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Characteristics of Compressed Wood and its Application

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The mechanical properties of compressed wood with various densities are investigated through tensile, abrasion and friction tests, and the possibility of manufacturing a highly-hardened compressed charcoal is explored. The tensile test results show that the Young's modulus increases with increase in the compression ratio, while the tensile strength decreases with higher compression ratios. As the compression ratio increases, the abrasive wear resistance improves and the coefficient of friction decreases. In addition to the mechanical properties, it is shown that a compressed charcoal with superior hardness and flammability characteristics can be manufactured by intentionally controlling the compression volume.
Key words: compressed wood, tensile, abrasion, friction, charcoal

1. INTRODUCTION

Compressed wood is a material that is formed by compressing wood at a high temperature in order to achieve both higher strength and hardness. The compression process produces a high-density material that has a strength comparable to lightweight metals, such as aluminum. Compressed wood is also a durable renewable natural resource. A number of recent studies on this material have improved the dimensional stability after compression and discovered the mechanism of permanent deformation [1-3]. This advanced research has enhanced the practicality of using compressed wood as a structural and floor material, however, few studies have focused on the mechanical and surface properties of the material [4-5]. As a result, compressed wood cannot be effectively considered during the design process. This paper investigates the mechanical properties of compressed wood with various densities using tensile, abrasion and friction tests. The possibility of manufacturing highly-hardened compressed charcoal is also considered.

2. MATERIAL AND METHODS

Sugi wood (Japanese cedar wood: *Cryptomeria japonica* D. Don) with a heartwood density of 0.35 g/cm^3 was used in this experiment. The sample specimens were compressed in both the radial and tangential directions, relative to the annual rings, by a hot-press and roller-press apparatus that controlled the compression temperature. The sugi wood compression ratio ranged from CR = 10% to 77% when the compression temperature was fixed at T_1=180℃.

Tensile test specimens with various initial thicknesses were compressed to a final radial thickness of 15 mm. Therefore, the tensile tests were conducted using wood specimens with the same dimensions. An Instron testing machine tensed the specimens in the longitudinal direction at a nominal strain speed of $5.5\times10^{-4}s^{-1}$.

The abrasion test specimens were fabricated to have a 4 mm x 3 mm abraded surface in the axial section. These specimens were produced from various densities of compressed wood. The abrasion properties of the wood were investigated by rubbing the specimen against an abrasive paper with a fixed abrasive grain. During this test, the #400 abrasive paper, with a mean grain size of 40 μ m, was mounted on the movable table and a vertical pressure was applied to the test specimen. The specimen was rubbed unidirectionally over a distance of 100 mm. Two different surface pressures were applied to the wood specimens: 0.04 MPa and 0.12 MPa.

The friction test specimens were fabricated by compressing sugi wood with a variety of initial thicknesses and finishing the specimen with #180 abrasive paper. During the friction test, a test specimen was mounted on the movable table. A 10-mm diameter steel ball was rubbed in a reciprocating manner at a friction speed of 20 mm/s while a 0.04 MPa surface pressure was applied from the top.

Carbonized wood specimens were produced by compressing sugi wood, having an initial thickness of 20 mm, in the radial direction. The compressed wood specimen was then carbonized by a large-capacity type thermo balance apparatus (TG-7000HVT) . Next, the performance of the compressed charcoal was evaluated using hardness and combustion tests relative to the amount of solid fuel material. The hardness test utilized a durometer hardness tester, which determines hardness from the indented depth of a stylus [6]. An adiabatic calorimeter was used to measure the flammability of the specimens. These tests were conducted by sealing the charcoal specimen in a container filled with oxygen at a pressure of 30 kgf/cm^2. The quality of the compressed charcoal was evaluated by comparing the results from the hardness and combustion tests with those of ubamegashi wood, also known as Bincho-charcoal, that is know to exhibit superior quality characteristics.

3. RESULTS AND DISCUSSION

3.1 Mechanical properties of compressed wood

Figure 1 shows the relationship between the Young's modulus E, obtained from the tensile test stress-strain curve, and the compression ratio CR. The average value of E increases exponentially with increase in CR. This suggests that the stiffness of the compressed wood grows with increases in the compression volume.

Figure 2 shows the relationship between the tensile strength σ_t, obtained from the stress-strain curve, and the compression ratio CR. The tensile strength of the compressed wood is almost same as that of uncompressed sugi wood until CR = 30%. After this point, σ_t increases to approximately double the uncompressed value between CR = 50% and 70%. An analysis of these two figures reveals that the tensile strength decreases with much larger compression ratios, while the Young's modulus increases exponentially.

