Transactions of the Materials Research Society of Japan 24 [3] 315-318 (1999)

Development and Evaluation of Woodceramics/Cu Composites

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A new powder method has been developed in order to improve the mechanical strength of woodceramics, which have been ordinarily made by sintering the MDFs (Medium Density Fiberboards) impregnated with phenolic resin. Wood powder, phenolic resin powder, woodceramics powder, copper powder and copper fiber were mixed and compacted at the pressure of 98 MPa at room temperature and sintered at 1073 and 1293K. The increase in copper content of the specimen increased the bending strength. The maximum bending strength (83 MPa) was obtained when the specimen containing 95 mass% of copper was sintered at 1073K. In the case of sintering at 1293K, the maximum bending strength increased to 97MPa. The addition of wood powder to phenolic resin powder increased slightly ductility. By substituting copper fiber for a part of copper powder, ductility increased remarkably.

Key words: woodceramics, bending-test, strength, ductility, powder, composite, copper, carbon, phenolic resin

I. INTRODUCTION

Woodceramics are new porous carbon materials which are made by carbonizing wood or woody materials such as MDFs (Medium Density Fiber boards) impregnated with phenolic resin in a vacuum furnace [1]. During the carbonizing process, the phenolic resin changes into glassy carbon, which has superior corrosion resistance and mechanical strength and reinforces the charcoal(wood-originating soft carbon).

As woodceramics have superior mechanical properties[2], wear properties[3], electric properties[4] and electromagnetic shielding properties[5], they will be used in the several kinds of industrial fields. However, woodceramics are not ductile and the maximum bending strength is lower than 30 MPa and is still insufficient as the structural material compared with another industrial materials such as metals and carbon/carbon-fiber composites. Moreover, the shape of woodceramics is limited to only the board-type one, because they are made usually by burning the MDFs impregnated with phenolic resin.

Therefore, in this study, we tried a new method (powder method) which has the possibility to improve the mechanical strength by mixing other materials such as metal powder and fiber, and to make the shape of woodceramics free. Copper powder and fiber were chosen as the mixing metal powder and fiber in this study, because copper has good electrical conductivity and good mechanical property.

2. EXPERIMENTAL

The compositions (volume ratios and mass percentages) of the powders and fiber in the starting mixtures are shown in Table I. Wood powder (Pinus Koraiensis, 38 mesh under), phenolic resin powder (Shonol BRP-5933, 200 mesh under), copper powder (99.9%, 300 mesh under) and copper fiber (kogi Co., 60 μm in diameter x 3 mm in length) were mixed in a mortar and then compacted at the pressure of 98 MPa at room temperature. The compacted specimen with tetragonal shape was heated to 1073 K at a heating rate of 1 K · min^{-1} and cooled slowly after sintering for 4 h. After cooling, the changes of the shape and density of these specimens were measured. Moreover, bending tests and SEM observations of the fracture surfaces of the tested specimens were performed. The bending test was performed by using three point bending system. The span of beam was 20mm and cross head speed was 0.5 mm · s^{-1}.

Another experiment was done by exchanging wood

Table I Compositions (volume ratio and mass %) of starting mixtures.

	volume ratio				mass%			
No.	W.P.	Ph.P.	Cu P.	Cu F.	W.P.	Ph.P.	Cu P.	Cu F.
A1*	.....	1	.....	.....	.....	100	.....	.....
A2	.....	1	0.5	.....	.....	22.5	77.5	.....
A3	.....	1	1	.....	.....	12.8	87.2	.....
A4	.....	1	2	.....	.....	6.8	93.2	.....
A5	.....	1	0.35	0.15	.....	22.5	54.2	23.3
A6	.....	1	0.7	0.3	.....	12.8	61.0	26.2
A7	.....	1	1.4	0.6	.....	6.8	65.3	27.9
B1	1	1	.....	.....	67.9	32.1	.....	.....
B2	1	1	1	.....	5.9	11.9	82.2	.....
B3	1	1	2	.....	3.2	6.6	90.2	.....
B4	1	1	4	.....	1.7	3.4	94.9	.....
B5	1	1	0.7	0.3	5.9	11.9	57.5	24.7
B6	1	1	1.4	0.6	3.2	6.6	63.2	27.0
B7	1	1	2.8	1.2	1.7	3.4	66.4	28.5

W.P. : wood powder , Ph.P. : phenolic resin powder
Cu P. : copper powder , Cu F. : copper fiber
* : swelled out and could not be tested

Table II Compositions of starting mixturs (mass%) and appearance of sintered specimens.

