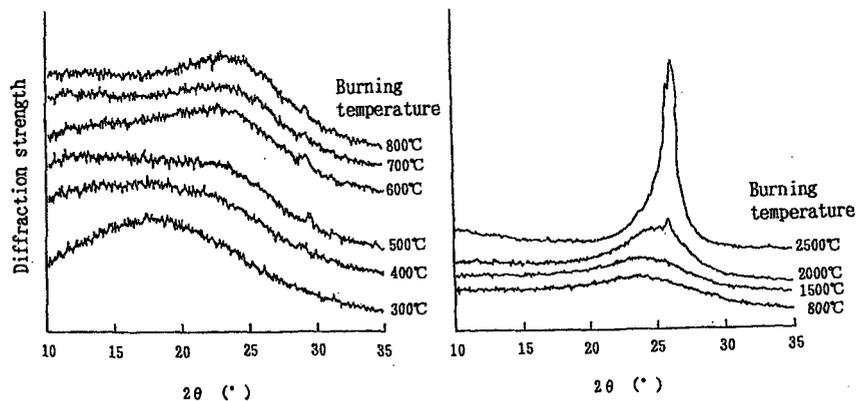


Figure 1. X-ray diffraction pattern (phenolic resin loading: 68.9%).

testing machine equipped with three point bending system. The span of beam was 50mm. The load was applied to the beam along the thickness direction. The deflection was measured with a dial gauge.

Brinell hardness was measured. The steel ball of 10mm was indented into the test face along the thickness direction. The depth of steel ball indented in was 0.20mm.

2.3. X-ray diffraction measurement

In order to examine the change in crystallinity of Woodceramics by burning, X-ray diffraction pattern of powder sample taken from bending test specimen was measured with a rotary-target type X-ray diffraction apparatus.

3. RESULTS AND DISCUSSION

3.1. Changes in crystallinity and density by burning

Figure 1 shows X-ray diffraction patterns of Woodceramics(phenolic resin loading 68.9%) made at different burning temperatures.

With increasing burning temperature, the diffraction strength near 25° increased and its peak shifted to a high angle range. This fact shows that crystallization progressed as the burning temperature was elevated. Above 2000°C, sharp peak appeared in a little higher range than the

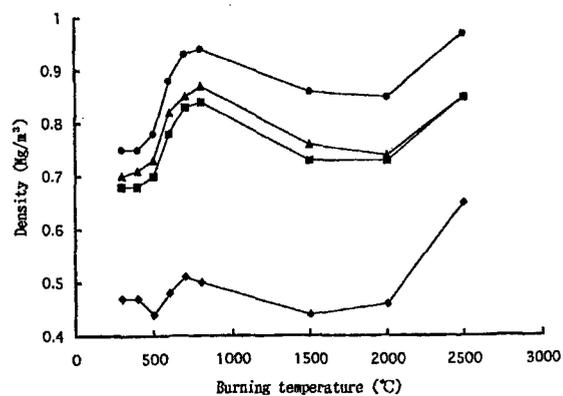


Figure 2. Relationships between burning temperature and density.

Legend: Phenolic resin loading:
 ◆ 0%, ■ 53.9%,
 ▲ 56.9%, ● 68.9%.

broad peak and grew remarkably at 2500°C. It was observed that the peaks at 2000°C and 2500°C grew more remarkably in 0% resin loading than in 68.9% resin loading. The behavior of 0% resin loading in high burning temperature was in good agreement with that of charcoal. This is called multi-phase graphitization, and the composite profile of (002) diffraction line consists of three component profiles: one broad peak and two sharp peaks with different interplanar spacings. In high temperature, the component with broad peak (small crystal size) may change abruptly into two components with sharp peaks (large crystal size)

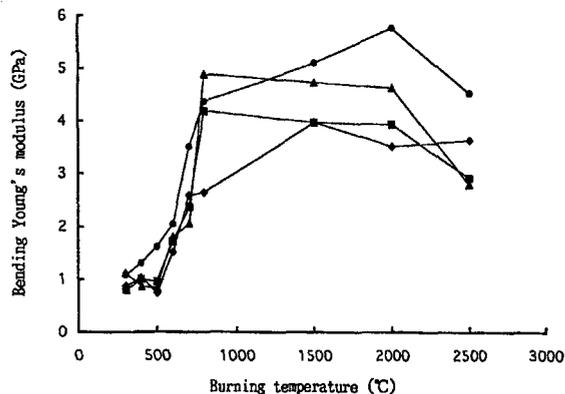


Figure 3. Relationships between burning temperature and bending Young's modulus.
Legend: See Figure 2.

[1]. The phenomenon that sharp peak of 68.9% resin loading grew less can be explained by the reason that the component with broad peak of glassy carbon formed from phenolic resin is difficult to change into components with sharp peak.

Figure 2 shows the relationships between burning temperature and density of Woodceramics. For every resin loading, density hardly changed between 300°C and 500°C and increased markedly between 500°C and 700°C. It decreased between 800°C and 2000°C and increased again between 2000°C and 2500°C. The marked increase in density above 2000°C would be due to the change in crystal structure. For every burning temperature, density increased remarkably with an increase in phenolic resin loading.

