fiber properties

- Highest tenacity in the world
- Very low elongation
- High durability
- Lighter than water

Introduction

The ultra-high-strength Dyneema* fibers are produced in the so-called gel spinning process, invented and patented by DSM. The intrinsic properties of the basic material, ultra-high-molecular-weight polyethylene, the parallel orientation of the molecules and the high crystallinity give Dyneema fibers their unique properties.

Basic properties

The HPPE (high performance polyethylene) fibers have a unique combination of properties.
The density is slightly less than one, so the fiber floats on water. But the tenacity of the Dyneema fibers is the highest in the world and can be up to 15 times that of a good-quality steel! Perhaps the best illustration of Dyneema's unique combination of high strength and low weight is given by the free breaking length.
This is the theoretical length of a fiber at which it will break under its own weight. The free breaking length is independent of the size of the fiber or rope and is determined only by the material properties. See figure 1.

The modulus of the Dyneema fibers is very high and so the elongation is very low.
Only metals such as steel have a lower elongation at break. Figure 2 gives the basic properties of the high performance fibers used in the production of ropes and twines and figure 3 summarizes the physical properties of the Dyneema fibers.

Durability

Dyneema has a chemical and crystalline structure that gives the fiber very good resistance to all kinds of aggressive agents and environmental influences.
Solvents and chemicals scarcely affect the performance of the Dyneema fibers. For ropes the resistance to UV radiation, sea water, weather and temperature cycles is of major importance and Dyneema has excellent long-term properties. Figure 4 shows for instance the light resistance of the most commonly used synthetic fibers.

Figure 2
Tenacity, elongation and modulus of yarns

	Density	Tensile strength	Tenacity		Modulus	Elongation
	g/cm³	N/mm²	N/Tex	g/den	N/Tex	%
DYNEEMA SK60	0.97	2700	2.8	32	91	3.5
DYNEEMA SK65	0.97	3000	3.1	35	97	3.6
Aramid regular	1.44	2950	2.05	23	41	3.6
Polyester HT	1.38	1100	0.8	9	10	13
Polyamide HT	1.14	900	0.8	9	5	20
Polypropylene	0.90	600	0.6	7	6	20
Steel	7.86	1770	0.2	2	25	1.1

*Dyneema is a trademark of DSM

Figure 1
Free breaking length

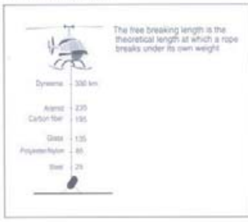
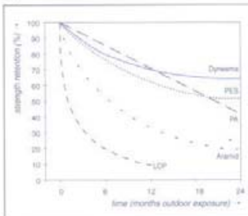


Figure 3
Physical properties of Dyneema fibers

Water and chemicals	
Moisture regain	none
Boiling water shrinkage	< 1%
Attack by water	none
Resistance to acids	excellent
Resistance to alkalis	excellent
Resistance to most chemicals	excellent
Resistance to UV light	very good
Thermal	
Melting point	144 - 152° C
Thermal conductivity (along fiber axis)	20 W/mK
Thermal expansion coefficient	-12.10^{-6} per K
Electrical	
Resistance	> 10^{14} Ohm
Dielectric strength	900 kV/cm
Dielectric constant (22° C, 10 GHz)	2.25
Loss tangent	2.10^{-4}
Mechanical	
Creep (22° C, 20% load)	1.10^{-2} % per day
Axial tensile strength	3 GPa
Axial tensile modulus	100 GPa
Axial compressive strength	0.1 GPa
Axial compressive modulus	100 GPa
Transverse tensile strength	0.03 GPa
Transverse modulus	3 GPa

Figure 4
Light resistance



dynamically loaded ropes

- *High tension fatigue*
- *High bending fatigue*
- *High abrasion resistance*
- *Improved safety, low backlash*

Service life

The durability of ropes is affected not only by environmental effects but also by the rope's mechanical loading history. Durability may be limited by yarn fatigue during bending or tensioning or by friction between the yarns in the rope. Due to the low friction of the fibers and the very good flex and tension fatigue properties, these internal processes are of no concern in a Dyneema rope. The external abrasion caused by contact of the rope with the metal parts should be controlled. A suitable cover or coating may be necessary to attain the required long service life.

