



Tangle of silicate fibres. The smallest (arrowed) have diameters of less than 10 nm and may be individual molecular tubules. (Courtesy of Bruce A. Harrington.)

and devitrifying it. This results in elongated crystals which easily break parallel to the tube axis. The tubes can be separated by replacing the SiO^- groups on the sides of the tubes with $\text{SiOSi}(\text{CH}_3)_3$ groups so that there is only weak van der Waals bonding between them. This can be achieved by slow reaction on the solid silicate. The result is a material which seems to be bundles of fibres with a length of up to 60 μm . The diameter of the bundles ranges up to 800 nm but some fibrils have diameters of only 4 nm, comparable with that expected for a single tube (see figure).

On the nanometre scale, it is not obvious whether to treat these materials as polymers or fibres. There has been an effort over the last few years to make 'molecular composites'. A number of stiff, high-melting-point polymers were developed, principally at Wright Patterson Air Force Materials Laboratories⁴. These had a high strength parallel to the axis of the spun fibre but turned out to be very prone to fibrillation (like the lengthwise 'splitting' of the ends of human hair). This led to the idea that the stiff molecules might be given more lateral strength if they were dispersed into a tougher polymer matrix as if they were fibres in a composite⁵. In practice it proved impossible to get anything like molecular-scale dispersion and nothing has yet come of this approach.

There was also a time when it was hoped that thin (0.1 μm) whiskers of carbon, silicon carbide or metals could be used as reinforcements for composites. These did not need to be continuous if the axial ratio (length/diameter) was large, greater than 20. This approach never really succeeded because the whiskers never became available in sufficient quantities.

Composite theory lays much emphasis on the axial ratio but the effect of fibre

diameter has attracted little interest. At constant axial ratio, or for long fibres, there is no reason to expect a change in strength or stiffness of the composite with fibre diameter. This is provided that the properties of the fibres themselves do not change. Simple models for the pull-out energy and debonding energy of a single fibre scale these as radius cubed, r^3 . Because the number of fibres in a cross-section increases with decreasing fibre diameter only as $1/r^2$, one would expect the work of fracture to decrease as the fibre size is decreased⁶.

Contrary to this, our intuition would say that smaller fibres should be better, at least on the basis of maximum flaw size as outlined above. There should be some optimum strength before molecular scales are reached, because we do not expect a molecular mixture to act like a true composite. The opening up of new routes to inorganic fibres suggest that we should soon be able to put these ideas to the test.

There is a great deal at stake in this issue, as there would be extensive use of such composites to replace metal sheet in cars and elsewhere. A serious problem is the high price of forming composites layer by layer. Small fibres could allow readily mouldable composites to be made, with a consequent dramatic reduction in production costs. □

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Plastic nightmare

THE modern craze for recycling is driven more by the middle-class desire to feel virtuous than by any economic logic. Plastics pose the hardest problem, because the most earnest recycler cannot distinguish one plastic from another. Only homogeneous polymers can be reprocessed at all usefully; the ghastly mixture delivered by most recycling programmes is just about valueless. And yet all the thermoplastics share a similar molecular architecture. Each is made by linking together many copies of a basic monomer unit. The result is a carbon backbone decorated with specific side-chains: phenyl groups for polystyrene, methyl groups for polypropylene, chlorine atoms for PVC and so on. Polyesters and polyamides have phenyl groups and oxygen or nitrogen atoms inserted at intervals into the backbone. A mixture of such similar molecules, says Daedalus, should be recycled on the monomer level. The result would be a homogeneous long-chain polymer, made of all the different monomer units linked together at random.

The chemistry should be fairly simple. Some plastics revert to their original monomer on simple heating. The others could be encouraged to do so by adding the catalyst which originally polymerized them — a catalyst accelerates its back reaction just as much as the forward one. So a mixture of plastics, cunningly catalysed and carefully heated, should slowly homogenize. The various chain-breaking and re-linking reactions should all run simultaneously, scrambling the different monomer units randomly together into long, patternless chains. The mixture would slowly 'anneal' to the thermodynamically most stable copolymer that could be made from the original components.

The resulting chemist's nightmare, Daedalus's 'Massplastic', will be a stable, homogeneous polymer with very consistent physical properties. Simply on statistical grounds, most initial mixtures of recycled plastics should give very similar Massplastics.

Plastics moulders, fabricators and extruders will be able to make just about anything from Massplastic. It will be the perfect average of all they are used to, the ultimate mediocre plastic. As more and more Massplastic products hit the market, it will turn up ever more frequently in recycled material, which will scramble to an even more predictable product. Ultimately the vast bulk of plastic items will be made from this one composition, endlessly recycled. Only its colour will be against it. Averaged and re-averaged from many initial tints, it will inevitably converge to a depressing muddy brown.

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