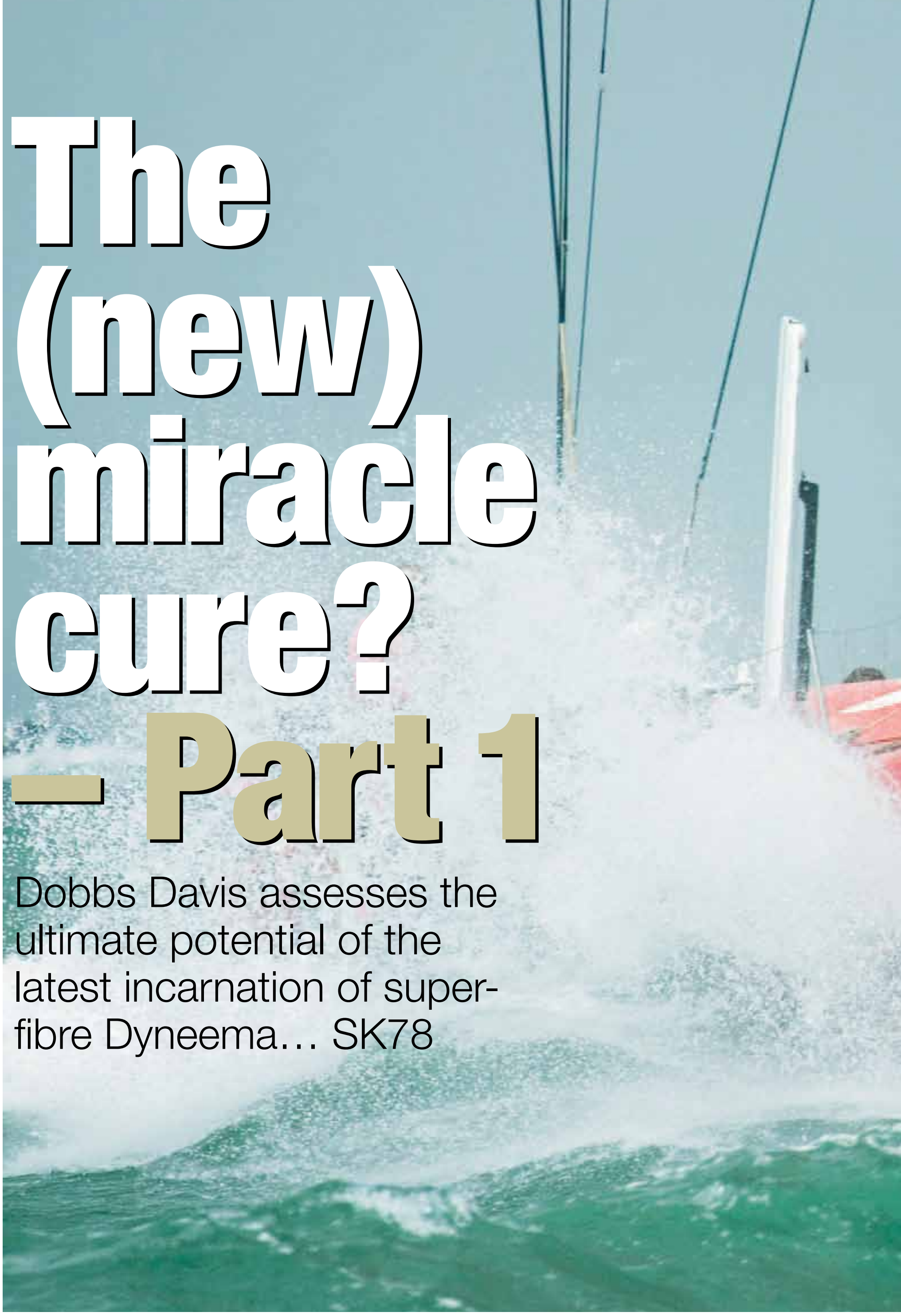
The (new) miracle cure? – Part 1

Dobbs Davis assesses the ultimate potential of the latest incarnation of super-fibre Dyneema… SK78



