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Reinforcement of Woodceramics by Impregnation of Metals (Al and Brass)

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In order to improve the mechanical and electrical properties of woodceramics, which have been ordinarily made by carbonizing the MDFs (medium-density fiberboards) impregnated with phenolic resin, molten aluminum and brass were impregnated into the woodceramics boards which had been carbonized at 1073K (800℃). The apparent densities of non-impregnated, Al-impregnated and brass-impregnated woodceramics were 0.83, 1.8 and 3.8 $Mg \cdot m^{-3}$, respectively. The volume percentages of impregnated aluminum and brass were 54% and 39%, respectively. The maximum bending stress values of non-impregnated, Al-impregnated and brass-impregnated woodceramics were 10MPa, 50MPa and 80MPa, respectively. The electrical resistivity values of non-impregnated, Al-impregnated and brass-impregnated woodceramics were 2.1×10^{-3}, 4.6×10^{-7} and 9.0×10^{-7} Ωm, respectively.

Key words:woodceramics, composite, aluminum, brass, bending strength, electrical resistivity

1. INTRODUCTION

Woodceramics are new porous carbon materials which are made by carbonizing wood or woody materials such as MDFs (medium-density fiberboards) impregnated with phenolic resin in a vacuum furnace [1]. The impregnated phenolic resin changes into hard glassy carbon during carbonizing process and reinforces the soft charcoal which originated from wood fibers in the MDF.

As woodceramics has superior mechanical properties [2], wear properties [3], electrical properties [4] and electromagnetic shielding properties [5], they are going to be used in many kinds of industrial fields. However, woodceramics are not ductile and the maximum bending strength is lower than 20 MPa and is still insufficient as the structural material compared with another industrial materials such as metals and CMC (ceramic matrix composites).

In the previous study [6], we tried to prepare the woodceramics/metal composites by sintering the compacted mixtures of wood powder (or woodceramics powder), phenolic resin powder, copper powder and copper fiber in order to improve the mechanical strength of the woodceramics. It is clarified from the previous study that the maximum bending strength of 80 MPa can be obtained by using such new powder method. However, more than 80 mass% of copper powder was needed for obtaining the maximum bending strength and the density of the composite became about 5 $Mg \cdot m^{-3}$. This density value seems to be too much higher than that needed for light structural materials.

Therefore, in this study, we have tried to reinforce the woodceramics by impregnating molten aluminum and brass, which have lower density than copper and have good electrical conductivity, into pores of the woodceramics boards.

2. EXPERIMENTAL

Woodceramics boards (100 x 50 x 10 mm^3 in size), which had been made by carbonizing at 1073 K for 4h MDF boards impregnated with phenolic resin of a half weight of the MDF board, were used for the impregnation of the molten aluminum and brass. The schematic representasion of the equipment used for the impregnation of molten metals is shown in **Fig. 1**. The woodceramics board was put on the bottom of a steel mold (inner diameter: 200mm, height: 500mm) pre-heated at 593 K and then covered with the molten aluminum of 1073 K (or brass of 1233 K). Then, the molten aluminum (or brass) was pressed by a plunger at the pressure of 100 MPa for 7 min. After cooling, the metal-impregnated woodceramics boards were cut out from the solidified metal ingots. The purity and composition of metals used for this impregnation were 99.5% pure Al (JIS:A1050) and Cu-36mass%Zn brass (JIS:C3601), respectively.

Test specimens of 50 x 10 x 5 mm^3 in size for bending test and density measurement were cut out from the metal-impregnated woodceramics boards. Bending tests were undertaken by using the Instron-5582 test machine with three point bending system. The span of beam was 30 mm and cross head speed was 0.5 $mm \cdot min^{-1}$. The deflection was precisely measured by counting the displacement of the cross head moving at the constant rate. After bending test, the fracture surfaces were observed by a scanning electron microscopy (SEM). The contents of metals impregnated into woodceramics boards were estimated from the measured density values and confirmed by X-ray fluorescence analysis. The electrical resistivity was measured by four probe method.

