Dyneema®
With you when it matters

Selecting the right fiber for mooring lines

DSM

The maritime sector is as dynamic as ever. New regulatory requirements, high safety standards, cost pressure, and increasingly large vessels are just some of the challenges operators are facing today. Combined with demands for faster port turnarounds, there is increasing pressure to ensure that mooring operations are as quick, safe, and smooth as possible.

In this environment, there is an industry-wide focus on safety and efficiency in mooring. Through the creation of Dyneema® SK78, and thanks to its involvement in the development of OCIMF MEG4 guidelines, DSM is playing a key role in enabling the development of mooring lines to meet the challenges of the modern maritime sector.

The 6 key factors in selecting the right fiber for mooring lines

In this document, we examine the key factors that operators need to consider when selecting the right fiber for mooring lines, and what makes Dyneema® SK78 fiber the number one choice:

1. **Tension fatigue**
2. **Abrasion resistance**
3. **Creep life**
4. **High and low temperature performance**
5. **Low environmental footprint**
6. **Quality, certification and compliance**

Any HMPE fiber based mooring line will result in faster moorings and better ergonomics. *However, only ropes made with Dyneema® SK78 fiber offer the highest reliability from day one onwards and a superior service life compared to other HMPE.* This is because they are built from a HMPE fiber material with engineered and better characteristics to overcome the main failure mechanisms of a fiber rope.

Dyneema® SK78 combines superior tension fatigue, abrasion resistance, creep life, high and low temperature performance, and low environmental footprint. This results in the high reliability, superior service life and peace of mind required for operators to deliver cost-effective, safe and efficient mooring in ever more challenging conditions.

While selecting the right fiber is the first step in exceptional mooring line performance, it is equally important to adopt the right line design and service platform to enhance safety and service life. Our premium fiber rope partners are dedicated to making light, durable, strong, and safe mooring lines with Dyneema® SK78, and providing the service and maintenance packages that ensure they keep performing, year after year.

1. Tension fatigue

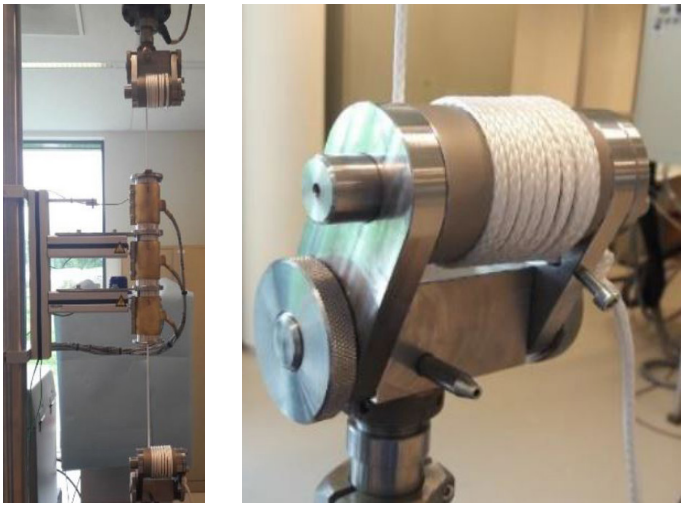
Mooring is a complex operation that can place severe wear and stress on the lines used for securing vessels. Wind, waves, currents, and passing ships mean that, even when docked, ships are in constant motion. This means that the tension placed through mooring lines is also changing all the time, contributing to material fatigue and reduced service life. This is further affected by yarns and strands continuously rubbing against each other, and being subject to changing bending angles, e.g. in the fairlead.

- DSM has engineered its Dyneema® SK78 fiber in such way that it offers at least 3x the fatigue life of generic HMPE fibers – proven at both fiber and rope level
- In addition, accurate fatigue modeling can help predict the lifetime of a mooring line, and demonstrate why Dyneema® SK78 is the right fiber for the job

Modeling and testing

With increased knowledge of rope performance comes substantial safety improvement. DSM has developed accurate models for fatigue lifetime modeling. Modeling of mooring lines made with Dyneema® SK78 under cyclic loading allows for greater predictability of rope service life, meaning that the chances of failure are reduced – improving mooring safety.

Lines made with Dyneema® SK78 are also fully stress-tested by DSM, its customers, partners, and external bodies. The following parameters are taken into account when modeling: line construction, minimum breaking load, duration of use, and metocean data.