Figure 3 displays the compressed wood relationship between the wear resistance WR and the compression

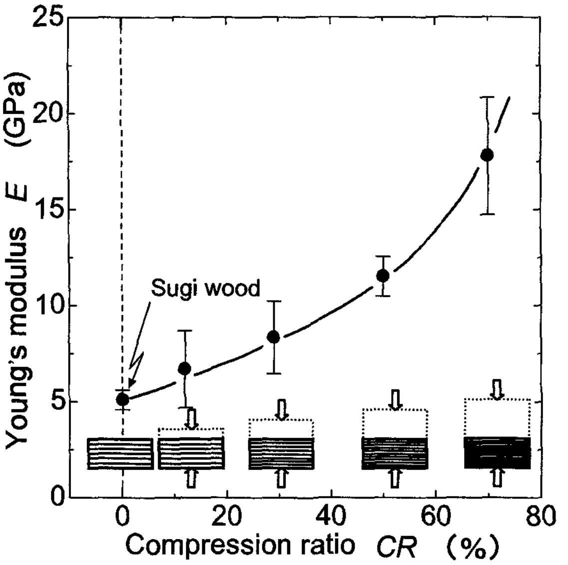

Fig.1. Relationship between the Young's modulus E and the compression ratio CR.

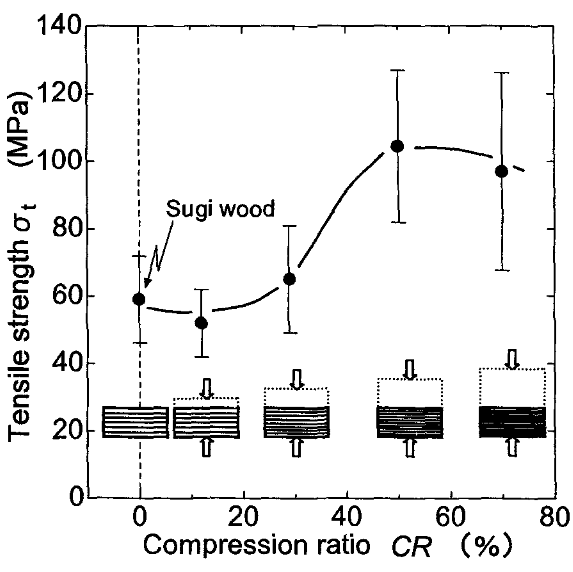

Fig.2. Relationship between the failure stress σ_f and the compression ratio CR.

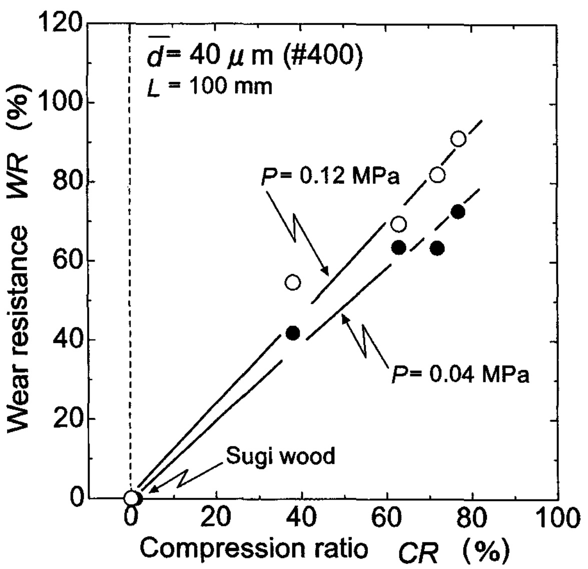

Fig.3. Relationship between the wear resistance *WR* and the compression ratio *CR*.

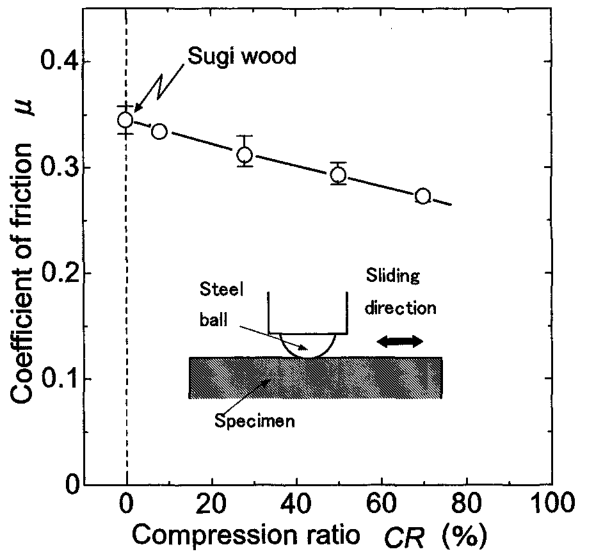

Fig.4. Relationship between the coefficient of friction μ and the compression ratio *CR*.

ratio *CR* at various densities. The wear resistance was calculated as the difference in the wear rate between the compressed wood and the uncompressed sugi wood, divided by the value for uncompressed sugi wood. The value of *WR* was calculated according to the following equation [7] :

$$WR = \left(\frac{\dot{W}CR = 0\% - \dot{W}CR = X\%}{\dot{W}CR = 0\%}\right) \times 100 \qquad (\%)$$

This figure reveals that *WR* increases linearly with *CR* on both applied surface pressure P of 0.04 and 0.12 MPa.

A comparison of the results of Fig. 3 with those from Fig. 2 indicates that the wear resistance increases linearly while the material's tensile strength increases exponentially with the compression ratio until *CR* surpasses 50%. This suggests that both wear resistance and tensile strength are dependent upon the compression volume, although to different degrees. In fact, wear resistance under lower compression ratios is higher than the strength of the compressed wood.

