A more sustainable material to reinforce concrete structures

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Credit: Alain Herzog / 2019 EPFL

The next generation of ultra high-performance fiber-reinforced concrete (UHPFRC) has just been created at EPFL. The new material will be used to strengthen and to extend the life span of bridges and other structures—both new and old. What's more, the process of manufacturing this material releases 60–70 percent less CO_2 than the previous generation of fiber-reinforced concrete.

The construction industry accounts for around 40 percent of global CO_2 emissions, much of which can be attributed to the manufacture of concrete. And countries like Switzerland, where concrete structures have flourished since the 1960s, now face the task of maintaining these structures to ensure they remain safe far into the future. This is a daunting challenge with both environmental and technical considerations.

EPFL's Structural Maintenance and Safety Laboratory (MCS), headed by Eugen Brühwiler, has built up cutting-edge expertise in this field over the past 25 years. The MCS specializes in two areas: developing more ecofriendly concrete, and carrying out increasingly sophisticated, largely monitoring-based, assessments of existing structures, such as road and rail bridges in Switzerland and around the world.

For his Ph.D. thesis, MCS researcher Amir Hajiesmaeili sought to develop the next generation of ultra high-performance fiber-reinforced concrete (UHPFRC). His aim was to develop a material that retains the mechanical properties found in today's concrete, but without the steel fibers. The UHPFRC that Hajiesmaeili came up with is 10 percent lighter than other fiber-reinforced concrete, and its environmental impact is 60–70 percent lower. This new material is so effective that the first tech transfer will take place in 2020, when it will be used to reinforce a bridge.

Right recipe

Hajiesmaeili likes food and knows his way around a kitchen. After completing a Master's degree in civil engineering at the University of Tehran, he came to EPFL to do his Ph.D. as part of the Swiss National Science Foundation's NRP "Energy Turnaround" (NRP 70) project. He spent nearly four years "cooking" at EPFL. Each week he would prepare various combinations of powders in a scientific way, according to a novel comprehensive packing model that they developed in MCS and stir them up in a mixer. He would then run his samples through various strength and tensile tests and refine his calculations. His aim was to produce a new UHPFRC that is just as strong as the one currently used in the construction industry but that produces less CO_2.

"After three years of this trial-and-error, we finally found the right recipe—one that also meets stringent building standards," says Hajiesmaeili. How did he do it? Instead of steel fiber, he used a very stiff synthetic polyethylene fiber that adheres well to the cement matrix. He also replaced half of the cement, a commonly used binder in concrete, with limestone, a material that is widely available around the world. "The trick was to find a material that's very strong and produces the right consistency."

Swiss technology

For the past 15 years, first-generation UHPFRC has been used to reinforce bridges to make them more sustainable, thanks to a technology developed in Switzerland and exported abroad. Its carbon footprint is already lower than that of conventional reinforced concrete. "With this material, we can add value to age-old structures by ensuring they will last for a long, long time," says Brühwiler, whose lab has already overseen the structural reinforcement of more than 100 bridges and buildings in Switzerland. "This solution is also much more financially and environmentally sound than razing and rebuilding existing structures like bridges and historical monuments."

In Brühwiler's experience, technology transfer in the construction industry is only effective when three criteria are met: people at every step of the construction chain—from construction managers to workers—are well-trained (as is the case in Switzerland); there is a building code; and there are both financial and individual incentives for stakeholders to change their habits.

More information: Amir Hajiesmaeili, "Next generation synthetic fibers UHPFRC for sustainable structural applications," PhD thesis No. 7362, EPFL, November 2019.

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