(a) (b)

Figure 1.
(a) Rope tension fatigue test set-up with tube oven (b) Winding clamp

2. Abrasion resistance

Mooring lines are subject to high abrasive forces, making durability an essential part of performance. Dyneema® SK78 is used in a variety of applications and conditions where abrasion resistance is critical for optimum performance. When used in an unjacketed line, or as a cover in a jacketed line, Dyneema® SK78 has excellent abrasion resistance. In most applications, the use of DSM's proprietary abrasion resistance coatings will further enhance the resistance to both external and internal abrasion.

When designing a mooring line for maximum abrasion performance it is important to start with the right fiber. However, evaluating abrasion resistance of HMPE fibers is a challenge. Some fibers perform exceptionally in hex bar and yarn-on-yarn abrasion tests, but these tests do not represent maximum performance of ropes in real-life use.

- DSM wants to deliver the fibers with maximum abrasion performance, and as such, invests significantly in developing equipment and methods to test ropes and fibers in realistic conditions
- Ropes made with Dyneema® SK78 fiber have up to 4x better abrasion resistance than ropes with generic HMPE
- DSM's proprietary coatings can further enhance this abrasion resistance

Abrasion in a fairlead

Dyneema® fibers show higher performance in abrasion resistance compared with generic HMPE fibers. Depending on the load conditions, Dyneema® SK78 lasts up to 4x longer when measured as the number of cycles to failure.

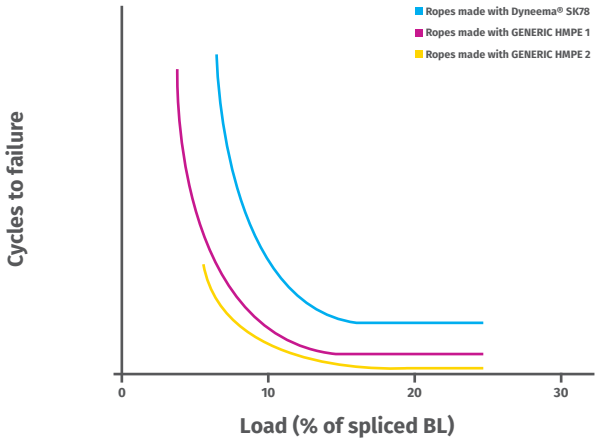


Figure 2. Comparison of fairlead abrasion performance of Dyneema® SK78 vs generic HMPE

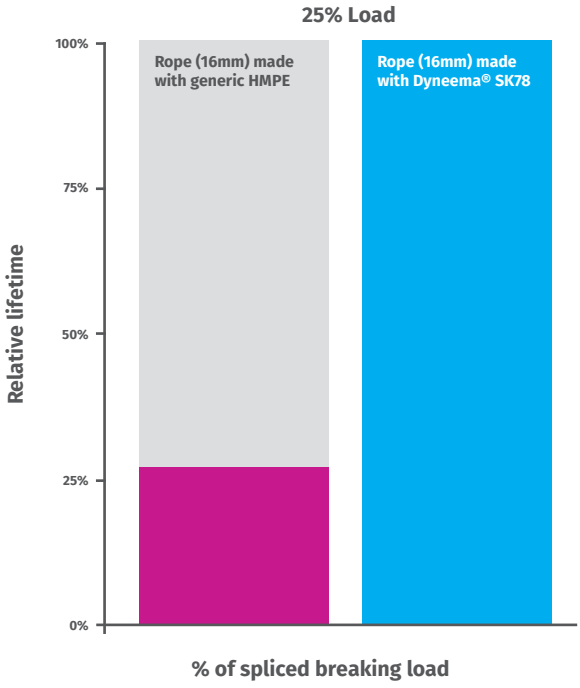


Figure 3. Ropes made with Dyneema® SK78 have a 4x better abrasion resistance than generic HMPE

DSM coating to improve performance

DSM has developed the ICO-DYN 22 rope coating that manufacturers can add to their design. Designed to protect lines against external abrasion caused by rough surfaces such as fairleads, the coating delivers a performance increase up to a factor of 3.5 in mooring situations, giving the line a much longer and more reliable lifetime.

This highly effective protection dramatically increases the service life of high-performance lines that are subjected to extreme contact and pressure points – often making them the most economical alternative.

