Development and Practical Application of 3D Printing Technology Using Fiber-reinforced Cementitious Composite

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1. Outline

Shimizu Corporation has developed a fiber-reinforced cementitious composite suitable for 3D printing and established 3D concrete printing technology that can print large-scale elements with excellent mechanical characteristics and durability. This technology can fabricate laminated structures with structural characteristics and mass transfer resistance equivalent to or better than those of ordinary concrete. It also allows for direct 3D printing at construction sites by use of a gantry system (Figure 1).

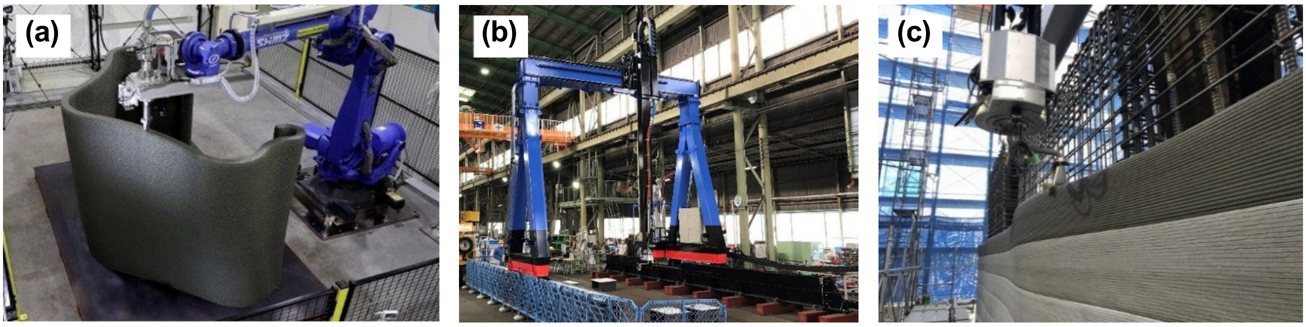

Fig. 1 Printing system using (a) a robotic arm and (b, c) a gantry system.

2. Materials

Both numerical analysis and experiments were conducted to find a mix proportion that satisfies both extrudability and buildability, leading to the development of the fiber-reinforced cementitious composite called LACTM® (Laminatable Cement-based Tough Material). This material is suitable for 3D printing in its fresh state and exhibits superior mechanical characteristics and durability, with the printed specimens having compressive and bending strengths of 109 MPa and 14 MPa, respectively. The reinforcing effect of the fibers across crack planes allows for deflection hardening behavior under bending stress (Figure 2), and experiments verified that the flexural capacity and ductility of columns built by filling LACTM formwork with concrete are equal to or greater than those of conventional concrete columns (Figure 3). Also, because of the dense interfaces between all the filaments layered by printing (layer-to-layer interfaces), water does not penetrate the printed structure, thereby maintaining high durability (Figure 4).

Fig. 2 Deflection hardening behavior of LACTM (inset: magnified image of crack plane).

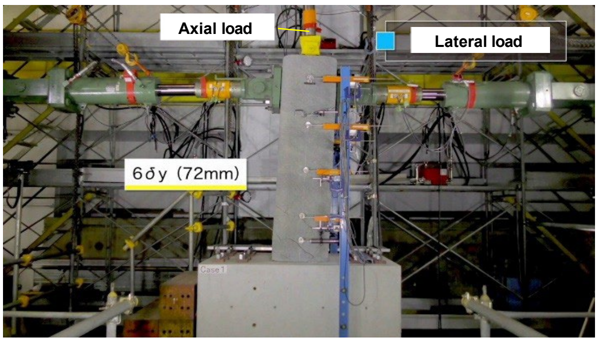

Fig. 3 Reversal cyclic loading tests of RC column built using LACTM formwork.

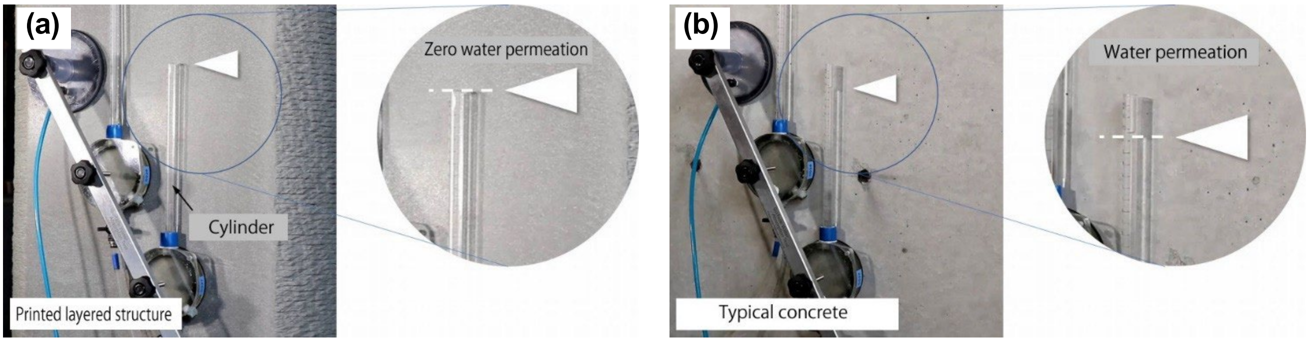

Fig. 4 Surface water permeability test results for (a) LACTM and (b) typical concrete (experiment conducted to investigate the rate of water absorption from the surfaces of the structures by measuring the change in water volume in a glass cylinder).

