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MECHANICAL RELIABILITY OF WOODCERAMICS BAKED FROM MEDIUM DENSITY FIBERBOARD OF *PINUS RADIATA*

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In order to assess the mechanical reliability of woodceramics which were baked from medium density fiber board (MDF) of *pinus radiata*, the crushing strength was determined by compression test and the data are statistically analyzed by the conventional method based on Weibull distribution. Two types of materials are tested: one is baked from MDF fabricated by conventional method (WC/TRI) and the other is baked from MDF prepared by a special process (WC/MONO). In the former the packing density of fibers is not uniform in the thickness direction, while in the latter it is considerably uniform. Anisotropy of crushing strength is found for both materials. It is also found that woodceramics have the Weibull modulus (m) between 5 and 8, showing more reliable than so-called old ceramics (typically, $m < 5$) but less reliable than the engineering ceramics (typically, m=10-20).

1. Introduction

Recently, porous materials are watched with keenest interest because of their high specific strength based on the cell structure. Aluminum honeycomb is a typical example of artificial porous materials[1]. Charcoal is another example of familiar porous material which has been used as solid fuel and absorbent. However, mechanical properties of charcoal as structual materials has never been evaluated.

WOODCERAMICS are wood based porous carbon materials which were developed by Okabe and Saito in 1990. Woodceramics has excellent thermal resistance, corrosion resistance, oxidation resistance, antifriction and mechanical properties in addition to good shielding effect of electromagnetic wave and radiating far infrared rays in the current on. Woodceramics are not expensive because they are based on wood[2),3),4)]. Pyrolignous acid extracted in producing it becomes good soil improvement agent and moth-proofing agent. Woodceramics as absorbant is harmless to the environment even in dumping it after use as waste, and hence being eco-materials.

Woodceramics produced from natural timber have such drawbacks as pronounced mechanical anisotropy and low accuracy in dimension after baking which are common to charcoal[5)]. On the other hand, woodceramics can be made by baking the medium density fiberboad (MDF) . This type of woodceramics are superior to those based on natural wood not only in dimension accuracy after baking but also in the wideness of processing condition. MDF based woodceramics have almost no in-plane anisotropy in contrast to timber based woodceramics, the mechanical properties of which are strongly depend on the loading directions, i.e., axial, radial and tangential directions[1),5)].

Woodceramics are produced as follows. Raw materials such as dryed timber or MDF are impregnated with phenolic resin in pressure reduction. After the hardening in dry air atmosphere, phenol impregnated materials are baked within the vacuum oven. During this process, phenolic resin

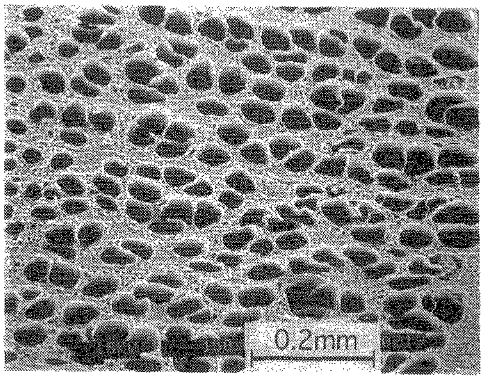

Fig.1 SEM micrograph of charcoal prepared from *beech wood*
(Plane normal to the axial direction)

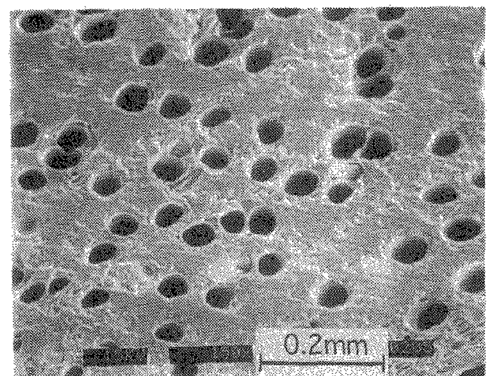

Fig.2 SEM micrograph of woodceramics prepared from *beech wood*
(Plane normal to the axial direction)

turns into hard and glassy carbon resulting in the reinforcement of soft and amorphous graphite which is a main component of charcoal. Thus charcoal is effectively strengthened by hard carbon[2]. The structural change described above is obvious in SEM micrographs for charcoal and woodceramics of timber (See Fig.1 and Fig.2).

The process conditions of woodceramics have widely been examined. The mechanical response of woodceramics has also been studied with various methods such as compression test, bending test and hardness test. In this study, the crushing strength of woodceramics based on two types of MDF is determined by compression test. Taking the highly porous microstructure of woodceramics into consideration, the information on their mechanical reliability are inevitable in exploiting the porous materials[6]. The experimental data are statistically analyzed by the conventional method based on Weibull distribution in order to evaluate the reliability.