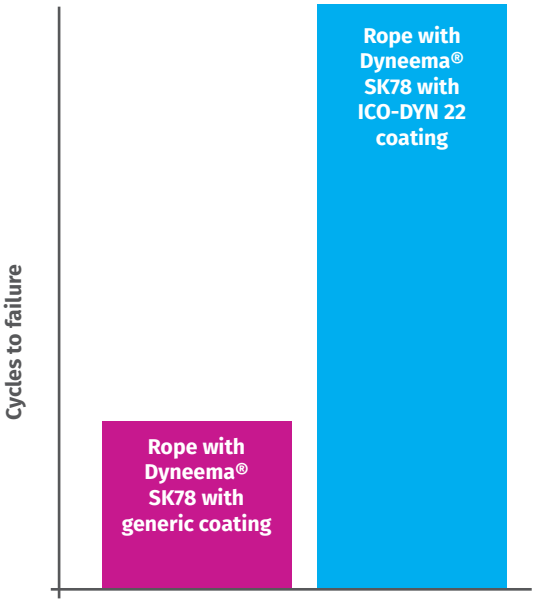


Figure 4. Improvement of fairlead abrasion performance with enhanced coating on a rope with Dyneema® SK78

Modeling and testing

DSM has designed and built a dedicated rope Abrasion Test Machine. With this machine DSM can evaluate external abrasion, which is particularly useful for improving the fiber performance for winching, lifting and mooring. This involves a modular test surface used to measure the influence of sharp angles on abrasion rates, the effects of winching, and – particularly important in mooring line – the abrasion caused by rubbing in fairleads.

Watch the video '**The future of abrasion testing**': https://www.youtube.com/watch?v=kDOJbhFUrhk

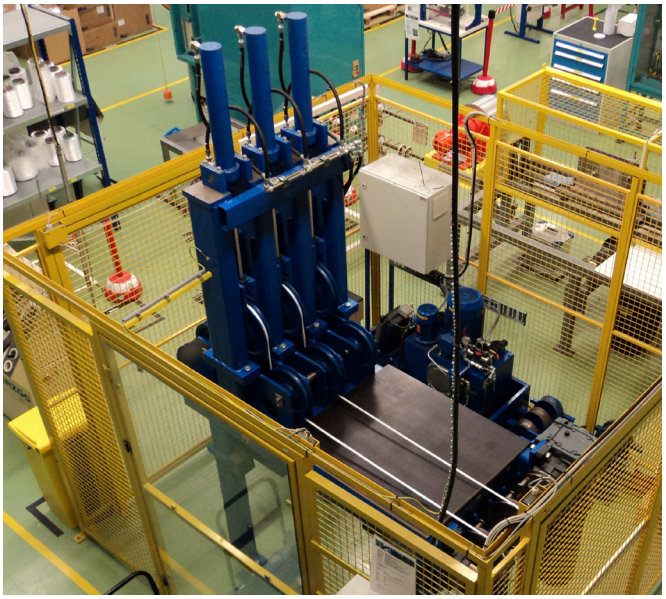
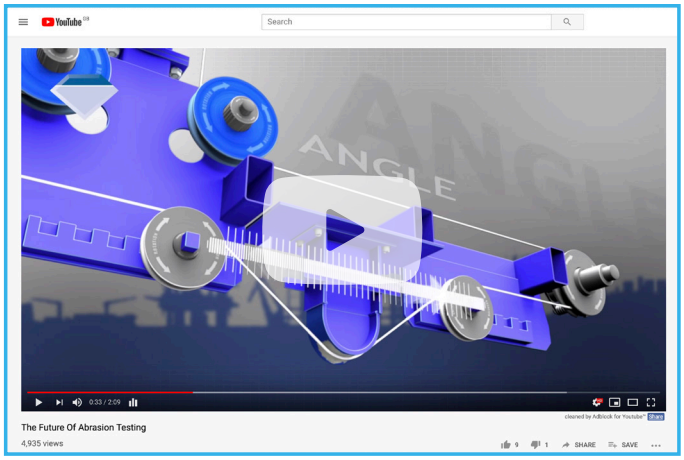


Figure 6. Abrasion Test Machine at DSM Dyneema Tech Center



3. Creep life

Generally speaking, all HMPE fibers are sensitive to long-term loads, meaning that lines made with HMPE will elongate proportionally with time. This is known as creep – a process in which the long molecular chains slide along each other and ultimately reduce the lifetime of a line.