3. Practical Application

The developed system has been put to practical use for columns, beams, roofs, benches, and other printed structures, examples of which are shown in Figure 5.

Fig. 5 Examples of printed structures in practical applications.

Figure 6 shows an application involving concrete columns for TOYOSU MiCHi no Eki. The target columns have a height of 4.3 m and a 3D curved surface that would be difficult to achieve by conventional construction methods using wooden formwork, with a shape that flares out into a petal-like shape while twisting from bottom to top. By manufacturing the formwork for the columns and evaluating their finished shape and quality, it was demonstrated that the developed 3D printing technology can be used to construct high-quality laminated structures with free-form surfaces.

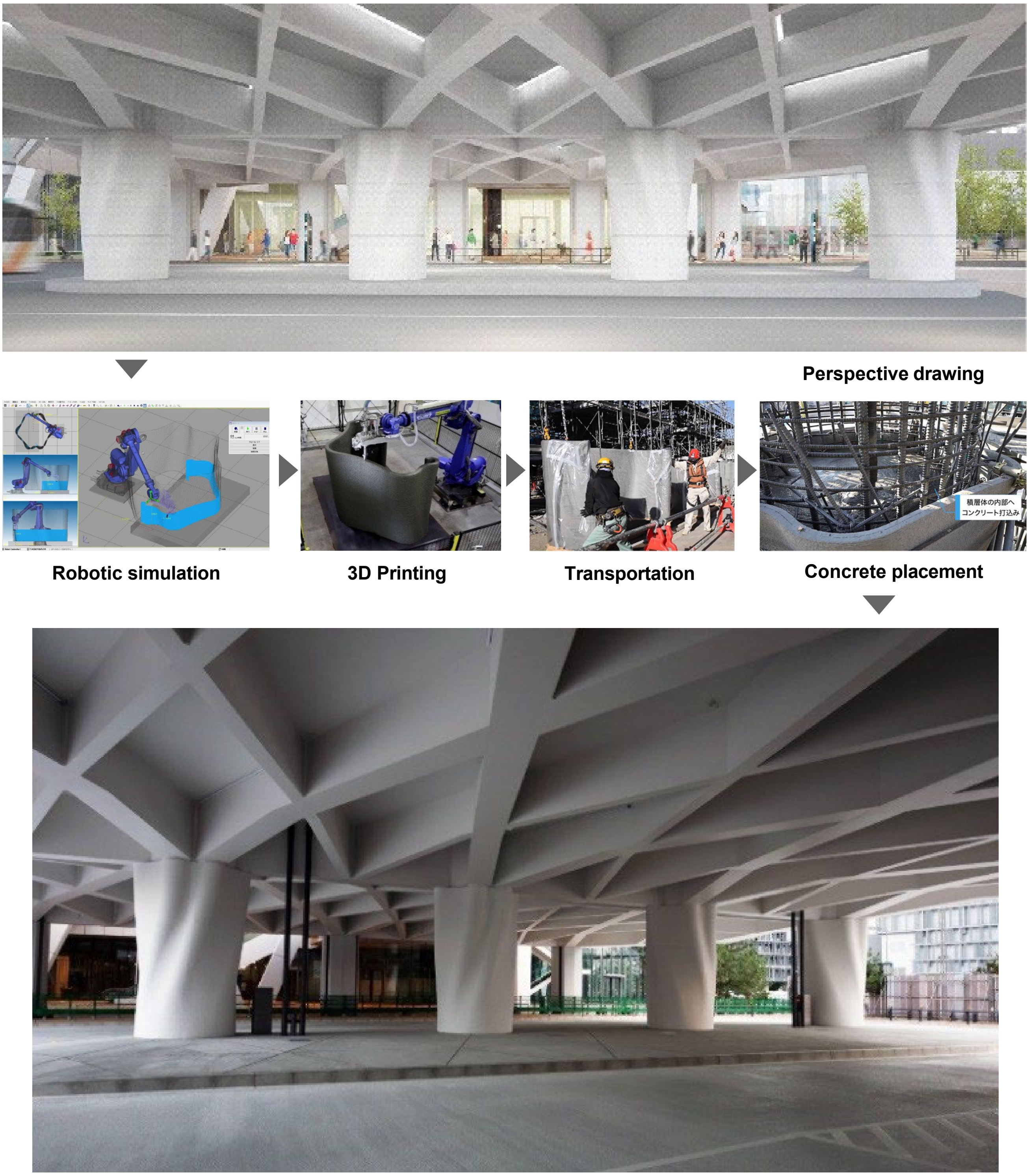

Fig. 6 Application at TOYOSU MiCHi no Eki

Figure 7 shows an example of on-site printing using a gantry-type printer. The printer has printing ranges of 20 m in depth, 4.5 m in width, and 4.3 m in height and a printing speed of 100 mm/s. A permanent formwork with a depth of 20 m and a height of 4.5 m was constructed for a steel-framed reinforced-concrete wall column.

Fig. 7 Application at NOVARE