Tension fatigue

Dyneema ropes were tested according to the Thousand Cycles Load Level (TCLL) test of OCIMF (Oil Companies Int. Marine Forum). The TCLL test is an accelerated fatigue test in which the rope is loaded and unloaded a 1,000 times with loads of 50%, 60%, etc. of the breaking load. The residual strength is determined after testing at 80% if the rope has not broken during testing. In tests carried out on the Dyneema ropes, the increasing strength of these ropes frustrated the testing procedure. The testing was continued to 95% of the breaking load and then the residual strength was determined at 130% of the initial breaking load! See figure 5.

Bending fatigue

Dyneema ropes should be used with a sheave/rope diameter greater than 10/1. This will help ensure a very long service life which, at normal working loads, will be at least as long as that of wire ropes.
Figure 6 shows the results of tests carried out on Dyneema ropes, wire ropes and aramid ropes.

Abrasion resistance

Dyneema has very high abrasion resistance compared with other synthetic fibers. However, a Dyneema rope in direct contact with unpolished or corroded steel may need a cover. The most common one is a braided cover. If the protection should be as high as possible an extruded cover can be applied.

Safety and backlash

A Dyneema rope has very high safety margins. When the rope is used for the first time, the load is rearranged over the Dyneema fibers, and this results in a better load sharing and a breaking load that is about 10% higher.
A Dyneema rope has very low elongation. See figure 7. This is important for the risk of backlash. The low elongation in combination with the low weight gives a low energy storage. If a rope breaks, the stored energy is released and produces a high-speed, high-energy backlash. A Dyneema rope which breaks is are certainly not harmless but due to the low energy storage the risk is much lower than in the case of wire ropes or polyamide ropes.

Figure 5
Tension fatigue (OCIMF)

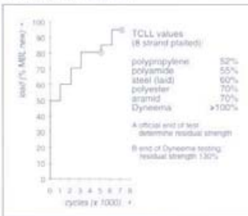


Figure 6
Bending fatigue

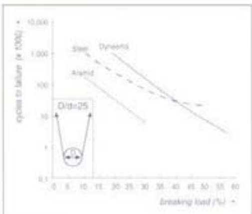
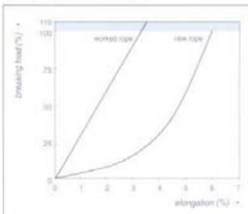
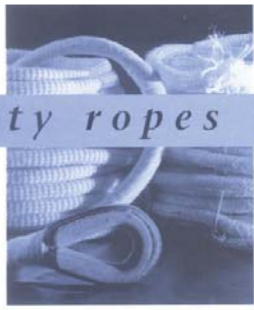


Figure 7
Worked rope and new rope





heavy-duty ropes

- Laid and plaited ropes
- Highest breaking strength
- Efficient terminations
- Diameter similar to wire ropes

Variety of constructions

Dyneema ropes are produced in a variety of constructions, the reason being that for ropes in general a maximum strength and a maximum service life are contradictory. So a rope has to be designed for a given application. See figure 8.

4 Laid rope constructions

This type of rope, which uses three or more strands, is a standard construction. In this construction Dyneema ropes can have about the same diameter and strength as wire ropes but with only 15% of the weight! This is a great advantage if wire ropes need to be replaced in an existing construction. See figure 9. For maximum strength retention long lay lengths are recommended, but the ropes will then be more vulnerable to damage and will generally need a cover. Shorter lay lengths are recommended for easier handling and splicing. Semi-parallel ropes are a special version of this type of rope. In this construction three-strand ropes are laid parallel in an external cover. These Dyneema ropes have maximum strength retention and good shape stability and so have good characteristics for use on a winch.

Plaited and braided ropes

Plaited rope constructions are used in engineered Dyneema ropes for professional applications. Common constructions are 4 x 2 strand plaited or 12 x 1 strand plaited.

These ropes combine adequate strength retention with good flexibility, easy splicing and good dynamic properties. See figure 10. For these reasons these ropes are often used in tugging and mooring. The fact that the Dyneema ropes float on water and have a low backlash is also very important in this application. The braid-on-braid construction is used as standard for yacht ropes with a polyester cover and a Dyneema core. In heavy-duty ropes both core and cover are made from Dyneema fibers.