Figure 4 shows the relationship between the coefficient of friction μ and the compression ratio *CR* for different compressed wood densities. The parallel and perpendicular forces F_p and F_n were measured five times during the friction test, and the apparent coefficient of friction μ was calculated as the average value of $\mu = F_p/F_n$. The figure shows that μ decreases linearly with increases in *CR*. These results as shown in Figs.3-4 indicate that the wear resistance improves and the compressed wood surface becomes smoother with larger compression volumes.

3.2 Invention of high-hardness compressed charcoal

The hardness of the charcoal that was fabricated from the compressed wood was measured, and the resulting relationship between the durometer hardness *HDD* and the density ρ for the charcoal specimen is shown in Figure 5. At *CR* = 50%, the *HDD* value is larger for the compressed wood, and the hardness is ten times higher than the value for uncompressed sugi wood. This larger *HDD* value is very close to that of the ubamegashi wood.

Figure 6 shows the flammability results for the compressed charcoal combustion test. The white dot in this figure represents the maximum calorific value Q_{max}/t during combustion, and the black dot represents the time T_{Qmax} needed to reach this maximum calorific value. Compressed charcoals with smaller densities result in larger changes in the calorific value of Q_{max}/t, while higher density specimens produce smaller changes. In addition, smaller density specimens require shorter amounts of time to reach the maximum calorific value T_{Qmax}, and higher density specimens require a longer period of time. These results indicate that high-hardened charcoal fabricated from compressed wood can be

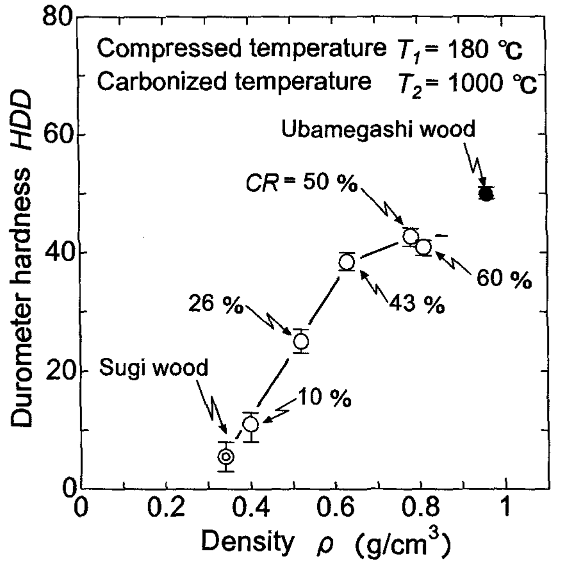

Fig.5. Relationship between the durometer hardness *HDD* and the density ρ.

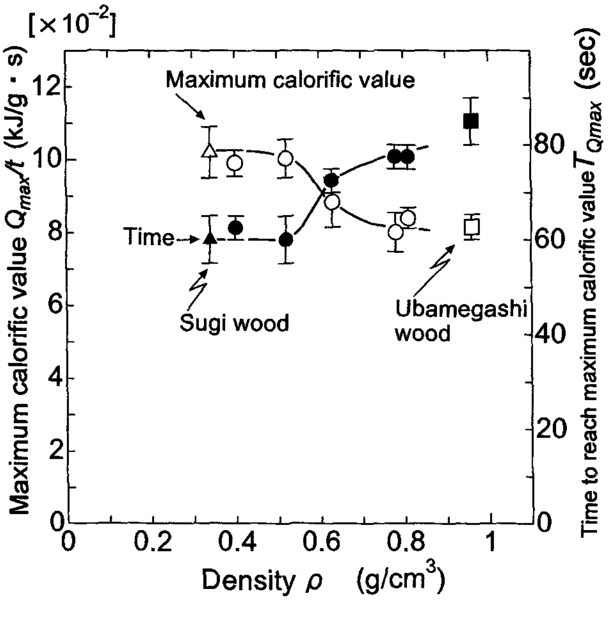

Fig.6. Relationship between the maximum calorific value Q_{max}/t and the time to reach maximum calorific value T_{Qmax} relative to the density ρ of the compressed charcoal.

manipulated to produce a smaller calorific value while combusting for an extended period of time, as is the case for ubamegashi charcoal. It might also be possible to optimize the compressed charcoal's hardness and flammability during the manufacturing process by intentionally controlling the compression volume.

4. CONCLUSION

The mechanical properties of compressed sugi wood with various densities were investigated through tensile, abrasion and friction tests. The possibility of manufacturing highly-hardened compressed charcoal was also explored. The results are summarized below.

(1) The tensile tests revealed that the Young's modulus for the compressed wood increases with increase in the compression volume, while the tensile strength decreases with higher compression ratios.

(2) As the compression ratio increased, the abrasive wear resistance improved and the coefficient of friction decreased. The wear resistance at lower compression ratios was higher than the strength of the compressed wood.

(3) A charcoal with superior hardness and flammability characteristics can be manufactured from compressed wood by intentionally controlling the compression volume.

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