3.2. Change in bending strength properties by burning

Figure 3 shows the relationships between burning temperature and bending Young's modulus of Woodceramics. The bending Young's modulus for 0% resin loading remained almost unchanged between 300°C and 500°C, but increased remarkably with increasing burning temperature above 500°C. And then it had maximum value at about 1500°C. It was found that any specimens

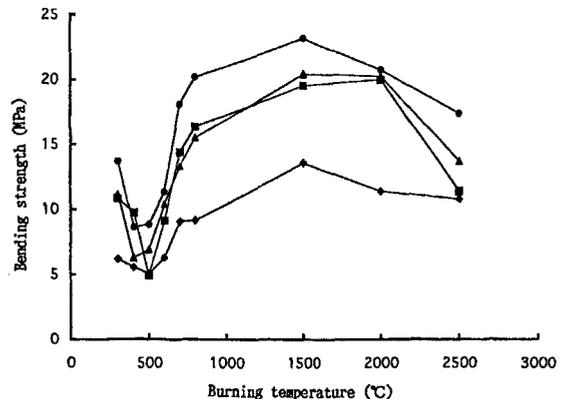


Figure 4. Relationships between burning temperature and bending strength.
Legend: See Figure 2.

impregnated with resin also had almost similar change patterns of bending Young's modulus.

Figure 4 shows the relationships between burning temperature and bending strength of Woodceramics. The burned specimens showed almost similar change patterns of bending strength regardless of resin loading. The bending strength decreased considerably between 300°C and 500°C, but increased remarkably between 500°C and 800°C. Furthermore, they increased considerably between 800°C and 1500°C, and had maximum values at about 1500°C.

These change patterns of bending Young's modulus and bending strength with increasing burning temperature agreed with those reported by Okabe *et al.* [2]. The bending Young's modulus kept almost constant between 300°C and 500°C, and increased remarkably between 500°C and 800°C. This behavior would be due to the fact that the main components of wood and phenolic resin are subjected to thermal decomposition mainly between 300°C and 400°C, and at the same time the condensation aromatic polynuclear structure starts to form and develops above 500°C [3, 4]. Between 300°C and 800°C, its change was parallel to the changes in density and crystallinity.

On the other hand, the bending strength

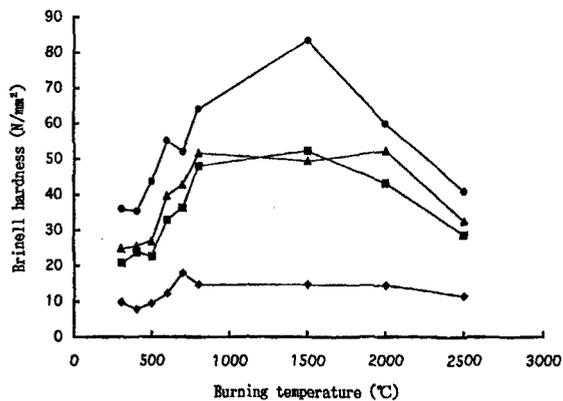


Figure 5. Relationships between burning temperature and Brinell hardness.

Legend: See Figure 2.

decreased between 300 °C and 500 °C probably because the bending strength was more sensitive to local defects caused by the thermal decomposition than bending Young's modulus. Between 500 °C and 800 °C, the bending strength showed behavior similar to that of the bending Young's modulus.

Between 800 °C and 2500 °C, the bending Young's modulus and the bending strength were not always related to those in density and crystallinity. In spite of decrease in density, they increase or remained almost unchanged between 800 °C and 2000 °C. The density and crystallinity were markedly improved between 2000 °C and 2500 °C, but the bending strength and bending Young's modulus decreased probably because residual strain and crack were caused by change in internal structure accompanied with crystallization.

Next, let us discuss about the effect of resin loading on the bending Young's modulus and the bending strength at 800 °C, 1500 °C and 2000 °C. The bending strengths for 68.9% resin loading were 1.7, 1.3 and 1.6 times those for 0% resin loading respectively and reached the maximum value of 5.8GPa. The bending strengths for 68.9% resin loading were 2.2, 1.7 and 1.8 times those for 0% resin loading respectively and reached the maximum value of 23MPa.

The change pattern of specific bending Young's modulus with burning temperature had tendency similar to what that of bending Young's modulus had. There was little difference in specific bending Young's modulus among the specimens impregnated with resin. The specific bending strength also had change pattern similar to that of the bending strength and the specific bending strength were greatly affected by burning temperature, but hardly affected by resin loading.

3.3. Change in Brinell hardness by burning

Figure 5 shows the relationships between burning temperature and Brinell hardness of Woodceramics. The Brinell hardness generally tended to show almost constant value between 300 °C and 500 °C, and to increase remarkably between 500 °C and 800 °C. And then it remained almost unchanged between 800 °C and 2000 °C and decreased between 2000 °C and 2500 °C. However, its increase for 0% resin loading was small between 500 °C and 800 °C. The Brinell hardness became strikingly larger as the resin loading increased. The hardness for 68.9% resin loading was 4.4, 5.8 and 4.2 times that for 0% resin loading at 800 °C, 1500 °C and 2000 °C respectively. This can be attributed to the reason that since in the hardness measurement the force is applied to wood fiber in the direction perpendicular to the fiber axis, cells are crushed and cell walls are subjected to bending deformation, and the bending deformation and fracture of cells are suppressed by impregnating cell walls and lumina with resin.

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