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THE USE OF HIGH PERFORMANCE SYNTHETIC FIBERS IN ROPES FOR LOGGING APPLICATIONS

Paul Smeets, BSc
DSM Dyneema
Mauritslaan 49, 6129 EL Urmond, The Netherlands.
paul-p.smeets@dsm.com

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Abstract: *After the introduction of synthetic fibers like polyamide and polyester in the early part of the last century, a next generation of so called high performance fibers was discovered and developed during the last decades. HMPE (High Modulus Poly Ethylene) is one of the high performance fibers which in the mean time is established on a larger scale in all kind of applications like ballistic protection (bullet resistant vests, car armoring, helmets), sports (yachting lines, fishing lines, paralines) but also in netting and large diameter engineered ropes. Due to their high strength per weight, good UV-resistance and excellent dynamic fatigue properties like tension and bending fatigue, HMPE based ropes result in easy handling, improved safety and increased life time. These fiber and rope properties have enabled HMPE to replace other synthetic and steel wire ropes in an economical viable way in a number of predominantly dynamic applications. At the moment HMPE ropes are in use in a large number of offshore, marine and on-land applications. In this paper a general overview of fibers will be presented and the chemistry and properties of HMPE fiber will be highlighted. The properties which are important in forestry will be discussed in more detail. Some examples of rope applications in comparable industrial applications based on the HMPE fiber Dyneema® will be presented.*

1. Introduction

The introduction of synthetic fibers like polyamide and polyester in the early part of the last century resulted in replacing natural fibers in a number of textile applications including ropes.

The properties in many cases exceeded the natural fibers making these synthetic fibers the first choice. This resulted in tremendous volume growths for these fibers which in the mean time are defined as commodity industrial fibers. Polyester and polyamide fibers are manufactured world wide and arrived in a mature product phase. Nevertheless properties like strength, chemical resistance and outdoor resistance restricted in many cases the opportunities of these products to compete with steel wire ropes.

With the introduction of high tenacity, high modulus and low stretch fibers for composite and ballistic applications new opportunities opened up for light-weight alternatives for rope applications. These fibers are able to replace steel wire ropes in a number of applications where existing commodity industrial fibers did not yet succeed.

2. Overview of fibers for rope applications

Beneath a general overview is given of commercially available fibers and wire in use in rope applications (1,2).

2.1. Steel

For steel wire ropes there is a history of practical experience going back for over a 150 years; the rope constructions and terminations are proven technology.

Steel has a well-known simple elastic-plastic response compared to the more complicated (temperature dependent) load-elongation properties of synthetic fibers.

The steel wire ropes are made of a limited number of thick wires; synthetic ropes consist of millions of fine filaments.

Corrosion and metal fatigue are the potential problem areas for steel wire ropes. The lubrication may be of concern for environmental reasons. Steel wire ropes wear grooves in fairleads and other deck equipment.

Because of its weight, steel ropes are not easy to handle and cause dangerous situations when they part. Broken wires may cause injuries while handling.

2.2. Commodity Industrial Fibers

Polyamide

The first man-made fiber to be used in cordage was polyamide (nylon).

Two polyamide types are used in rope making (type 6 and 6.6). The ropes will stretch approximately 15% under normal working load, which can be desirable for some applications. Surface and internal abrasion resistance is good. Polyamide has a good resistance to most chemicals, bacterial decay and mildew. Polyamide fiber absorbs water and will shrink in a wet environment with a strength reduction of 10-15%. Polyamide fibers can be solution-dyed and are available in colours from some producers.

Polyester

The attributes of industrial grade polyester fiber are relatively lower stretch (approximately 5-10% under normal working load), no water absorption (no cold water shrinkage), good ultraviolet resistance, and good abrasion resistance, particular when wet. Polyester has a slightly lower strength-to-weight ratio than polyamide. Polyester yarn can be solution-dyed and is available in colours from some fiber producers.

2.3. High Performance Fibers

High performance fibers can be divided in 3 classes(2): polymeric fibers, carbon fibers and inorganic fibers. Since carbon fibers and inorganic fibers are in general not fit for use in most dynamic rope applications we will focus in this paper on the polymeric fibers in comparison to steel wire.

All high performance polymeric fibers resemble each other in the fact that the production process is far more complicated than for the commodity industrial fibers which can be produced via melt-spin technology.

Research is ongoing and new fibers are introduced, one of them being PBO (polybenzoxazole) which has promising tenacity but limited in use in engineered ropes due to its low UV and outdoor resistance.

The polymeric high performance fibers, also known under the names high tenacity- or high modulus fibers, are all in a sense based on long linear strings of atoms with a relatively high orientation in the axial direction.

