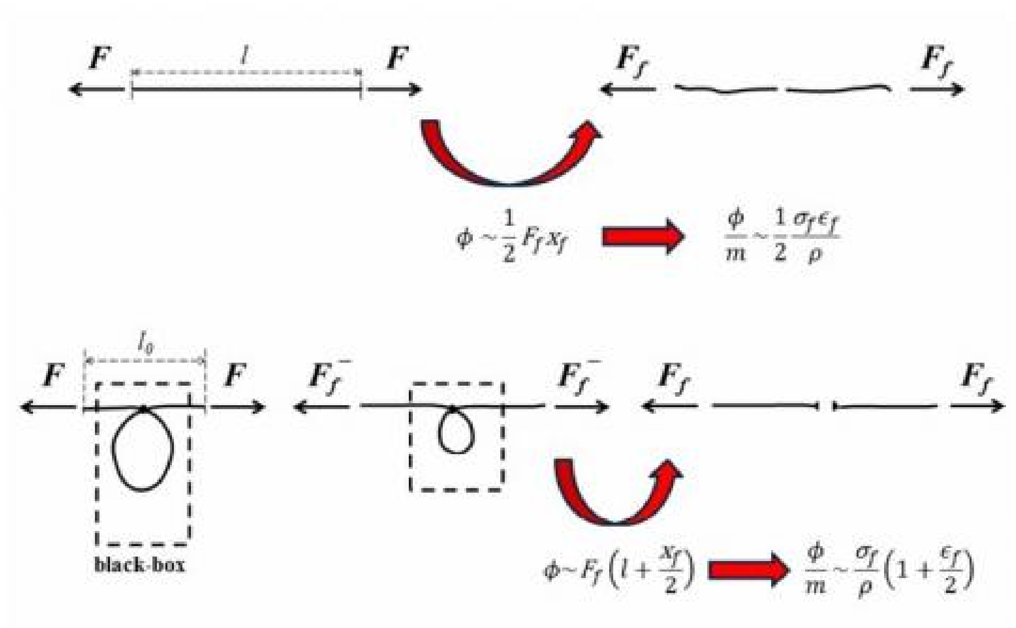
Materials scientist creates world's toughest fiber by adding slip knot

May 1 2013, by Bob Yirka



Concept. The classical fibre dissipates during fracture its cumulated strain energy. In contrast, a fibre with a slider, e.g. knot, can dissipate much more energy, thanks to a sliding friction force. Credit: arXiv:1304.6658 [cond-mat.mtrl-sci]

(Phys.org) —Italian materials scientist Nicola Pugno has realized amazing gains in adding toughness to fibers by twisting them into slip knots resulting in materials that can take far more abuse before breaking than those currently in use. In his paper he's uploaded to the preprint server *arXiv*, Pugno details how and why adding slip knots to fibers can make them much tougher.

Materials scientists describe a materials' ability to take abuse in two ways: strength and toughness. Strength is measured by describing how much force it can support, while toughness is how much energy it can absorb before it breaks—hard brittle materials such as ceramics are strong, but not tough, while rubber is pretty tough, but not necessarily very strong. Pugno's new slip knot technique—which he's named Egg of Columbus—increases a material's toughness, but not its strength—the underlying composition of the fiber isn't changed—it's more the way it's arranged.

To gain this new toughness, Pugno looked at the simple slipknot—it's a kind of knot that grows tighter around an object when the rope used to make it is pulled. Pugno noticed that as a rope was pulled through other parts of the rope, friction occurred, slowing the pulling of the rope. When applied to single fibers, he found, the same principle caused the fiber to be able to absorb more energy than it would were it simply left as a single strand. Using this technique he was able to increase the toughness of Endumax—already the world's toughest fiber—from 44 J/g up to 1070 J/g. Of course, because the material can only be pulled once, closing the slip knot, the increased toughness of the fiber is a single-shot deal.

Pugno has also found that adding coils to the slip knots, just as is done with rope, can increase the amount of friction and therefore its toughness. In experimenting with different knots and coils, he's also discovered that some work better on others and for that reason, is keeping this part of his research to himself, clearly believing there is money to be made from his fiber toughening technique.

Of course, before that can happen, Pugno, or others will have to figure out if it's possible to manufacturer fiber strands with tiny slip knots in them, in a cost effective manner. There's likely to be millions of them in a single bullet-proof vest, for example.

More information: The Egg of Columbus for making the world toughest fibres, arXiv:1304.6658 [cond-mat.mtrl-sci]
arxiv.org/abs/1304.6658

Abstract
A great flourish of interest in the development of new high-strength and high-toughness materials is taking place in contemporary materials science, with the aim of surpassing the mechanical properties of commercial high-performance fibres. Recently, macroscopic buckypapers, nanotube bundles and graphene sheets have been manufactured. While their macroscopic strength remains 1-2 orders of magnitude lower than their theoretical strength, and is thus comparable to that of current commercial fibres, recent progress has been made in significantly increasing toughness. In particular, researchers have produced extremely tough nanotube fibres with toughness modulus values of up to 570 J/g, 870 J/g and very recently, including graphene, reaching 970 J/g, thus well surpassing that of spider silk (170 J/g, with a record for a giant riverine orb spider of 390 J/g and Kevlar (80 J/g). In this letter, thanks to a new paradigm based on structural mechanics rather than on materials science, we present the Egg of Columbus for making fibres with unprecedented toughness: a slider, in the simplest form just a knot, is introduced as smart frictional element to dissipate energy and in general to reshape the fibre constitutive law, showing evidence of a previously hidden toughness, strictly related to the specific strength of the material. The result is a nearly perfectly plastic constitutive law, with a shape mimicking that of spider silk. The proof of concept is experimentally realized making the world toughest fibre, increasing the toughness modulus of a commercial Endumax fibre from 44 J/g up to 1070 J/g. The maximal achievable toughness is expected for graphene, with an ideal value of 100000 J/g.

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