No.	WCS P.	Ph.P.	Cu P.	Cu F.	apperarance
C1	71.6	28.4	·····	·····	
C2	20	30	35	15	crack
C3	30	20	35	15	
C4	40	10	35	15	
C5	50	0	35	15	*
C6	10	20	49	21	
C7	15	15	49	21	
C8	20	10	49	21	
C9	30	0	49	21	*

WCS P. : woodceramics powder
Ph. P. : phenolic resin powder
Cu P. : copper powder, Cu F. : copper fiber
* : compacting was impossible

powder for woodceramics powder, which was obtained by grinding the bulk woodceramics made by sintering a MDF impregnated with phenolic resin at 1073 K for 4 h. The compositions of the starting mixtures containing the woodceramics powder are shown in Table II.

3. RESULTS AND DISCUSSION

Figure 1 shows an example of the appearance of the specimens in the as-compacted and as-sintered states. All specimens except specimen A1 were contracted by sintering because wood powder and phenolic resin powder decomposed and liberated vapor, pyrolignous acid and another materials in the process of carbonizing. The specimen A1 (phenolic resin only) was swelled out with the liberated vapor and could not be tested . The reason why the other specimens did not swelled out during carbonizing may be attributed that the liberated vapor and gas went to the compacted specimen surfaces from the inside of the specimens through the vessel of wood powders and the spaces between wood and copper powders and fibers .

Figure 2 shows the volume changes by sintering of these compacted mixtures. The volume change of the specimen decreased with increasing copper contents in the specimen. That is, the decrease in volume was about 20 % for the specimen containing 80 mass% of copper and about 10 % for the specimen containing 90 mass% of copper. The volume changes of the specimens containing woodceramics powder in the

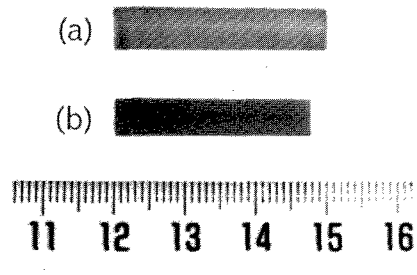

Fig.1 Appearance of the specimens in the as-compacted state (a) and as-sintered state (b).

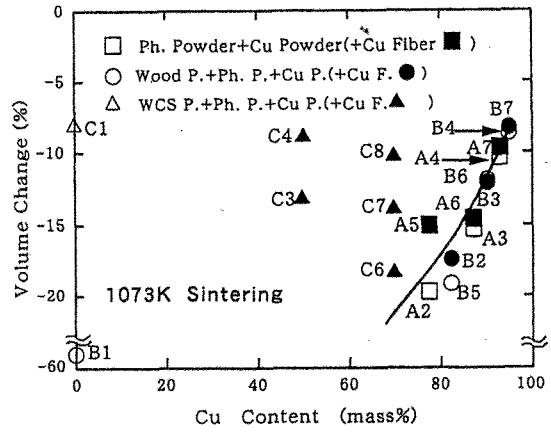

Fig. 2 Relation between volume change and Cu content of the composite specimens obtained by sintering the compacted mixtures of phenolic resin powder , wood powder,woodceramics powder, Cu powder and Cu fiber.