SALLY COLLISON

The use of manmade fibrous materials on sailing yachts is all-pervasive: the composites used in the hull, deck and appendages start with woven and/or uni-directional glass fibre, aramids or carbon, bonded to itself and to core materials using resins of various types and sophistications. Composite spars are commonly now made of uncored uni-directional and woven carbon as well, and there's increasing use of composite materials in winches, blocks and other deck hardware. Sails are, of course, constructed using either woven fibrous materials and stabilising resins, or varying densities of yarns of fibres bonded to film materials using thermoset resins.

But over the past decade or so much of the focus on development and innovation in fibre types has centred upon their application in running rigging, and, most recently, standing rigging. This development has prompted a vigorous expansion in the rope manufacturing industry as new products have been offered that combine the best qualities of the various fibre types to suit specific applications on the boat.

Nearly all performance sailors, and not just riggers, are now at least nominally conversant on what these qualities are, even though so much of the performance of these products depends not solely on the material qualities of the fibre, but how it is twisted, braided into a rope construction, combined with other fibres and coated.

Nevertheless, and regardless of these nuances in composition and construction, there have been some recent developments among suppliers of high-modulus fibres that promise to expand and improve their use in current applications and prompt us to start looking outside the box for their use in completely new contexts. Therefore the time is right to provide a summary overview of these properties to compare them against each other and engage in some speculation as to their potential for the future.

In this first of a two-part examination of the technical properties of fibres and their use, particular attention will be given to a fibre that is well known and accepted, having proved itself over the past two decades in multiple running rigging applications, but is still somewhat misunderstood; it may also be victim to an undeserved bias against its newest incarnation which may yet prove to rival carbon as a veritable wunderkind of materials. This fibre is Dyneema.

Modern synthetic fibres – an overview

The three most common manmade synthetic fibres – nylon, polyester and polypropylene – have all been produced for several decades and remain in use for many applications in the marine trade. At the time of their introduction in the 1950s they quickly replaced natural fibre materials which were generally weaker, less tenacious and prone to degradation in marine environments.

Nylon, with its low stiffness modulus, is still the material of choice where high extension is important. Also known by its chemical name polyamide, nylon does, however, suffer a 10% loss in strength in fibre form when wet, which can climb to up to a 20% loss in rope form. Wet nylon ropes experience this strength loss due to a high degree of disorientation of the molecules from the moisture absorption. After drying, strength goes back to normal levels but the rope shrinks. Nylon is also susceptible to internal abrasion during tension cyclic loading, such as occurs in mooring lines, yet certain types of nylon (such as Cordura) have proved excellent for abrasion resistance.

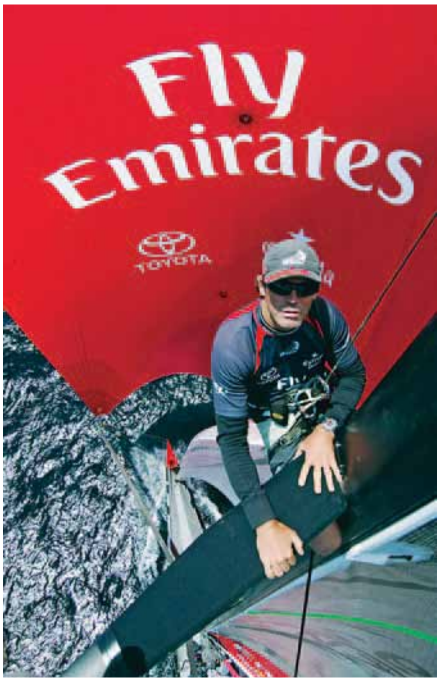
Ropes and other materials made from polyester, in contrast, have proved more durable in cyclic tensile fatigue loading, are higher in modulus strength, and do not lose strength as dramatically as nylon when wet.

