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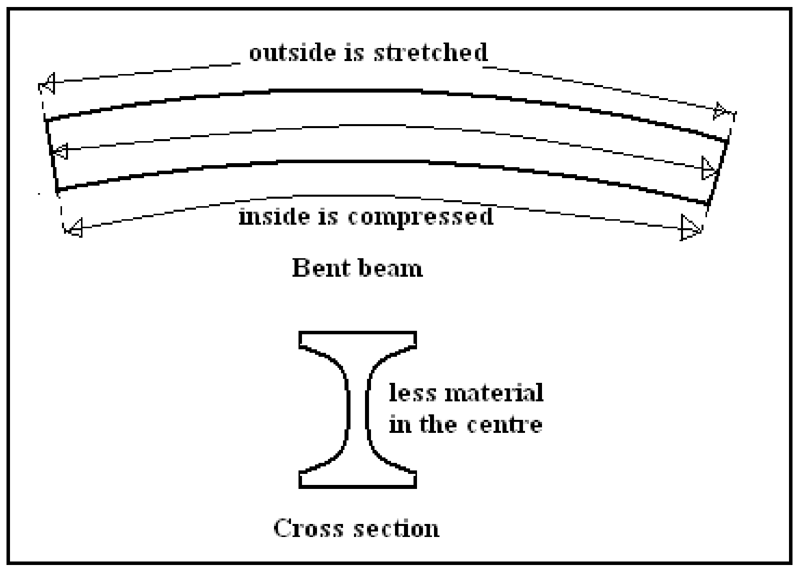
Mega Strength in Nano Materials

There is more grit to the gram in materials found in nature, says S.Ananthanarayanan.

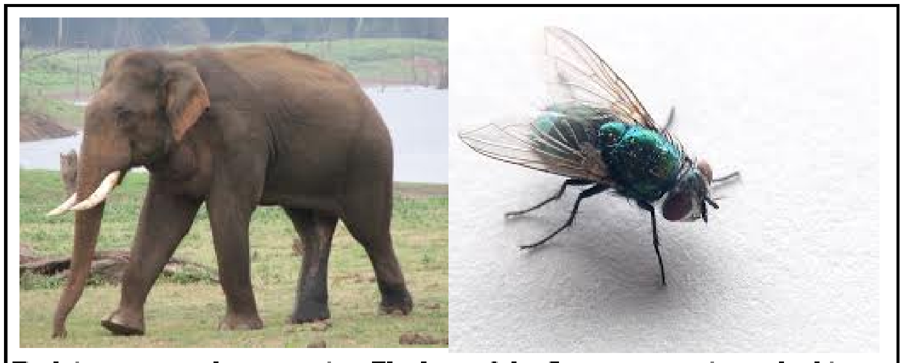
Microscopic organisms found in the sea build themselves light-weight, mineral frameworks that support the bulk of the organism. ***Radiolarians*** are single cell creatures, less than a fifth of an mm across, found in zooplankton, and they have an intricate mineral skeleton. ***Diatoms*** are microscopic, sometimes single cell, creatures that have a shell made of silica, or the material of sand. ***Sponges*** are multi-cell animals that consist of a porous network of the material of fibrous tissue.

The common feature of these organisms is that their supporting framework displays remarkable strength, considering the material of which the framework is made. In a paper published in the journal, ***Nature Materials***, Dongchan Jang, Lucas R. Meza, Frank Greer and Julia R. Greer, at the California Institute of Technology and the Jet Propulsion Lab, Pasadena, report their work on creating mimics, using the principles of natural structures, and find that the look-alikes show the same strength to weight ratio as the real thing.

Strength and dimensions

One element in efficient framework structures is that all parts of the cross section of a support are not equally important. When a beam is bent, for instance, it is the inner or the outer parts of the length of the beam that are compressed or stretched. Hence a beam can be equally strong even if material in the middle is removed – which leads to the 'I' cross section of beams used in engineering. In animal bones too, the bone is hollow, the load bearing, hard material being on the outside.	

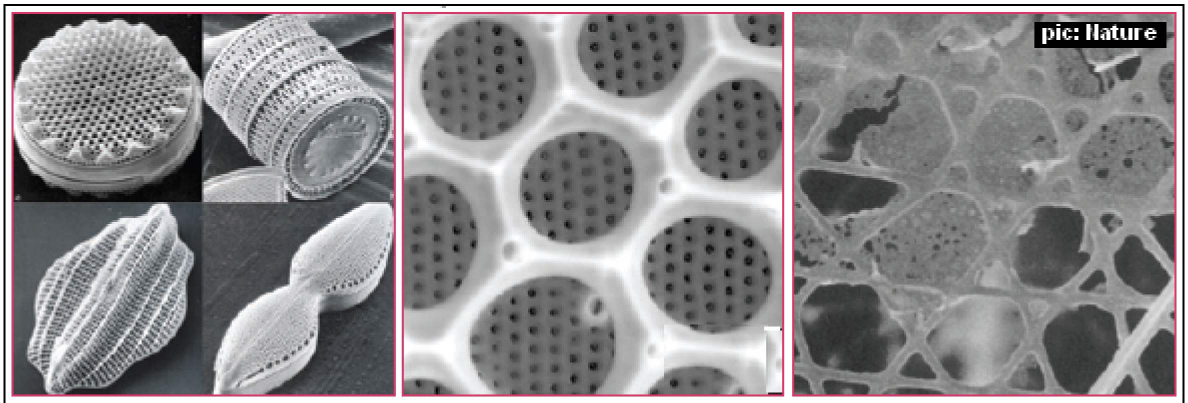
This apart, when objects become smaller, the cross section of supports can shrink faster than the dimensions of the object, because the weight to be supported depends on the cube of the dimensions, while the strength of the supports depends only on the square. This is the reason that an ant has narrow legs, compared to its body, but not so the elephant.

