Finite element analysis of the effects of cellulose nanofibers on the bending properties of the CFRP I-shaped cross-sectional beam

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Introduction. Recently, the strength of cellulose nanofibers (CNFs) is focused(1). Therefore, to improve the strength of carbon fiber reinforced plastic (CFRP), the method to disperse CNFs in the matrix of CFRP has been studied. However, an expensive hydrophobic treatment is unavoidable since CNFs are hydrophilic. Previously, authors have developed the electro-activated deposition molding (ERM) method to fabricate CFRP. In the ERM method, resin is impregnated in the electrodeposition solution, which contains polymers having an epoxy group(2). Thus, neither prepreg nor vacuum packaging process is necessary. In addition, CFRP in which carbon fibers are arbitrarily oriented can be manufactured by sewing carbon fibers using an embroidery machine. Further, after the ERM, by applying CNF without hydrophobic treatment on the surface, the mechanical properties of CFRP could be enhanced. In this study, the finite element analysis was conducted to estimate the effects of CNFs on the bending properties of the I-beam with and without CNF on the surface.

Methods. Firstly, based on our previous study using the ERM method, the CFRP I-shaped cross-sectional beam (I-beam) with 2-ply and 4-ply flange were fabricated(3). Non-crimp carbon fiber fabric (NCF) was immersed in the electrodeposition solution. Resin was impregnated with applying the current. The shape of I-beam was molded using the PTFE mold, and thermally cured. Moreover, CNF without hydrophobic treatment was applied on the surface of the I-beam specimen. Then, carrying out the 3-point bending test, it was experimentally confirmed that the bending properties of the I-beam specimens could be enhanced by CNF.

Secondly, the bending properties of the I-beam with and without CNF were simulated by the finite element method (ANSYS 18.1 was used). The CFRP I-beam with 2-ply and 4-ply flange and three fulcrums were modeled by the shell element with taking the orientation of carbon fiber into account. The material constants were assumed as follows. The elastic modulus in 0° direction of CFRP with and without CNF were assumed to be $E_1$, with CNF $= 72$ MPa and $E_1$, without CNF $= 60$ MPa, respectively. In our previous study, it was experimentally confirmed that the elastic modulus of the CFRP specimen with CNF was enhanced to be 120 % of that of the CFRP specimen without CNF(4). For the specimen with and without CNF, the shear modulus $G_{12}$ and Poisson’s ratio were assumed to be $G_{12} = 7.0$ GPa and $\nu_{12} = 0.30$, respectively.

Results. Figure 1 shows the load-displacement relationship of the CFRP I-beam with 4-ply flange. The effect of CNF was clearly observed from the experiment and FEM. For the I-beam without CNF, the maximum stiffness ($=$Yield load/Displacement) obtained from the experiment was 1775 N/mm (Simple moving average, N=7), and was 98 % of the value from the FEM. For the I-beam with CNF, the maximum stiffness from the experiment was 1846 N/mm, and was 96 % of the value from the FEM. For the I-beam with 2-ply flange, the same tendency was observed.

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References.