The high level of orientation makes that these fibers show a far higher tenacity and modulus combined with a low elongation to break when compared to the class of commodity industrial fibers.

The basic building blocks or feedstock materials determine a number of chemical and mechanical properties, next to the processing technology.

Beneath an overview of the commercially available new fiber generation is given:

Aramids

Aramids were the first high performance fibers developed and commercialized by Du Pont and Akzo (now Teijin Aramid). The fiber is based on an aromatic polyamide structure (PPTA polyphenylene terephtalamide). In the last decades more fibers have been developed in the same class of chemistry and also showing identical generic properties but with improvements in specific areas like bending fatigue.

The fiber can withstand temperatures to 425°C, has low elongation to break and relatively low creep. Aramid fibers are prone to abrasion, sensitive to ultraviolet light and some chemicals and have a low resistance to axial compression fatigue, making them less suitable for dynamic rope applications.

Liquid crystal polymers (LCP)

Within polyester chemistry further developments resulted in a fully aromatic polyester developed by Celanese (now Kuraray).

LCP fiber exhibits low creep and relative good temperature resistance.

As with aramids abrasion, bending- and flex fatigue and outdoor resistance (UV) are limited.

High modulus polyethylene (HMPE)

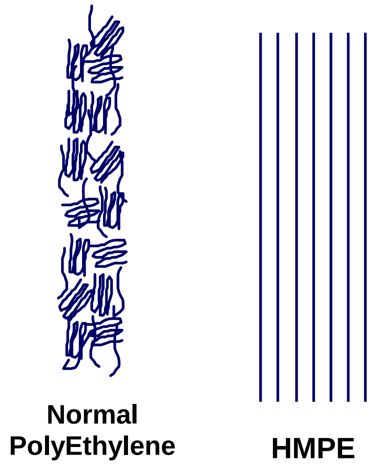
In the late seventies of the last century DSM patented the production process to manufacture HMPE fibers under the brand name Dyneema® based on their own UHMWPE (Ultra High Molecular Weight Poly Ethylene) feedstock material.

Ropes with HMPE fiber will be 7 times stronger than steel wire ropes on a weight for weight basis. They float, have excellent abrasion, bending- and tension fatigue properties and chemical resistance. UV resistance is among the best within synthetic fibers.

Limitations are in the higher temperature applications or static applications where elongation due to creep may be an issue.

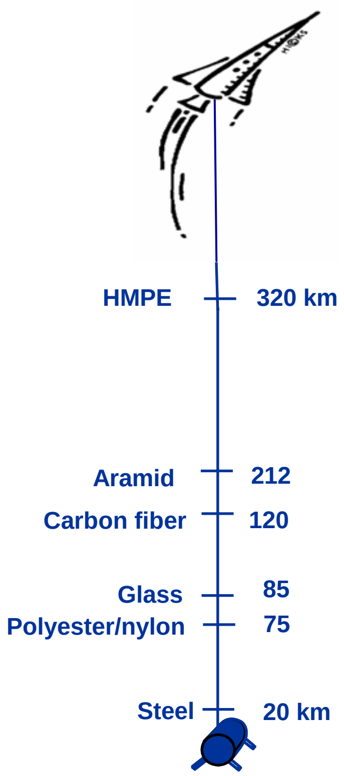
In fact HMPE molecules are comparable with PE (Poly Ethylene) but with far higher molecular weight and a far higher crystallinity (85% for HMPE compared to 60% for regular PE) as can be seen from fig. 1.

Figure 1: Schematic presentation of crystallinity in a regular PE fiber and an HMPE fiber.



Illustrative on the strength per weight of this fiber is fig. 2 where the height is given under which a specific fiber or wire would break under its own weight. The values are based on averaged values of the Cordage Institute table (3).

Figure 2: Tenacity (strength per weight) illustrated by the free breaking strength of single yarns of several fibers and steel wire



3. Required performance properties for synthetic ropes in logging operations

Both in the USA (4) and Europe (5) studies have been performed over the last years to develop light weight alternatives for steel wire ropes specifically for logging operations in mountainous terrain.

In both cases the choice was made for HMPE fiber Dyneema® based on its property profile.

To understand the selection of these fibers by the rope manufactures involved, an overview of fiber properties which are important for the logging industry in mountainous terrain are addressed here in more detail.

3.1. Weight and Diameter

As can be seen in table 1 and 2 the big advantage in many applications where ropes have to be man-handled is the weight and size.

Ropes with HMPE fibers have the advantage that they can replace steel wire ropes by the same diameter with the same strength but at only 15% of the weight!