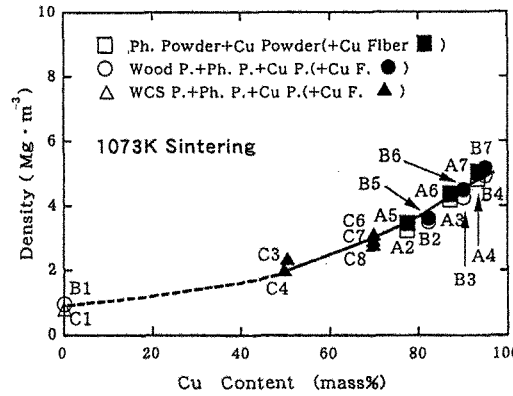

Fig. 3 Relation between density and Cu content of the composite specimens obtained by sintering the compacted mixtures of phenolic resin powder , wood powder, woodceramics powder, Cu powder and Cu fiber.

starting mixtures were fairly smaller than those of the specimens containing wood powder. The reason is probably that the woodceramics powder scarcely decompose during sintering.

Figure 3 shows the densities of the sintered specimens. The density increased with increasing copper content. The densities of the specimens containing 50 mass% and 95 mass% of copper are about 2 and 5 Mg · m^{-3}, respectively .

Figure 4 shows the bending stress-strain curves of the sintered specimens. The maximum bending stress (bending strength) increased with increasing copper content in the specimen. The replace of a part of copper powder with copper fiber increased the fracture strain (ductility) as shown in A5, A6 and A7.

Figure 5 shows the bending stress-strain curves of the specimens obtained by sintering the compacted mixtures which consist of wood powder, phenolic resin powder, copper powder and copper fiber. The bending strength increased with increasing copper content. The addition of wood powder to phenolic resin powder promoted

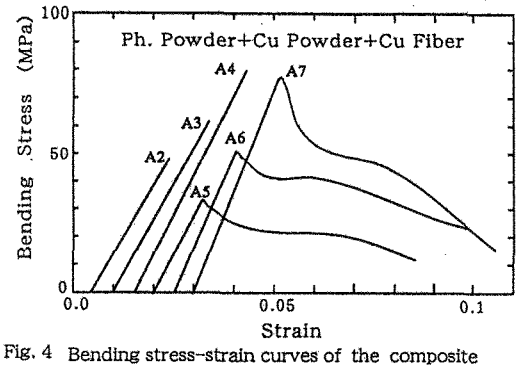

Fig. 4 Bending stress-strain curves of the composite specimens obtained by sintering the compacted mixtures of phenolic resin powder, Cu powder and Cu fiber.

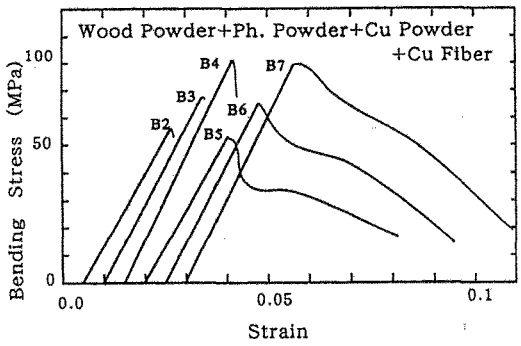

Fig. 5 Bending stress-strain curves of the woodceramics/ Cu composite specimens obtained by sintering the compacted mixtures of wood powder, phenolic resin powder, Cu powder and Cu fiber.

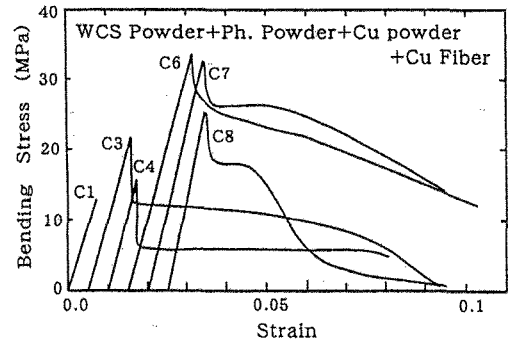

Fig. 6 Bending stress-strain curves of the woodceramics/ Cu composite specimens obtained by sintering the compacted mixtures of woodceramics powder, phenolic resin powder, Cu powder and Cu fiber.

slightly the fracture strain (ductility) (see B2, B3 and B4). The replace of a part of copper powder with copper fiber increased remarkably the ductility (see B5, B6 and B7).