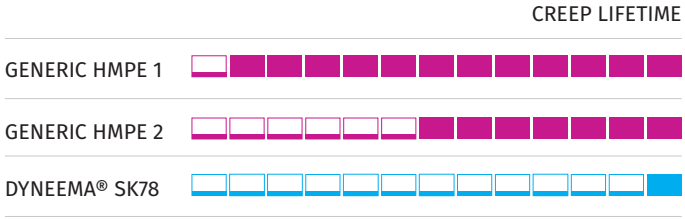
The creep phenomenon is present in all synthetic fibers yet most prominent in HMPE. Creep rates increase when using mooring lines in high ambient temperatures seen in the Middle East, for example. This makes it particularly important to be able to accurately predict the rope performance over time.

- DSM has engineered its Dyneema® SK78 fiber in such a way that it offers up to 4x the creep life performance of generic HMPE fibers – proven at both fiber and rope level
- In addition, accurate creep performance modeling can help predict the creep performance, and demonstrate why Dyneema® SK78 is the right fiber for the job

The creep of HMPE fibers is influenced by the fiber type, the ambient temperature and the applied load. Very high loads or a high temperature will accelerate the creep process. However, the time at which a HMPE line should be discarded is dependent upon load, temperature and line weight. There are also significant differences in creep resistance and characteristics across different HMPE fiber types. Those made by DSM offer the lowest creep rate and weight.

Creep Lifetime

Ropes made with Dyneema® have up to 4x longer creep lifetime compared to generic HMPE.



*Under equal load and temperature

Graph 1. Creep lifetime Dyneema® SK78 vs generic HMPE

Since the commercialization of HMPE fiber back in the 1990s, DSM has recognized the importance of predicting creep in customer applications and has since run a multi-year research program to determine which variables have a bearing on a HMPE fiber's resistance to creep. This led to the introduction of the SK78 fiber grade, which offers good creep properties for most of the applications that HMPE is used in.

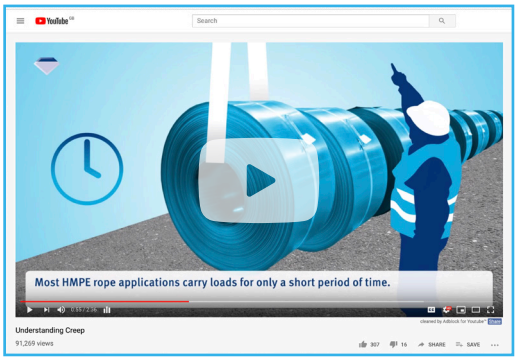
Table 1: Comparing Dyneema® SK78 vs generic HMPE in a 1,000kN BS (break strength line)

Fiber Type	Rope Core Weight (1000 kN BS)	Creep Load	Temperature	Creep Lifetime
SK78	650 g/m	200kN	20°C	8 years
other HMPE				< 3 years

Modeling and testing

Over the course of a multi-year research program, DSM has developed the Creep Performance Tool, which takes into account multiple parameters including: Type of HMPE, temperature, time, and tension. With this tool, DSM is capable of predicting creep rate and elongations, and estimating creep lifetime of applications made with its HMPE fibers.

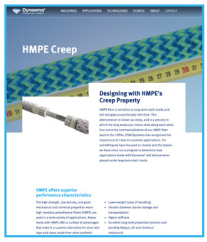
Watch the video **'Understanding Creep':**
https://www.youtube.com/watch?v=opPWceW-YKc



Innovation to increase creep lifetime in Dyneema® SK78 fibers

One challenge involved in the creation of ultra-low-creep HMPE fiber is the manufacturing process itself, which relies heavily on the agility of the polymer. However, it is this agility that means it can also elongate (creep) under permanent loads.

With Dyneema® SK78, we have found a way to retain the flexibility of the polymer during fiber manufacturing, while reducing creep when in use. This has been achieved by altering the molecular chain in such a way that these long chains no longer significantly slide along each other.