Terminations

Ropes need terminations. Laid ropes and semi-parallel ropes can be spliced but this will require relatively long splice lengths or a special coating. For these ropes potted terminations can also be used. These terminations have proved to give good results on Dyneema ropes up to 100 tonnes breaking strength. Braided and plaited ropes are easier to splice. Even on board these ropes can easily be re-spliced. The splice efficiency can be up to 90% of the linear strength of the rope.

Figure 8
Different rope constructions

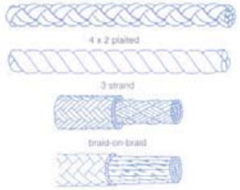


Figure 9
Breaking strength and weight of laid ropes

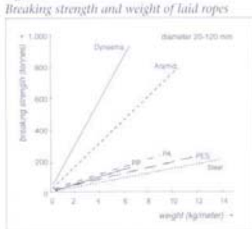
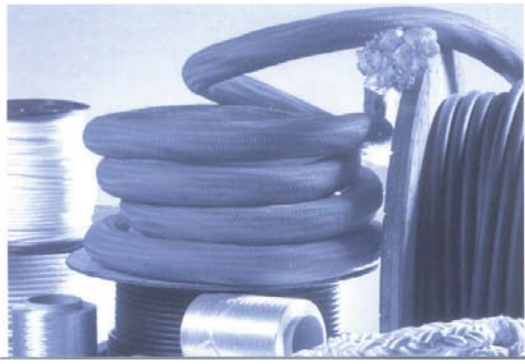
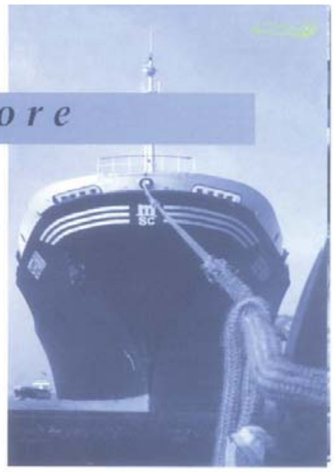


Figure 10
Breaking strength and weight of plaited ropes



marine and off-shore



- *High strength, low weight*
- *Easy handling*
- *Floating ropes*
- *Increased safety*

Marine and off-shore

Heavy-duty Dyneema ropes have proved to be a breakthrough in the replacement of wire ropes in the marine and off-shore industry.
Low weight, flexibility and easy handling result directly from the high strength and low weight.

Tugging

Easy handling and long service life are the salient features of Dyneema tug ropes used in harbour towing.
Due to the long service life, the costs of using Dyneema ropes are no higher than the costs of using "normal" ropes. Added advantages such as increased safety, easy handling, easy recovery of the floating rope and labour-saving are a bonus.
In escort-tugging a tug accompanies a tanker near the harbour for safety reasons. In these operations the speed with which the tug can be connected to the ship in an emergency is of major importance. Ropes made of Dyneema will combine the required strength with low weight and enable high-speed use.

Salvage systems

After recent tanker accidents, the discussion about rescue systems aboard tankers was accelerated.
The basic idea is that a rope is fitted to the tanker. Should the tanker go afloat or get out of control this rope will be released. A Dyneema rope is lightweight and can easily be deployed. The rope floats and can be picked up by a tug during the salvage of the tanker.

On a sandy or shallow coast it is very difficult to put out a wire-rope salvage line to a ship that has run aground. Such a line will get caught up or be buried in the sand. A Dyneema rope will float and can therefore easily be taken from the ship to the tug allowing a fast and successful salvage operation.

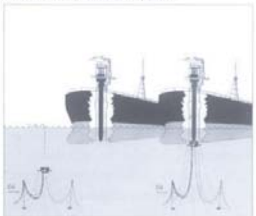
Floating pick-up line

In off-shore oil exploitation turret mooring systems have been installed. In this system a specially adapted tanker stays in place and functions as an intermediate. The tanker leaves only for special reasons, such as a typhoon. After the incident the tanker finds its way back to the turret by means of a floating pick-up line. The turret has a floating rope, made of Dyneema, that is used to make the initial connection between the tanker and the turret. See figure 11.