Figure 6 shows the bending stress-strain curves of the specimens obtained by sintering the compacted mixtures of woodceramics powder, phenolic resin powder, copper powder and copper fiber. The bending strength was increased with increasing copper content. However, it decreased inversely with increasing wood powder content in the starting mixture.

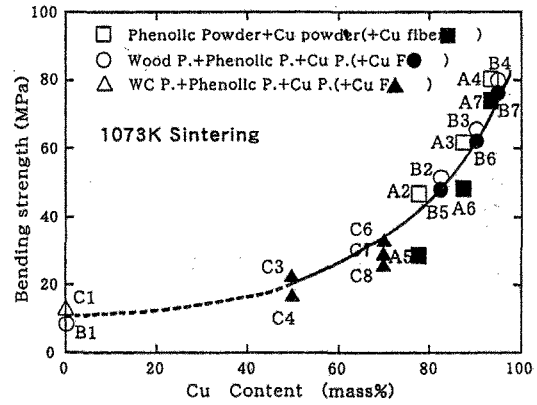

Fig. 7 Relation between Bending strength and Cu content of the composite specimens obtained by sintering the compacted mixtures of phenolic resin powder , wood powder, woodceramics powder, Cu powder and Cu fiber at 1073K.

Figure 7 shows the relation between the bending strength and copper content of the specimens obtained by sintering the compacted mixtures at 1073K. The bending strength of each specimen is nearly on the same curve and increased with increasing copper content of the specimen. Especially, in the case of the copper content beyond 50 mass%, the bending strength remarkably increased. The reason will be discussed later.

Figure 8 shows the SEM microstructures of the specimen surface of the sintered phenolic resin (a) and the bend fracture surface of the specimen obtained by sintering the compacted mixtures of phenolic resin powder , copper powder and copper fiber (b) . The surface of the specimen obtained by sintering only phenolic resin is very flat and has many small and large pores . On the other hand , in the case of the bend fracture surface of the specimen obtained by sintering the compacted mixtures of phenolic resin powder , copper powder and copper fiber , many coalesced copper particles and large copper fibers were observed on the flat carbon matrix .

Figure 9 shows the SEM microstructures of the bend fracture surfaces of the specimens obtained by sintering the compacted mixtures of wood powder, phenolic resin powder, copper powder and copper fiber. In the case of the compacted mixtures of wood powder and phenolic resin powder, the microstructure consists of the flat carbon (A) from phenolic resin and honeycomb-structure carbon (B) from wood powder. In the case of the addition of copper powder and copper fiber (b), the microstructure consists of the mixed structure of coalesced copper particles, large copper fibers and flat and honeycomb-shape carbon matrix. The coalescence of copper particles seems to be the main reason of the increase in the bending strength with increasing copper content.

Figure 10 shows the SEM microstructures of the fracture surfaces of the specimens obtained by sintering the compacted mixtures of woodceramics powder and phenolic resin powder, copper powder and copper fiber.

The microstructure was the mixed structure which consisted of honeycomb-structure carbon, coalesced copper particles and large copper fibers.

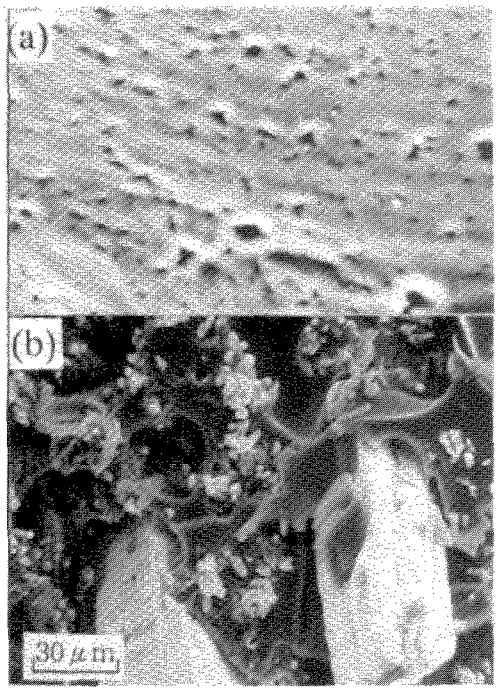

Fig.8 SEM observations of the surface of the specimens obtained by sintering the compacted phenolic resin powder (a), and bend fracture surface of the specimen obtained by sintering the compacted mixture of phenolic resin powder, copper powder and copper fiber (b).