Additional information

HMPE Creep:
www.dyneema.com/creep

Table 2. Simulation results on high ambient temperature mooring conditions for a vessel using ropes with Dyneema® SK78*

	LNG vessel mooring conditions	
	Dyneema® SK78	
Rope strength	**1.5 kN/**(g/m)	
24H avg. temperature (Middle East mooring conditions)	**30°C**	
	In-harbor	**Exposed**
Mean load	20% BL 300 MPa	30% BL 450 MPa
Load amplitude	5% BL 75 MPa	20% BL 300 MPa
Exposure	500 days	25 days
Equivalent stress (combined)	336 MPa	
Calculated creep lifetime	632 mooring days	
Calculated creep lifetime (based on 12 moorings a year with 3 days of mooring at a time)	**17.4 years**	

* M. Vlasblom, R. Bosman, A. Gualdi, and J. Plaia, "Fundamental understanding of HMPE mooring rope endurance" ODN 0967, OIPEEC Conference, The Hague, 2019.

4. High and low temperature performance

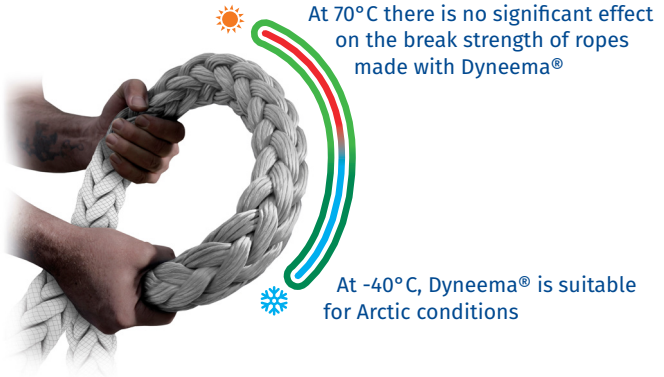
Ships are moored everywhere, from the Arctic to the Middle East, meaning that lines need to perform in a wide range of ambient temperatures. In addition to ambient temperatures, movements and tension in mooring lines generate internal friction, which can add heat and increase the core temperature of a line. Whatever the location, users need to be confident that their lines will keep performing.

HMPE fibers are known to withstand low temperatures, but most have a relatively low maximum operating temperature. For this reason, it is essential that users can predict rope performance, whatever the temperature.

- The rope temperature models developed by DSM allow for accurate prediction of rope core temperatures in static and dynamic conditions. Thanks to the properties of Dyneema® SK78 and accurate modeling, ropes with Dyneema® SK78 can be used safely at higher operating temperatures than ropes with generic HMPE

Dyneema® SK78 is used in a variety of applications and environments, with elevated ranges in temperature and loading conditions. Whether used in mining equipment, crane ropes, offshore installations or in general purpose ropes, Dyneema® SK78 can withstand high temperature fluctuations – making it the most reliable choice from the first day onwards and suitable for use the world over.

Already proven to perform for large shipping companies in the Middle East, Dyneema® SK78 is engineered to survive at high temperatures, with accurate support models developed to reduce perceived risks.



Extreme cold

Moisture does not affect rope stiffness or strength of Dyneema® SK78. The fiber is suitable for use in cryogenic temperatures. For this reason, Dyneema® fiber is used in hoses designed for liquefied natural gas (LNG) transfer at -162°C. Mooring lines made with Dyneema® fiber have been tested at -40°C (Yamal, Russia). Even with induced bends, the break strength was higher than rated.

Mooring line performance

Temperatures up to 70°C have little effect on the break strength of lines. While individual fibers lose some strength at elevated temperatures, line strength does not deteriorate to the same degree.

Modeling and testing

Models have been developed to accurately predict the temperature performance behavior in any environmental condition, ranging from Middle East to Arctic conditions.

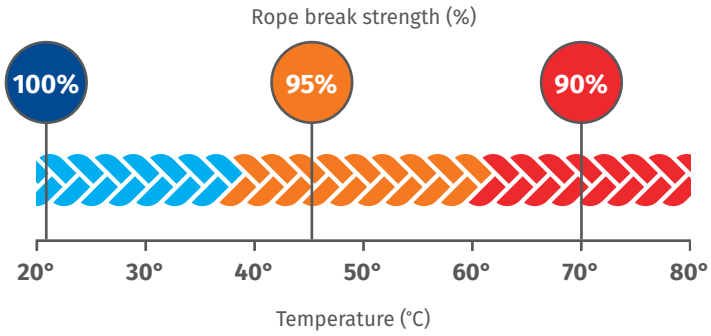


Figure 5. Rope break strength (BS) of a mooring line with Dyneema® SK78 at elevated temperature

DSM

5. Low environmental footprint

DSM has long made sustainability a core business driver and is committed to the United Nations Sustainable Development goals. Commitment to sustainability also sees DSM feature on the Dow Jones Sustainability Indices, and Fortune Magazine's 'Change the World' List, and has fed directly into the development and manufacturing of Dyneema® fiber products.

