Sustainable structural material for plastic substitute

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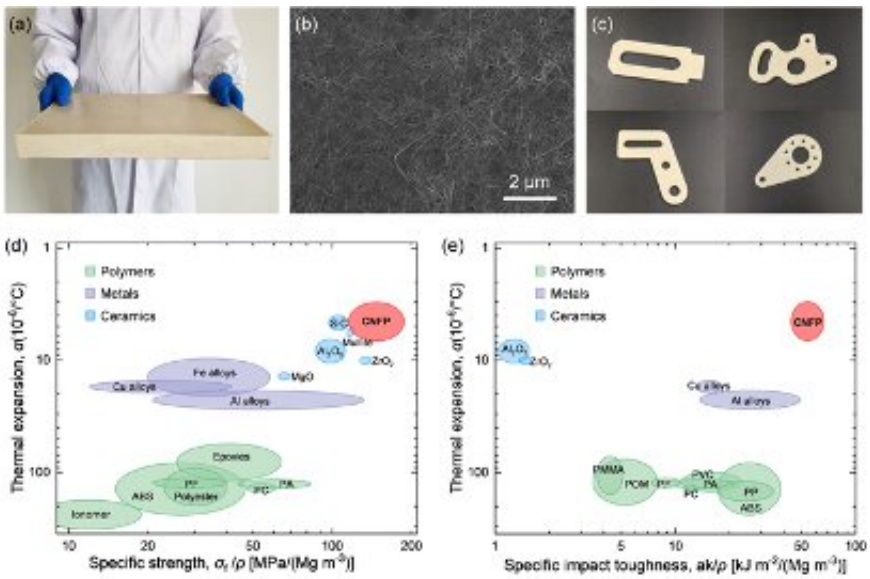

The cellulose nanofiber-derived bulk CNFP structural material and its characterization. (a) Photograph of large-sized CNFP with a volume of 320 × 220 × 27 mm3. (b) The robust 3D nanofiber network of CNFP. Numerous CNFs are intertwined with each other and combined together by hydrogen bonds. (c) Parts with different shapes of CNFP produced by a milling machine. (d) Ashby diagram of thermal expansion versus specific strength for CNFP compared with typical polymers, metals, and ceramics. (e) Ashby diagram of thermal expansion versus specific impact toughness for CNFP compared with typical polymers, metals, and ceramics. Copyright 2020, American Association for the Advancement of Science. Credit: Shu-Hong Yu

Plastic gives us a lightweight, strong and inexpensive material to use, but

it has also caused the plastic apocalypse. Much of the unrecycled plastic waste ends up in the ocean, Earth's last sink. Broken down by waves, sunlight and marine animals, a single plastic bag can become 1.75 million microplastic fragments. Those microplastics might finally end up in our bodies through the fish we eat or the water we drink.

During the long-term evolution of most plants on the earth, cellulose-based materials have been developed as their own structural support materials. Cellulose in plants mainly exists in the form of cellulose nanofibers (CNF), which have excellent mechanical and thermal properties. CNF, which can be derived from plants or produced by bacteria, is one of the most abundant all-green resources on Earth. CNF is an ideal nanoscale building block for constructing macroscopic high-performance materials, as it has higher strength (2 GPa) and modulus (138 GPa) than Kevlar and steel and lower thermal expansion coefficient (0.1 ppm K^{-1}) than silica glass. Based on this bio-based and biodegradable building block, the construction of sustainable and high-performance structural materials will greatly promote the replacement of plastic and help us avoid the plastic apocalypse.

Nowadays, a team lead by Prof. Shu-Hong Yu from the University of Science and Technology of China (USTC) report a high-performance sustainable structural material called cellulose nanofiber plate (CNFP) (Fig. 1a and c) which is constructed from bio-based CNF (Fig. 1b) and ready to replace plastic in many fields. CNFP has a high specific strength (~198 MPa/(Mg m^{-3}))—four times higher than that of steel and higher than that of traditional plastic and aluminum alloy. In addition, CNFP has a higher specific impact toughness (~67 kJ m^{-2}/(Mg m^{-3})) than aluminum alloy and only half of its density (1.35 g cm^{-3}).

Unlike plastic or other polymer based materials, CNFP exhibits excellent resistance to extreme temperature and thermal shock. The thermal expansion coefficient of CNFP is lower than 5 ppm K-1 from -120 °C to

150 °C, which is close to ceramic materials, much lower than typical polymers and metals. Moreover, after 10 times of rapid thermal shock between a 120 °C oven and the -196 °C of liquid nitrogen, CNFP maintains its strength. These results show its outstanding thermal dimensional stability, which allows CNFP to have great potential for use as a structural material under extreme temperature and alternate cooling and heating. Owing to its wide range of raw materials and bio-assisted synthesis process, CNFP is a low-cost material—only $0.5/kg, which is lower than most plastic. With low density, outstanding strength and toughness, and great thermal dimensional stability, all of those properties of CNFP surpass those of traditional metals, ceramics and polymers (Fig. 1d and e), making it a high-performance and environmental-friendly alternative for engineering, especially for aerospace applications.

CNFP not only has the power to replace plastic and saves us from drowning in it, but also has great potential as the next generation of sustainable and lightweight structural material.

The study is reported in *Science Advances*.

More information: "Lightweight, tough, and sustainable cellulose nanofiber-derived bulk structural materials with low thermal expansion coefficient" *Science Advances*, advances.sciencemag.org/content/6/18/eaaz1114

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