2. Experimental Method

Two types of woodceramic specimens were prepared; one is baked from conventional MDF of *pinus radiata* consisting of three layers (hereafter refered to as WC/TRI), and the other is baked from MDF especially processed so as to have a uniform fiber distribution (hereafter refered to as WC/MONO). The volume fraction of phenolic resin in WC/TRI and WC/MONO are 64% and 75%, respectively. The burning temperature is 1073K for both. Cubic specimens with side length of 10mm and 8mm were machined out of baked plate of WC/TRI and WC/MONO, respectively, and polished with emery papers prior to compressive test.

The compressive test were carried out on an Instron type testing machine at room temperature. The cross head speed was 0.5mm/min. The load was applied along laminating direction or fiber-stand direction. The total number of tests was fifty for each specimen.

3. Results and Discussion

Figures 3 and 4 show, respectively, the compressive strength and the specific strength in the direction parallel and perpendicular to the baked plate. The data on WC/TRI and WC/MONO are given in the left and right hand side, respectively. We can see that the data are scattering considerably for each specimen, the extent of which will be analyzed later. The mean values of strength data are denoted by the open circles.

The in plane and out of plane compressive strength for specimen WC/TRI are, respectively, 43MPa and 103MPa, which are much higher than

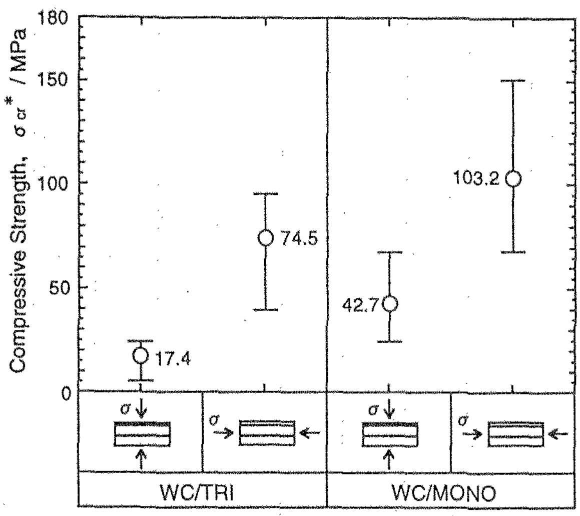

Fig.3 Effect of loading direction on the compressive strength of WC/TRI and WC/MONO