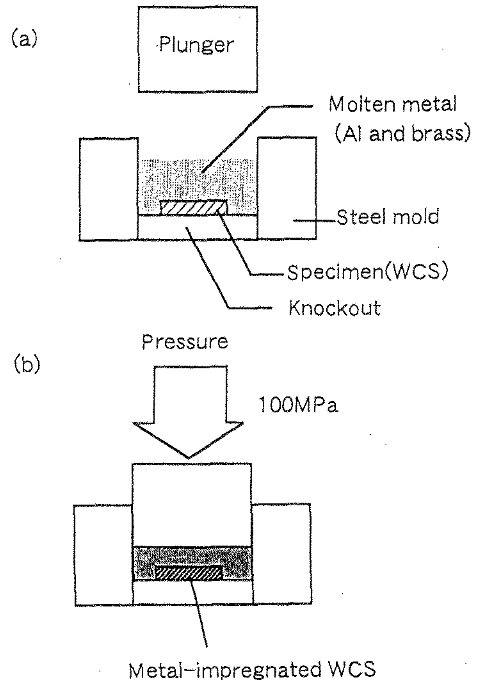


Fig.1 Schematic representation of the method for impregnating metals into woodceramics.

3. RESULTS AND DISCUSSION

The appearance of the Al-impregnated woodceramics board is shown in **Fig.2**. The Al-impregnated board looked gray compared with the black of the non-impregnated one. In the case of brass-impregnation, the color of the board changed slightly to gold. These color changes demonstrate that these metals have been successfully impregnated into woodceramics boards.

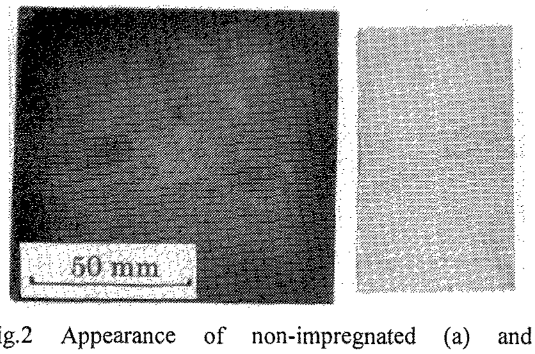


Fig.2 Appearance of non-impregnated (a) and Al-impregnated woodceramics (b).

Table 1 Densities of metals and metal-impregnated woodceramics. ($Mg \cdot m^{-3}$)

specimen	Al	brass	WCS	Al-WCS	brass-WCS
density	2.7	8.5	0.83*	1.8*	3.8*

* apparent density

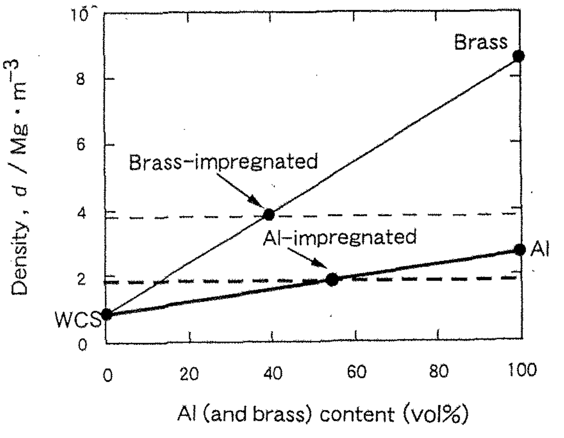


Fig.3 Estimation of aluminum and brass contents from the measured densities of Al-impregnated and brass-impregnated woodceramics.