Polypropylene fibre is weaker than both nylon and polyester, but it has a specific gravity less than one, which allows it to float on water. However, its low melting temperature means that high-speed cyclic loading of polypropylene rope can make it heat up, lose strength and experience creep under high loads.

High-modulus fibres

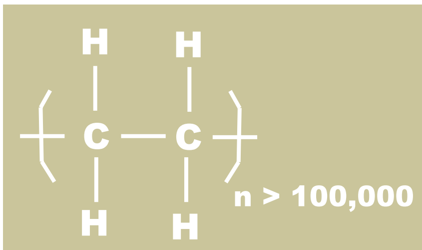
Use of the term high-modulus refers to fibre types that have elastic moduli that are significantly greater than those of the common fibres, and that also have much higher breaking strengths.

Aramid was the first high-modulus fibre, introduced as Kevlar-29 by Du Pont in the 1970s, and improved on in the 1980s with variants such as Kevlar-49. Aramid fibres are lyotropic and are produced by solvent spinning, and thus have high tensile strength, but do not melt at high temperatures. Their great strength is compromised, however, by susceptibility to weakness from



CHRIS CAMERON/DPPI

‘Pirate’ Jerry Kirby (*left*) and Adam Beashel (*above*), two men with a daily interest in the performance of anything claiming to be a ‘miracle fibre’. *Pirates* was one of the first boats to trial Dyneema SK78 in competition



Structure of UHMWPE

exposure to UV rays (in sunlight), and a rather large molecular structure makes the aramid rather dense and hydrophilic (ie water can be absorbed into the fibres).

Large cables and ropes made from aramid fibres can also experience significant strength loss due to axial compression fatigue when tightly woven fibres are forced into compression under load. This is why for standing rigging applications aramid fibres are aligned in parallel strand arrays.

There are two other principal aramid fibres: Twaron, made by Teijin, is very similar to Kevlar, and Technora, also made by Teijin, is similar though less prone to fatigue through axial compression loading and UV light exposure.

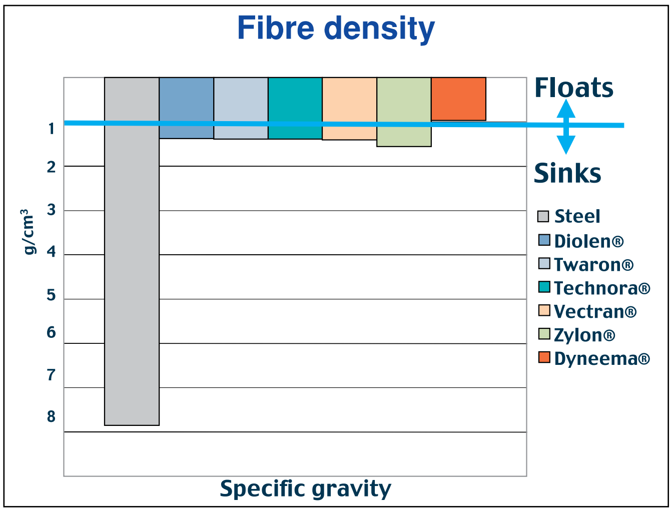
Around 1990 Hoechst Celanese introduced a fibre made from a liquid crystal polymer (LCP), or liquid crystal aromatic polyester (LCAP), called Vectran. This is now produced by Kuraray America as Vectran HT for use in cordage and sails, and Vectran UM for use in the reinforcement of composites and electromechanical cables.