 Both images are the same size. The legs of the fly are proportionately thinner	But in the case of natural skeletons of micro-organisms, it is found that the ratio of mechanical strength to weight, of the support, is better that what it should be, simply based on the dimensions and the bulk properties of the materials.

One explanation could be that materials become stronger when they are in small dimensions, and forces of crystal structure are important, rather than how well the many crystals hold together. In biological structures, the different segments have evolved to come together so that the component sizes are chosen according to the size-dependent properties – leading to the best overall strength, stiffness and fracture resistance.

Copying nature

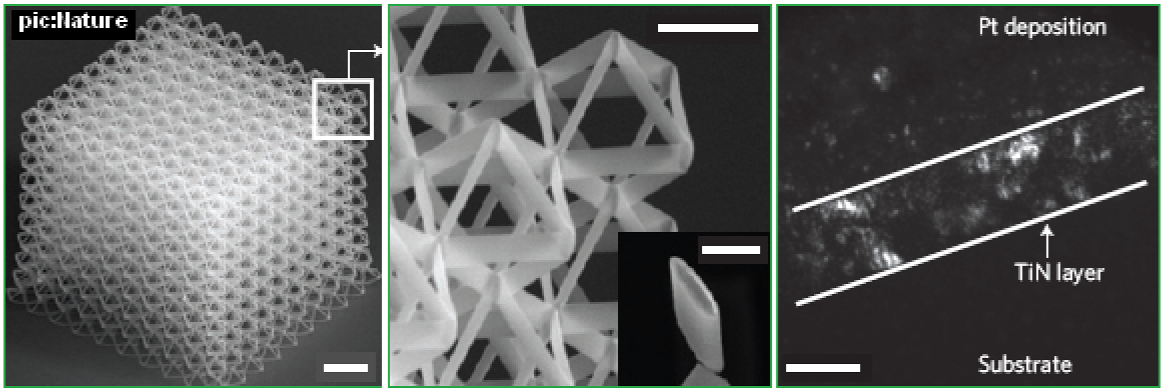
In their study, the California scientists used this idea, by first finding out the dimensions at which different materials began to show improved properties. Then, they created 3-Dimension structures, using members of the materials, of the appropriate sizes. Doing this required three conditions to be satisfied – First that the material grow stronger at some smaller dimensions. This property is found in metallic glass and in ceramics, which escape sudden collapse under load when they are the nano-scale, and also in metals in the form of single crystals. Second – there should be a technique to fabricate the components at these reduced sizes. And third, it should be possible to create a larger structure out of these smaller modules.



pic: Nature

Shell structure in different diatom species

The team was able to do all this with the ceramic material titanium nitride (TiN). The team first digitally created a 3-Dimensional structure similar to that of the diatom shell. The structure was then built up of TiN, using twin methods, called ***Two Photon Lithography*** (TPL) and ***Atomic Layer Deposition*** (ALD). The first method is similar to drawing miniature patterns for etching printed circuits on copper sheets. For making printed circuits, a full sized drawing is optically reduced and shone on a photo-sensitive layer on the copper sheet. The portion where light did not fall can then be etched away, leaving a miniature patterns of copper connectors. In TPL, a laser beam is focused to create 3-Demensional chemical changes in a photosensitive material, to leave a polymer scaffold with the required structure. TiN is then deposited, using ALD, which is a chemical vapour deposition technique where atom level layer control is possible. Etching out the polymer material then leaves a lattice of thin and hollow nano-tubes. The struts in the lattice can be about 7 microns long, of tubes with wall thickness 75 nanometers, which is 0.075 microns.



Images of synthetic lattice made from TiN

Cross section of a strut

Testing the structure that was created with a varying load showed that the material displayed good stiffness and uniform bending till about 80% of its maximum strength and then became non-uniform and failed at a load of about 150 micro Newtons. This corresponds to stretching stress of 1.76 Giga Pascals (this is about 17 million times the atmospheric pressure). This strength is an order of magnitude higher that of most similar ceramics, whose values are measured only in Mega Pascals.

The size of the structure created is a one millimeter cube. The test results suggest that the fabrication technique developed could be used to build lightweight, robust components and devices.” "With this approach, we can really start thinking about designing materials backward," says Julia R Greer, professor at CALTECH. "I can start with a property and say that I want something that has this strength or this thermal conductivity, for example. Then I can design the optimal architecture with the optimal material at the relevant size and end up with the material I wanted……We are now able to design exactly the structure that we want to replicate and then process it in such a way that it's made out of almost any material class we'd like—for example, metals, ceramics, or semiconductors—at the right dimensions."