As shown in **Table.1**, densities of Al-impregnated and brass-impregnated woodceramics were 1.8 and 3.8 $Mg \cdot m^{-3}$, respectively. From these measured densities, aluminum and brass contents were estimated by the method shown in **Fig.3**. From Fig.3, 54 and 39 vol% were obtained as the contents of the aluminum and brass impregnated into woodceramics boards, respectively. From this aluminum volume percentage, aluminum mass% (wt%) was calculated to be 79.3% by using the density values of the woodceramics board and pure aluminum board. This calculated aluminum value is well consistent with the measured value (78.8 mass%) by X-ray fluorescence analysis. This fact suggests that the impregnated-metal content can be estimated almost precisely by measuring the density of the metal-impregnated woodceramics.

Figure 4 shows the stress-strain curves of the non-impregnated and Al-impregnated woodceramics compared with the commercial pure aluminum board. The maximum bending stress values of the woodceramics, Al-impregnated woodceramics and pure aluminum board were 10, 50 and 145 MPa, respectively. The impregnation of aluminum into woodceramics increased the strength of the woodceramics by about 5 times and improved slightly the ductility of the woodceramics.

Figure 5 shows the stress-strain curves of the non-impregnated, brass-impregnated wodceramics and commercial brass board. The maximum bending stress of the non-impregnated, brass-impregnated woodceramics and commercial brass board were 10, 80 and 450 MPa, respectively. The impregnation of brass into woodceramics reinforced the woodceramics by 8 times and increased slightly the ductility.

Figure 6 shows the relationship between the bending Young's modulus and impregnated metal content based on Figs.4 and 5. **Figure 7** shows the relationship between the maximum bending stress and impregnated metal content based on Fig.4 and 5. Both bending Young's modulus and maximum bending

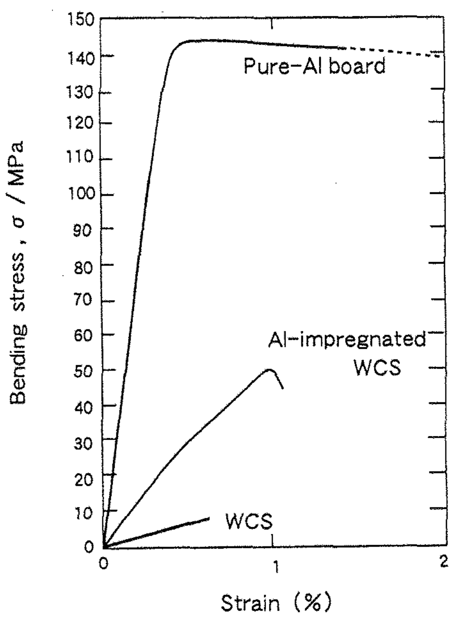


Fig.4 Bending stress-strain curves of non-impregnated, and Al-impregnated woodceramics and pure aluminum board.

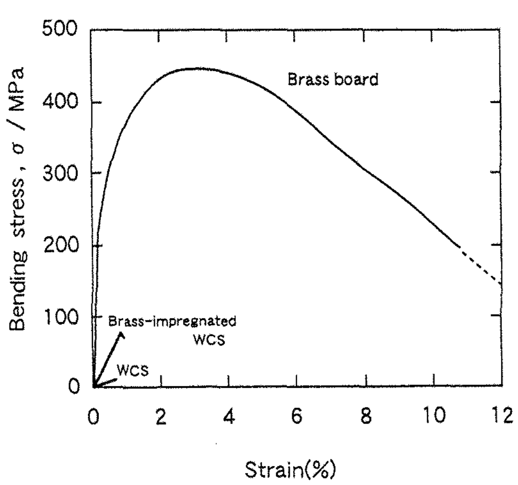


Fig.5 Bending stress-strain curves of non-impregnated and brass-impregnated woodceramics and brass board.

stress were lower than the values expected from the rule of mixtures based on the parallel model [7] (dotted lines in Figs. 6 and 7). The reason will be discussed later.