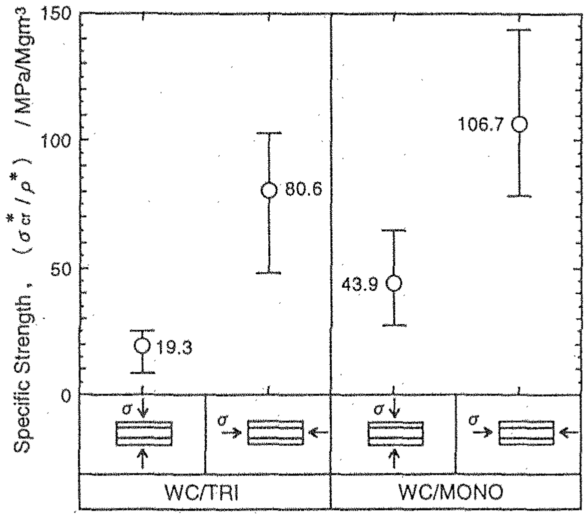

Fig.4 Effect of loading direction on the specific strength of WC/TRI and WC/MONO

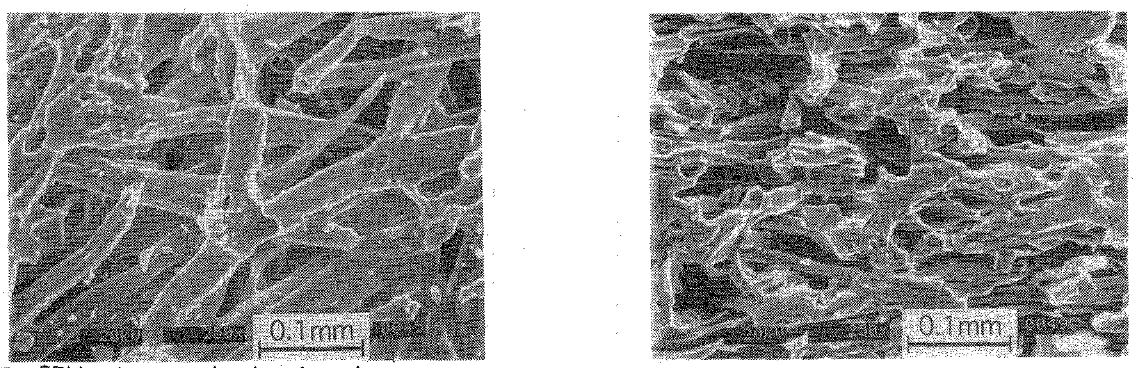

Fig.5 SEM micrograph showing the structure of WC/MONO

a) Top surface

b) Side surface

those for WC/MONO (17MPa and 75MPa, respectively). The difference can be explained partially by the fact that the rate of impregnation of phenolic resin into the specimen WC/MONO is higher than that in WC/TRI. It should be noted that the anisotropy of strength is weaker in the WC/MONO than in the WC/TRI. Since the mechanical anisotropy should be correlated with the microstructure, scanning electron microscopy has been performed on WC/MONO. Figure 5 shows SEM micrographs taken on the top and side surfaces. On the top surface the baked fibers lie one upon another in random directions, while on the side surface most of fibers lie along horizontal plane. Such an anisotropy of fiber configuration seems to cause the anisotropy of strength in woodceramics.

In the mechanical design, not the high absolute strength but the high specific strength (i.e., strength to density ratio) often becomes a criterion for selecting materials. As shown in Fig.4, the specific strength in the direction normal and parallel to the sheet palne of WC/TRI are respectively $19MPa/Mgm^{-3}$ and $81MPa/Mgm^{-3}$, while those for WC/MONO are $44MPa/Mgm^{-3}$ and $107MPa/Mgm^{-3}$. (These are in contrast to the specific strength of concrete, $20MPa/Mgm^{-3}$). Thus the specific strength of WC/MONO in the direction normal and parallel to the sheet palne is 2.3 times

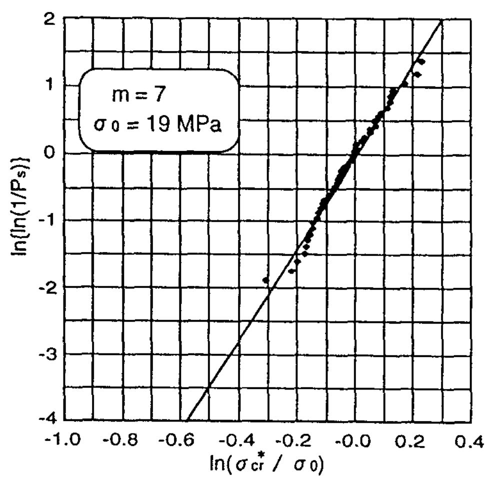

Fig.6 Weibull plot for the compressive strength of WC/TRI (Loading direction: ⊥ to the board plane)

and 1.3 times as large as that of WC/TRI.

The fact that the specific compressive strength is improved in the specimen WC/MONO especially in the direction normal to the board plane has an important meaning, because the in-plane strength is practically more important than the out-of-plane strength in the fiberboards.

The extent of scattering in data is narrower in WC/TRI than in WC/MONO (see Fig.3 and Fig.4). It is noticed that the mean values of WC/TRI are deviated towards lower direction, while that of WC/MONO are deviated towards upper direction.

As described above, there are notable scatter in data on both compressive and specific strength. This kind of data scatter is inevitable in ceramic materials, because the strength is quite sensitive to the defects contained in these materials. Therefore these data should statistically be analyzed by the method based on Weibull distribution, in which the degree of scatter, or materials reliability, is estimated by what we call the Weibull modulus, m[6].

Figure 6 shows an example of Weibull plots of the data obtained in this study. The modulus m which is given by the slope of straight part of dotted curve, is indicated within the figure. As for WC/TRI, the moduli in the directions perpendicular and parallel to the board plane are, respectively, 7 and 8. Those for WC/MONO are, respectively, 5 and 6. Thus it is found that the mechanical reliability of WC/TRI is higher than that of WC/MONO, though their difference is quite small. It should also be noted that our results are comparable to, or sometimes even more reliable than the conventional ceramics (typically $m \geqq 5$), while being less reliable than the engineering ceramics (typically, m=10-20).

4. Conclusions

The mechanical relaiability of two types of porous carbon materials, WC/TRI and WC/MONO, have experimentally been evaluated by compression tests. The results are summarized as follows:

1) Both WC/TRI and WC/MONO have higher strength in the width direction of the board than in the thickness direction, due to the difference in the configuration of fibers. Mechanical anisotropy is, however, weaker in WC/MONO than in WC/TRI.

2) The WC/MONO has higher specific strength as a whole than WC/TRI. This is mainly because more phenolic resin can be impregnated into it than into WC/TRI.

3) WC/MONO is slightly inferior to WC/TRI in mechanical reliability, as evaluated by the Weibull modulus.

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