Mooring

The low elongation of the Dyneema ropes make these ropes specially suited for the use as spring-lines. Dyneema lines can also be used on tension winches. The low weight and low diameter Dyneema lines are very easy to handle. It has been shown in practice that it is possible to use these lines without a pick-up line, which obviates the need for the winch normally used to handle this line.

Figure 11
South Chinese Sea turret system



yacht ropes

- *Low elongation*
- *Floats on water*
- *Replaces wire rope*
- *Weight saving*

Rigging with Dyneema

With Dyneema yacht ropes the most important properties are high strength, low weight and low stretch. The ropes float on water, but have at the same time the highest strength-versus-weight ratio. Stretch is low, much lower than in the case of polyester.

Dyneema ropes normally have a braid-on-braid construction with a polyester cover. If maximum strength versus weight or diameter must be achieved, the cover can be removed. The abrasion, wear and UV resistance of the Dyneema fibers have proved adequate.

Due to the high strength, too low a diameter for easy handling may sometimes be calculated for smaller ships. In this case a rope with a larger diameter may be used, of which the core consists of a combination of Dyneema and polyester. The superior properties of Dyneema fibers can in this way be retained to a great extend.

Sheets and halyards

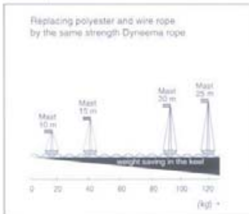
Running rig is the most important application for Dyneema yacht ropes. For racing Dyneema sheets and halyards are in fact the standard choice. The low weight and low stretch are the primary reasons for this. But the proven reliability of the Dyneema ropes during long demanding races such as the Whitbread Round-the-World and even single-handed round-the-world races may be even more important. Figure 12 presents a survey of the use of Dyneema yacht ropes on board a sailing ship.

Weight saving in the keel

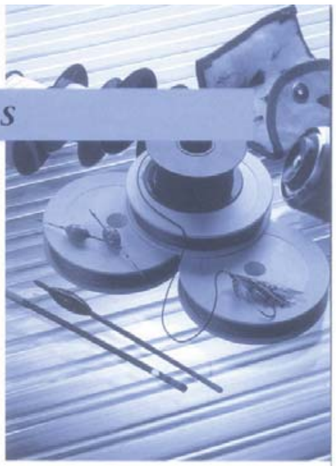
Dyneema halyards can save weight in the keel. The reasoning behind this is simply that if the top weight is reduced, a much larger weight saving can be achieved in the keel without affecting the stability of the ship. See figure 13. The top weight can be reduced by replacing existing ropes with much lighter Dyneema ropes. Dyneema ropes have a lower weight and a smaller diameter than polyester ropes of the same strength. But much more weight is saved when the wire-rope-parts of the halyards are replaced by Dyneema without a cover. This replacement is possible as the Dyneema ropes do not strictly need a cover. And the Dyneema ropes without a cover have roughly the same strength and diameter as wire ropes.

Figure 12
Use of Dyneema yacht ropes

Figure 13
Less weight in the keel



cordage and twines



- Fishing lines
- Parapent lines
- Low stretch
- Low diameter

Braided fishing lines

Dyneema braided fishing lines have the highest strength, lowest stretch and lowest diameter combination. The result is a fishing line with the highest possible performance.
The low stretch in particular is highly appreciated as this makes it possible to feel immediately the bite of the fish on the hook. Also, any action undertaken by the angler has a direct effect on the hook as there is no delay caused by the stretch, as is common with polyamide lines.
Improved catches in angling using Dyneema lines have resulted in very fast penetration of these lines in this demanding sport.

Parapent lines

In this sport a small diameter is needed to reduce air resistance, low stretch is required for maximum control of the parapent and, most important, the lines need to be reliable. Dyneema meets all these requirements. Dyneema's resistance to UV light is such that lines without a cover can be used for races. Relatively low vulnerability to local mechanical damage greatly increases the safety in this sport.

Cordage

There are many other applications in sports and professional use where Dyneema cordage and twines are used. Strong, thin Dyneema lines are used in kite flying and bowstrings in long-bow shooting are made from durable Dyneema yarns. In professional applications a lot of machinery and equipment use Dyneema cordage. Giant fishing nets are made from Dyneema twines and ropes, which result in energy savings from the reduced water resistance of the low-diameter lines.

Figure 14
Knot in a Dyneema fishing line