Figure 8 shows the results of SEM observations. The fracture surface of the non-impregnated woodceramics was very flat and smooth, showing the characteristics of brittle fracture (a). Moreover, many pores originated from the microstructure of wood were observed. On the other hand, the surfaces of Al-impregnated and brass-impregnated woodceramics were not smooth, namely many needles (fibers) of impregnated-metals stuck out from pores ((b) and (c)). From these facts, such mechanism as shown in **Fig.9** [7] seems to be suitable for the bending fracture

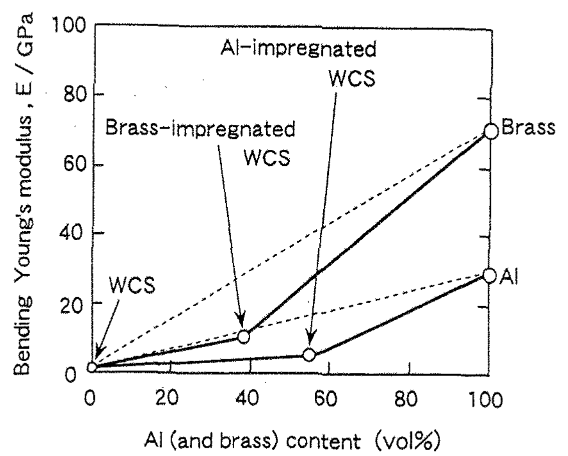


Fig.6 Relationship between bending Young's modulus and impregnated metal content. Dotted lines denote those of the rule of mixtures.

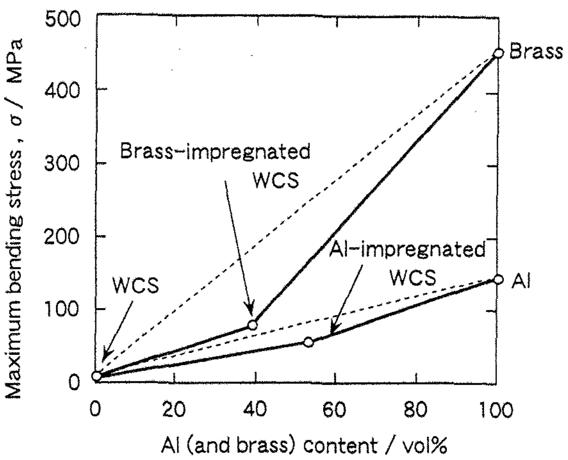


Fig.7 Relationship between maximum bending stress and impregnated metal content. Dotted lines denote those of the rule of mixtures.

mechanism of Al-impregnated and brass-impregnated woodceramics boards in this study. Main reasons why the values of the bending Young's modulus and maximum bending stress of Al-impregnated and brass-impregnated woodceramics composites in this study were lower than those expected from the rule of mixtures (the parallel model) may be due to the following two points; (1) low affinity and wettability between carbon matrix and impregnated aluminum (or brass) [8] and (2)irregular arrangement of metallic fibers in woodceramics matrics..

Figure 10 shows the result of the electrical resistivity measurements of the non-impregnated, Al- and brass-impregnated woodceramics and commercial pure aluminum and brass boards. The electrical resistivity values of non-impregnated, Al-impregnated and brass-impregnated woodceramics were 2.1×10^{-3}, 4.6×10^{-7} and 9.0×10^{-7}, respectively. The dotted line (calculated) shows the electrical resistivity change with increasing aluminum fiber content in the ideal composite which consists of the long aluminum fibers aligned uniaxially to the current direction and woodceramics matrix. The electrical resistance theory of

