Structural Behavior of Ice Composite for 3D Printing

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Abstract

Digital manufacturing is transitioning the building industry and will have a large impact on the way we construct buildings in the future. One application for 3D printing includes a 3D-printed habitat for Mars using robots with locally available material such as ice. Another application is 3D printing for sculptures. The third application is 3D printing for temporary structures in artic areas. The problem of using ice for construction is its brittleness. It is possible to reinforce ice with additives. Just as concrete or polymers can be reinforced with steel rods or fibers, ice can be reinforced with soil, silica, wood, paper fibers or polyphenol alcohol. The fibers increase the compressive and tensile strength of ice by three times. Ductility will even increase by ten times. The improvement of the material offers opportunities to explore new building possibilities. In 2014 the largest igloo ever (diameter of 30 meters) was built in Juuka Finland and in 2018 the highest thin shell dome (30 meters with an average thickness of 25cm) was built in Harbin, China. These examples were realized by spraying thin layers of a fiber-water mixture on a surface at a temperature of -8C or lower.

The extrusion of cellulose-reinforced ice leads to the drainage of water just before the extrusion nozzle. Therefore, the compressed water-cellulose mixture will form clots in the nozzle, leading to an unreliable process. By mixing fibers, water and jelly it is possible to bond the water to the fibers. The bonding will solve the problem of the drainage and the jelly will lubricate the extrusion of the mixture, solving the problem of nozzle clotting. The jelly consists of materials that do not have to be heated, namely Guar Gum and Xanthan Gum, and is combined with cellulose, water and/or fibers. A hybrid mixture with other fibers such as steel will increase the material properties of the ice composite further more. To have the right viscosity the amount of fibers has to be increased, making it possible to extrude the fiber-reinforced ice. In one embodiment, a mixture of 0.155 % Guar Gum and 0.155% Xanthan Gum with 8% cellulose gives a positive result with a low environmental impact. It was found that adding sand to ice will increase both its bending as its compression strength. Under bending stresses ice usually shows brittle post-peak behavior. Adding cellulose showed promising post-peak strain softening behavior. Experiments with different temperatures and testing speeds were conducted. From these experiments it was concluded that both the ultimate strength and the stiffness of the specimens decrease with increasing temperature. However, with temperatures approaching 0°C, the post-peak behavior also changes from brittle to more ductile. Furthermore, the bending tests were modelled in a FEM program and compared with the executed experiments. Based on these experiments in December 2018 the first 3D-printed grid shell in ice composite was realized in Harbin, China.

References

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