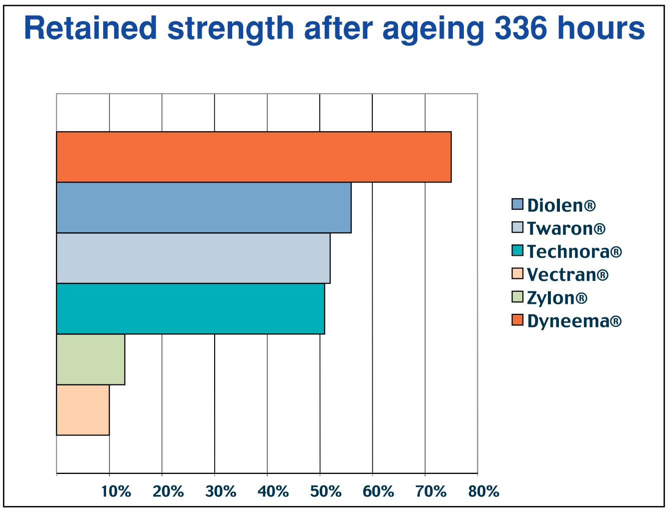
Unlike the rather loose chains of conventional polyester molecules, Vectran molecules are stiff, rod-like structures organised in ordered domains in the solid and melt states. These oriented domains lead to anisotropic behaviour in the melt state, thus prompting use of the term ‘liquid crystal polymer’. Vectran fibre is formed by melt extrusion of the LCP through fine capillaries, during which the molecular domains orient parallel to the fibre axis. The structure’s high degree of orientation and thermotropic character account for the fibre’s high melting temperature and properties of high tensile strength.

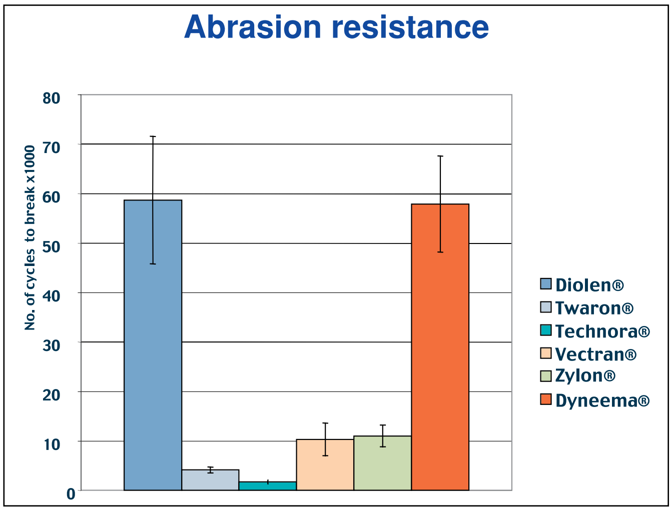
High Modulus Polyethylene (HMPE), also sometimes called Ultra High Molecular Weight Polyethylene (UHMWPE) or High Performance Polyethylene (HPPE), is a thermoplastic made from naptha. The first gelspun HMPE fibre was given the trade name Dyneema®, from the Greek for ‘strong fibre’, and the fibre and process to produce it was patented by DSM in Holland in 1979.

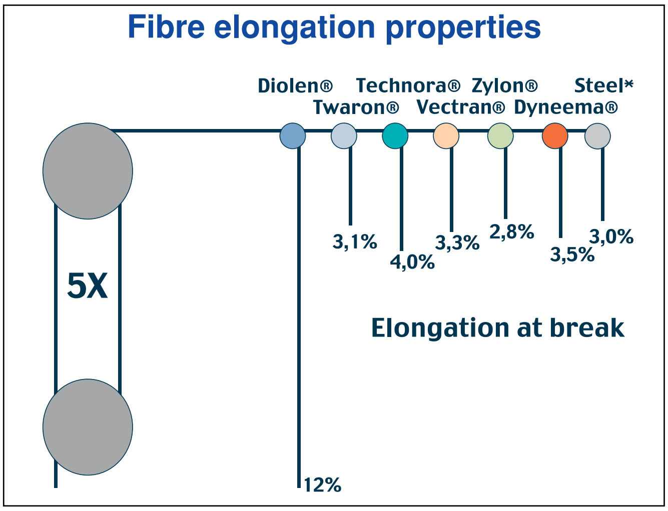
Since 1990 Dyneema has been produced by DSM at their plant in Heerlen and has been developed into different grades, such as SK60, SK65, SK75 and now SK78. In the mid-1980s DSM granted a licence for production in the US to Allied Signal Corp, which was more recently acquired by Honeywell and has been producing a similar fibre known in the US as Spectra. HMPE can also be produced using a less expensive melt-spinning and drawing process, but the resulting properties are inferior to that produced by gel spinning.