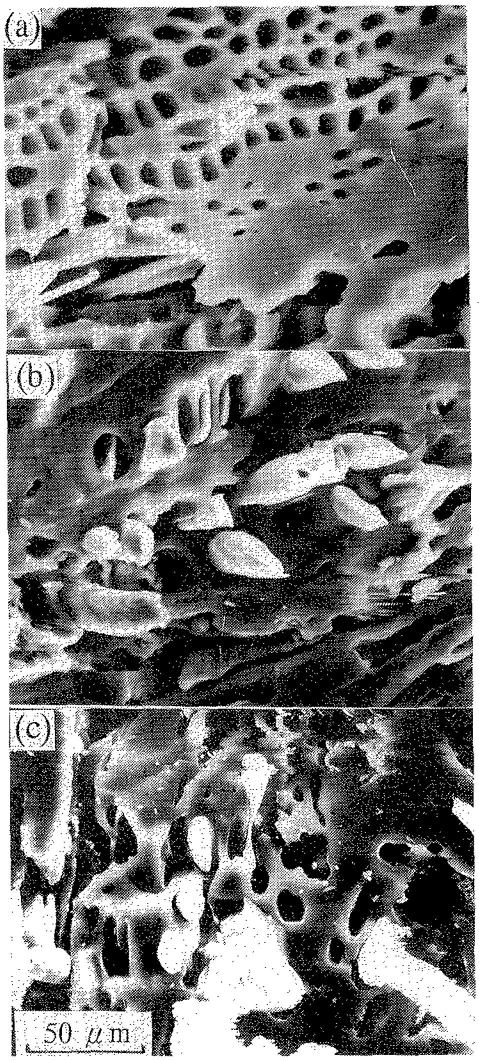


Fig.8 SEM observations of the bending fracture surfaces of non-impregnated (a), Al-impregnated (b) and brass-impregnated woodceramics (c).

the parallel circuit [9] was adopted to obtain this line. The experimental value of the Al-impregnated woodceramics was higher than the calculated value. The reason may be due to the shortness and irregular arrangement of the impregnated aluminum fibers.

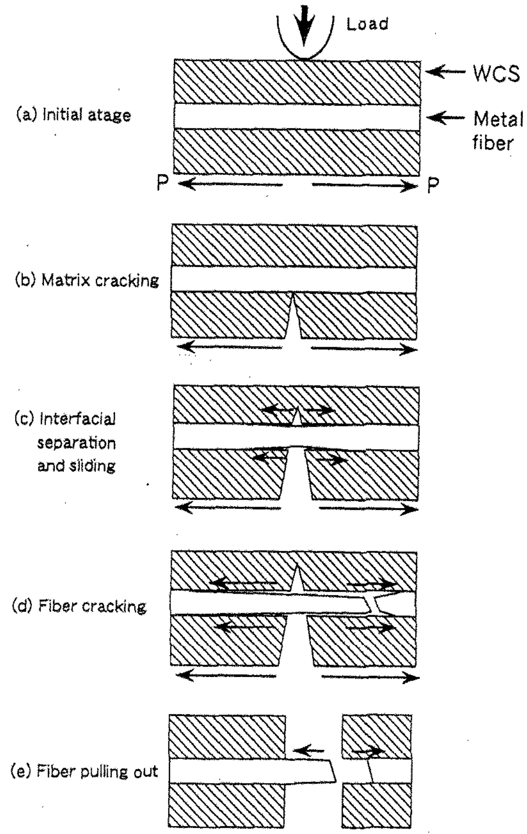
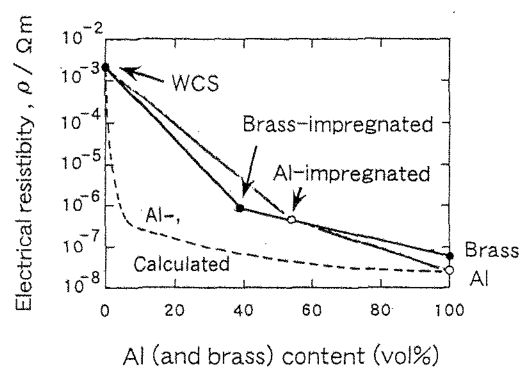


Fig.9 Schematic representation of the proposed fracture mechanism for metal-impregnated woodceramics.



Fig,10 Relation between electrical resistivity and contents of metals impregnated into woodceramics.

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