Compressive deformation behavior of wood impregnated with low molecular weight phenol formaldehyde (PF) resin

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The establishment of a sustainable society based on renewable and sustainable resources is desirable in the twenty-first century. In this sense, wood may be considered as a future-oriented material even though it is one of the oldest materials. However, wood possesses disadvantages like dimensional instability to moisture, low durability due to bio-deterioration and poor mechanical properties compared to other engineering material. To overcome these drawbacks, combination of PF resin impregnation and compression seems to be promising method by which dimensional stability and mechanical properties of wood could be improved considerably. PF resin impregnated compressed wood named as Compreg, exhibited high strength, good dimensional stability and high resistance to decay and termites [1]. However, processing this material is severely curtailed by the need for high hot pressing pressures in order to achieve its highly compressed condition, which results in a high cost product thus having limited applications. Hence, a method to obtain highly compressed wood at low pressing pressure was developed based on the analysis of the deforming behavior of PF resin-impregnated wood.

At first, the deformation behavior of low molecular weight phenol formaldehyde (PF) resin-impregnated wood under compression in the radial direction was investigated [2, 3]. Flat sawn grain Japanese cedar (*Cryptomeria japonica*) block with a density of 0.34 g/cm^3 were treated with aqueous solution of 20 % low molecular weight PF resin resulting in weight gain of 60.8%. Oven dried specimens were compressed using hot plates fixed to a testing machine. The temperature was 150°C and the pressing speed was 5mm/min. The impregnation of PF resin caused significant softening of the cell walls resulting in collapse at lower pressing pressures. With an increase of PF resin content, the Young's modulus of the cell wall perpendicular to the fiber direction decreases, and collapse initiating pressure decreases linearly with the Young's modulus. This indicates that the occurrence of cell wall collapse is strain dependent. Thus, pressure holding causing creep deformation of the cell walls was also effective in initiating cell wall collapse at a lower pressing pressure. Utilizing a combination of low molecular weight PF resin impregnation and pressure holding at 2 MPa resulted in a density increase of PF resin treated wood from 0.45 to 1.1 g/cm^3. Concurrently, the Young's modulus and bending strength increased from 10 GPa to 22 GPa and from 80 MPa to 250 MPa, respectively. It can be concluded that that effective utilization of the collapse region of the cell wall is a desirable method for obtaining high-strength PF resin-impregnated wood at lower pressing pressures.

Considering the application of this technique, the effects of the raw material or species was further clarified [5]. The deformation behavior of resin-impregnated wood up to 10 MPa was significantly different among the species. When PF resin-impregnated wood was compressed up to 2 MPa and the pressure was kept constant for 30 minutes, the density of Japanese cedar reached 1.18 g/cm^3, about 30% higher than the density of compressed Japanese birch, which possesses a 2.5 times higher original density. The mechanical properties of resin-impregnated wood, especially low density wood, increased with density. Hence, it is manifested that low density wood species such as Japanese cedar, albizia have an advantage as raw materials for obtaining high-strength wood at lower pressing pressure.

To obtain a further drastic deformation of PF resin-impregnated wood under compression, the effect of the removal of the matrix substances of the cell wall prior to resin impregnation was studied [4]. $NaClO_2$ treatment has shown considerable potential for high compression of PF resin-impregnated wood at lower pressing pressure, especially after adding moisture of 10-11%. This deformation is further enhanced during pressure holding by creep deformation. The density, Young's modulus and bending strength of four times $NaClO_2$ treated PF resin-impregnated veneer laminated composites compressed at 1 MPa, reached 1.15 g/cm^3, 27 GPa and 280 MPa, whilst those values in untreated PF resin-impregnated wood reached 0.8 g/cm^3, 16 GPa and 165 MPa, respectively.

The above treatment is attractive; nevertheless it is complicated in processing. Furthermore, it is somewhat difficult to remove the harmful chemical, $NaClO_2$, completely from the treated wood, a factor that poses a major drawback in the application of this treatment. Hence, the potential of steam pretreatment as a substitute treatment for making highly compressed PF (phenol formaldehyde) resin-impregnated wood at a low pressing pressure was evaluated [6]. The pressing pressure-density relationship of steam treated resin-impregnated wood is compared in Fig. 1 with those of $NaClO_2$ (a lignin removal treatment) treated resin-impregnated wood [4]. The weight loss due to $NaClO_2$ treatment was 21%, and the weight gain due to PF resin impregnation for $NaClO_2$ treated wood was 60%. As reported previously [4] there was a significant difference in compressibility between air-dried and oven-dried conditions for $NaClO_2$ treated PF resin-impregnated wood. The density of $NaClO_2$ treated resin-impregnated wood was 0.7 g/cm^3 for the oven-dried condition ($NaClO_2$ treatment, OD) at a pressing pressure of 1 MPa. After adding moisture of 10-11% to the $NaClO_2$ treated resin-impregnated wood ($NaClO_2$ treatment, AD), the density reached 1.0 g/cm^3. This is similar to the density attained by oven-dried steam treated resin-impregnated wood (200°C). It is thus recommended that steam treatment can be substituted for chemical treatment in the fabrication of highly compressed PF resin-impregnated wood, since steam treatment is much easier than the $NaClO_2$ treatment and is harmless to humans.

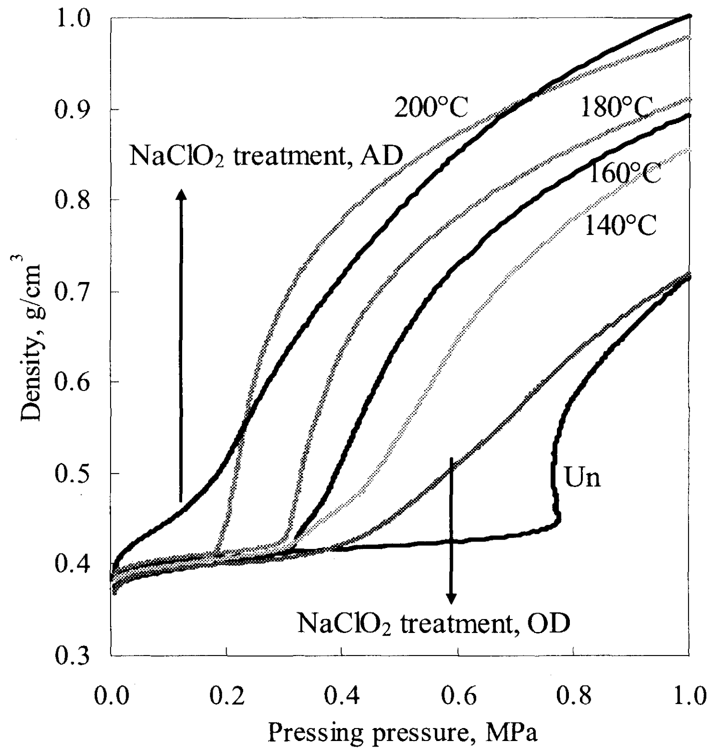

Fig. 1 Changes of density of PF resin-impregnated wood as a function of steaming temperature and comparison with those of $NaClO_2$ treatment [4]. AD and OD refer to air- dried and oven-dried conditions for NaClO2 treated PF resin-impregnated wood, respectively. Un refers to PF resin impregnated wood. Steaming time was 10 minutes

Considering that 1 MPa is a typical pressing pressure used for ordinary plywood and LVL production, our preliminary finding [7] indicates that overlaying veneer plasticized by low molecular weight PF resin on the particle mat before hot pressing resulted in selective densification of surface veneer, and improved the mechanical properties of particleboard significantly with a slight increment in density.

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