Of all high-performance fibers, Dyneema® delivers the lowest carbon footprint per unit strength. Approximately 95% of Dyneema® fiber production is based on renewable electricity, which saves CO_2 emissions equivalent to taking nearly 16,500 vehicles off the road for one year. The use of Dyneema® SK78 also helps reduce the carbon footprint downstream. The carbon footprint when using ropes with Dyneema® for mooring can be nearly 20% less than that for generic HMPE-based ropes.

Mooring lines made with Dyneema® SK78 deliver:

- Longer life expectancy, requiring less material use over the lifetime of a vessel
- Faster mooring times
- Reduced need for tugs during mooring, which also lowers operational costs
- The lowest environmental impact of any HMPE

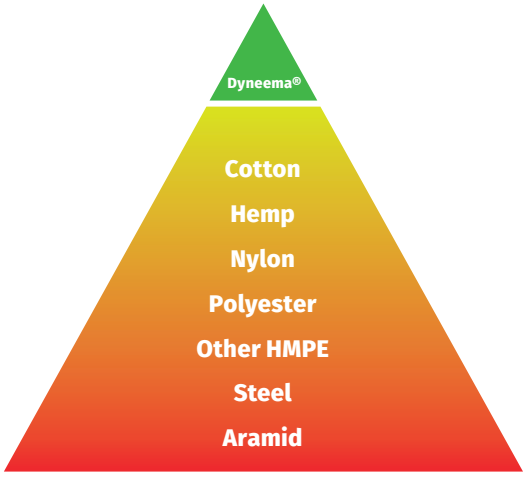


Figure 6. Dyneema® has the lowest carbon footprint per unit of strength

When measured by strength performance, Dyneema® has the lowest carbon footprint.

Because less material is needed to achieve a given performance, Dyneema® delivers the lowest carbon footprint per unit of strength.

Alternative materials and carbon footprint savings are application-specific. In every application, Dyneema® delivers the greenest strength. Please contact us to measure the environmental advantage of working with Dyneema® in a specific application.

6. Consistency in manufacturing, certification, and regulatory compliance

Dyneema® SK78 is accredited by certifying bodies like DNV GL, Bureau Veritas, and ClassNK, further demonstrating the high-performance and reliability of our fibers. In addition, our premium fiber rope partners are dedicated to making durable, strong and safe mooring and towing ropes with Dyneema® SK78 in accordance with MEG4 guidelines.

DSM has the following in place:

- DNV GL approval of fiber manufacturing
- DNV GL technology qualification: Creep Performance Tool
- Bureau Veritas type approval for mooring rope fibers
- Class-NK certification