The latest class of high-modulus fibre is a complex molecule called polybenzoxazole, or PBO, first developed by the US Air Force, then produced on a limited basis by Dow and now in production by Toyobo in Japan. When introduced to the marine trade a few years ago, it looked as though PBO was going to be the new wonder fibre, with strength and modulus properties unmatched by any other synthetic polymer fibres. However, it was soon discovered that exposure to light, and not just ▷









UV light, significantly degraded the fibre to having unreliable physical properties.

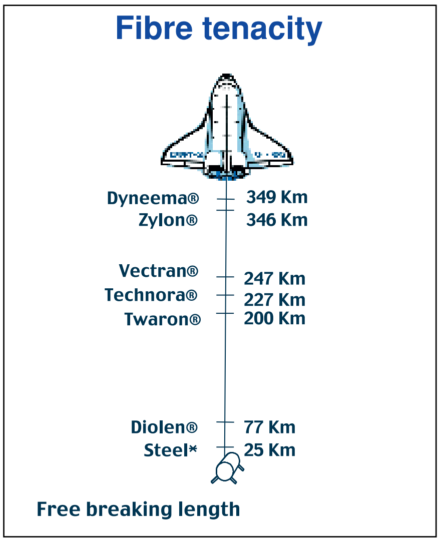
The 'strongest fibre in the world'

The molecular chemistry as well as the production process to manufacture Dyneema contribute to the fibre's unique balance of qualities that lead to its status as the strongest fibre currently in commercial production.

The starting material used is UHMWPE, a type of olefin, which is synthesised from monomers of ethylene and bonded together using a process based on metallocene catalysts into long chain molecules having 100-250,000 monomers each. These molecules have extremely high molecular weight, numbering in the millions, due to this extremely long length. This arrangement allows for excellent packing of the chains into the crystal structure, resulting in a tough material with the highest impact strength of any thermoplastic. (Aramids, in contrast, derive their strength from strong bonds between relatively short molecules.)

Production of HMPE fibre involves precision heating of the UHMWPE gel, which is forced by an extruder through a spinneret as the solvent evaporates. The extrudate is then drawn through the air. This technique produces a fibre with over 95% orientation of the polymer chains, and a level of crystallinity approaching 85%.

The close and efficient packing of the long molecular chains accounts for the tenacity of



Dyneema, where the strength of the fibre can be expressed in terms of its free breaking length. This is the theoretical length of a fibre, yarn or rope which breaks under its own weight when freely hanging, and thus is independent of thickness. When tested using ISO 2062, Dyneema's breaking length reaches in theory to the orbit of a geostationary satellite… 349 km.

The relatively simple structure of the UHMWPE molecule and weak Van der Waals bonds between chains also account for other important properties. These include low density (specific gravity is 0.97), the low melting point (152°C) and significant loss of strength at temperatures above 80°C. The slippery, non-adhesive feel, very low coefficient of friction, low moisture absorption and chemically inert nature of the fibre are also due to this simple molecular structure. This is in contrast to the complex aromatic polymers, which are susceptible to damage from solvents, aggressive chemicals and light radiation.

So does SK78 solve the creep problem?

OK, so if Dyneema has all these wonderful properties, why aren't all load-bearing fibre-based materials made from it? The answer is that, like all the high-modulus fibres, Dyneema seems to have creep too. Defined as the fibre deformation or elongation that can occur under conditions of high static loads and long periods of time, creep is different from stretch because it is inelastic and non-recoverable – clearly not a desirable quality for our purposes.