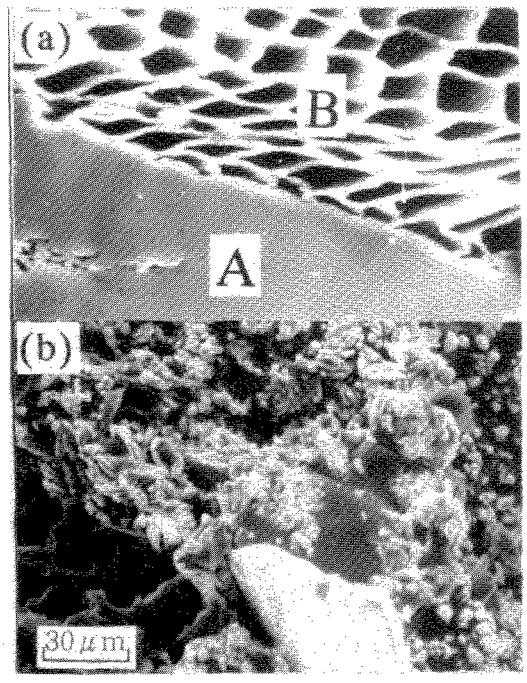

Fig.9 SEM observations of the bend fracture surfaces of the specimens obtained by sintering the compacted mixtures of wood powder and phenolic resin powder (a), and wood powder, phenolic resin powder, copper powder and copper fiber (b).

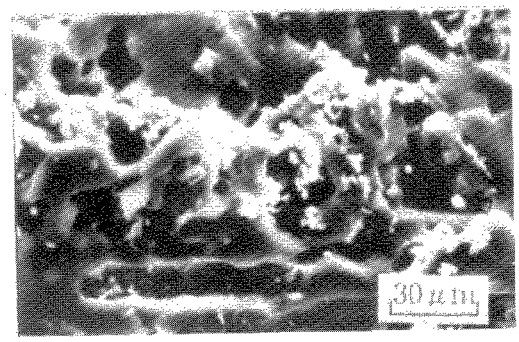

Fig.10 SEM observations of the bend fracture surfaces of the specimens obtained by sintering the compacted mixtures of woodceramics powder, phenolic resin powder, copper powder and copper fiber.

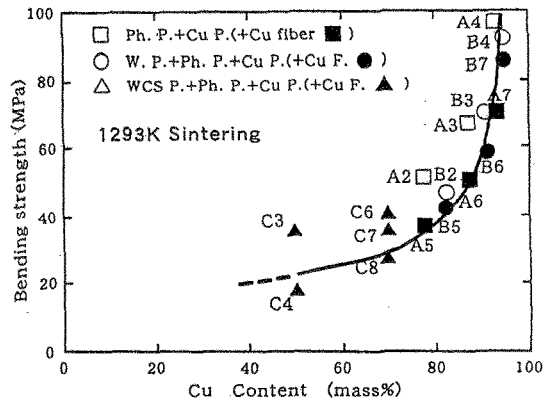

Fig. 11 Relation between Bending strength and Cu content of the composite specimens obtained by sintering the compacted mixtures of phenolic resin powder , wood powder, woodceramics powder, Cu powder and Cu fiber at 1293K.

As shown in Fig.11, the increase of about 15MPa in bending strength was observed in almost all the specimens sintered at 1293K. The maximum bending strength was 97MPa. On the bend fracture surfaces of the specimens sintered at 1293K, large coalesced copper powders were observed. Moreover, the densities of the specimens increased by the increase in sintering temperature. Therefore, the increase in density and the coalescence of copper powders seems to be the main reasons of the increase in the bending strength.

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(Received December 11, 1998; accepted March 18, 1999)