The number one choice for mooring

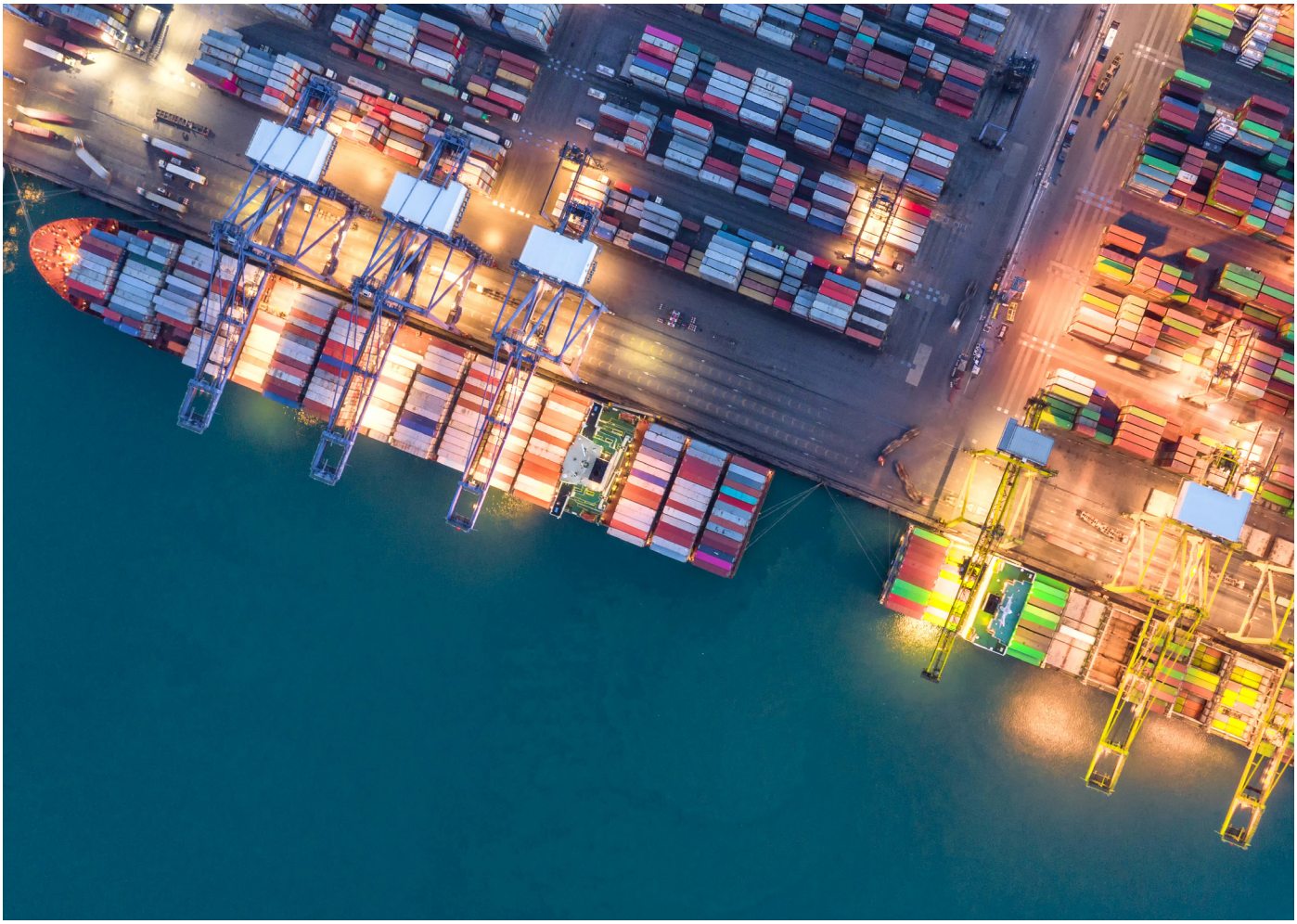
Thanks to the combination of tension fatigue and creep performance, abrasion resistance, high and low temperature performance, and reduced environmental impact, Dyneema® SK78 is the number one fiber choice for mooring lines.

When combined with the right line design – complemented by a strong maintenance and service package from one of our premium fiber rope partners – Dyneema® SK78 provides the highest reliability and peace of mind operators need to maintain safe and efficient operations.

Alongside our premium fiber rope partners, DSM remains at the heart of developing mooring safety and operational excellence. By sourcing mooring lines made with Dyneema® SK78 through an official Dyneema® licensee, operators can be sure not only of durable, strong, and safe mooring and tow lines, but also the service and maintenance packages to keep them performing, year after year.

There is a portfolio of Dyneema® fibers available for multiple heavy industry applications in maritime, offshore and heavy lifting – including Dyneema® SK78 and DM20.

To find out more about our portfolio of fiber solutions, please get in touch with one of our experts today.



The benefits of Dyneema® SK78, in summary

Only ropes made with Dyneema® SK78 provide the highest reliability from day one onwards and superior service life compared to other HMPE.

- At least 3x the fatigue life of a generic HMPE alternative. Dyneema® SK78 has the highest reliability of any HMPE fiber from day one onwards
- Up to 4x longer rope creep lifetime than generic HMPE alternatives
- Up to 4x longer rope abrasion lifetime than generic HMPE alternatives
- The only HMPE fiber engineered to withstand elevated temperatures
- DSM has accurate supportive models to predict the lifetime of ropes made with Dyneema® SK78 under various circumstances
- Of all high-performance fibers, Dyneema® delivers the lowest carbon footprint per unit strength
- Dyneema® SK78 is accredited by DNV GL, Bureau Veritas and ClassNK
- Mooring ropes made with Dyneema® SK78 surpass all OCIMF / MEG4 tests

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