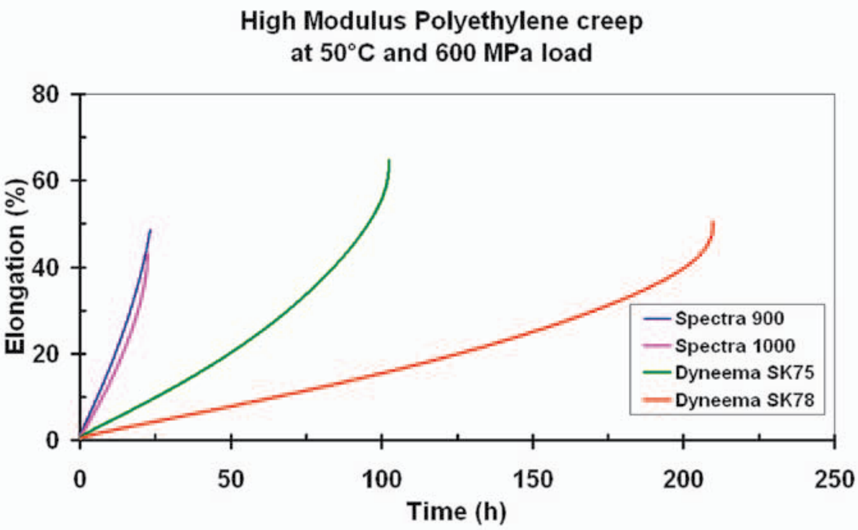
Early versions of Spectra and Dyneema seemed to suffer from noticeable degrees of creep, but this behaviour may actually have been overstated: only when subjected to high static loading for significantly long periods of time did SK75 display any measurable degree of creep.

Nonetheless, with a mandate to try to solve this vexing problem without compromising the qualities of an otherwise superior fibre (ie high strength, UV resistance, longevity, etc), scientists at DSM

Fibre property summary

Properties	Diolen® (PES)	Twaron® (Aramid)	Technora® (Aramid)	Vectran® (LCP)	Zylon® PBO	Dyneema® HMPE
Tenacity (cN/dTex)	7,6	19,6	22,3	24,2	33,9	34,2
Elongation (%)	12,3	3,1	4,0	3,3	2,8	3,4
Specific gravity (Kg/m³)	1,38	1,39	1,39	1,41	1,56	0,97
Aging/UV exposure	Good	Poor	Poor	Very Bad	Very Bad	Very Good
Abrasion	Very Good	Very Poor	Very Poor	Poor	Poor	Very Good

Creep comparison, Spectra vs Dyneema



Comparison of different HMPE fibres at the same specific load with huge differences in creep rate between HMPE fibre types. Note also significant differences in creep lifetime

started work two years ago on developing a specific new variant of Dyneema that would exhibit improved creep performance. This new fibre, dubbed SK78, was then subjected to rigorous tests supervised by the firm's sports applications manager, Dr Daniela Ribezzo. After this rope manufacturer Gottifredi Maffioli tested various lines made from SK78 successfully on *Pirates of the Caribbean* in the last Volvo Ocean Race.

Since the last VOR several manufacturing partners of DSM Dyneema have been busy incorporating SK78 into their own product lines. For example, Liros in Germany have conducted their own extensive testing regimen which demonstrated that lines made with SK78 will show extremely low or even negligible creep if the load is not held as static, but rather there are minor fluctuations in the rate and/or frequency of load levels. Using this condition, SK78's elongation measures at about the same level as those of the other high-modulus fibres.

And keep in mind that creep is a time-dependent phenomenon and so unnoticeable for most sailing applications, whether in cordage or sail fabrics, because the length of time the materials are subjected to high loads is simply too short. Test data shows that even under extreme conditions (50°C, 500 MPa applied load) Dyneema SK78 elongates only 1.5% in 24 hours, a marked improvement over SK75 which elongates 3.3% and Spectra 1000 which elongates 10.1% in the same set of conditions.

According to Rolf van Beeck, sports director for DSM, the results were very encouraging. 'The creep performance of SK78 is improved by a minimum factor of two times in comparison with SK75. This means the rope will elongate much more slowly, retaining optimal tension over time, which improves control of the sails and overall yachting performance. And handling characteristics did not change at all – only the amount of creep.'

Next month: out of the lab and into the real world ❑