Even compared to the other high performance fibers the weight advantage is at least 50% for the same breaking strength. See table 1.

Next to the high weight also the large diameter of ropes based on the industrial commodity fibers nylon and polyester makes that the latter fibers are eliminated for this application. See table 2.

In fact due to its lower density than water ropes with HMPE will float on water, an aspect which can be of advantage in case work has to be performed near lakes or rivers.

Table 1: Comparison of Break Strength [kN] per diameter for several fibers

Diameter [mm]	Steel 1770-2160 N\mm^2	PA	PET	Aramid	LCP	HMPE
12	84-132	33	37	148	142	142
24	350-543	134	124	485	465	493
96	5892 - 9917	1767	1877	5800	6206	5819

Table 2: Comparison of Weight [kg/100m] per diameter for several fibers

Diameter [mm]	Steel	PA	PET	Aramid	LCP	HMPE
12	53 - 66	9	11	12	13	8
24	227 - 259	37	47	45	47	31
96	3896 - 4676	583	694	704	793	461

3.2. Abrasion

Abrasion of synthetic fibers in a rope construction can occur internally between fibers and externally at the contact area with other surfaces.

Internal abrasion

Abrasion on yarn level can be caused by cutting, shear, heat generation, axial compression, particle ingress, difference in coefficient of friction, load level, moisture level etc. Due to this large number of parameters it is very difficult to develop test methods which can be related to practical applications. In general one can say that abrasion on yarn level for HMPE yarns is excellent which is most probably due to the low coefficient of friction of this fibre. Even without the need of additional coatings this will result in a high number of cycles before a rope with HMPE will fail in abrasion tests. Also the difference between wet and dry testing is small.

With additional coatings and/or optimized rope yarn, strand and rope designs internal abrasion can even be further reduced resulting in longer life time.

External abrasion

External abrasion very much depends on the surface against which the fiber or rope will have to operate.

There can be several abrasion modes which have to be known beforehand when a rope is designed for a certain application.

Abrasion on rope level can be influenced by the design of the rope which may give way to more or less construction deformation and thus causing loss in strength. Rope design can be very important in the reduction of external abrasion as will be presented in the paper from Kirth et al (6). The good cut resistance of HMPE (also used in cut-resistant applications) makes it also the preferred fiber for the outside rope protection like e.g. in covers for extreme abrasion applications.

3.3. Tension and bending fatigue

Also tension and bending fatigue are greatly determined by internal fiber interactions like shear, cutting, axial compression and buckling. The good axial compression resistance of HMPE fibers makes it possible to manufacture ropes in all kind of constructions like braided, torque-free constructions which is not preferred for e.g. aramid fibers.

Bending fatigue testing performed in 1992 and 1998 at IFT University Stuttgart (7), showed that ropes with Dyneema® can outperform steel wire rope constructions.

In the mean time further improvements in rope designs (e.g. coatings) resulted in further increased fatigue resistance. New testing at IFT is underway and will be published in due time.

3.4. Outdoor resistance

The outdoor and UV resistance of fibers can be of importance. In general how larger the rope diameter the less the UV resistance is an issue, since the penetration of UV radiation is limited to the surface. Nevertheless quite an amount of fiber in a rope construction is situated on the outer layers.

Aramids and LCP fibers will need additional precautions to improve the UV resistance. This can be achieved by additional coatings or covers. Although HMPE shows good UV performance coatings and or covers will further improve life time.

3.5. Temperature resistance

Synthetic fibers have a range of melting points.

Due to its relative low melting point of 148 °C, HMPE based ropes have a limited temperature window. The temperatures experienced in logging operations will pose no problems. However hot spots, sparks, welding etc. should be avoided when using these ropes.

3.6. Safety

Based on the low weight of HMPE ropes back injuries will reduce. Garland (4) reported the ergonomical advantages of these low weight ropes in forestry through heart rate measurements. In the case of parting of ropes under tension the low lash back and reduced mass of these ropes is a further advantage.

4. Experiences with ropes based on Dyneema®

Engineered ropes with HMPE are in use now for more than 15 years.

These ropes were first introduced in sports applications like yachting ropes for sail boats, kite lines, paraglider lines, tackle lines etc. In these cases predominantly synthetic fibers were replaced like nylon, polyester and aramids.

During the years also a number of steel wire rope applications were replaced by ropes with HMPE where weight, low stretch , fatigue performance and safety are important.

A number of existing applications are discussed in more detail below.

4.1. Harbour towing

In figure 3 a harbour towing configuration on a tug with a drum winch is depicted.
Due to the low weight of the ropes operations can be:

- performed faster
- with less deck crew (1 instead of 2)
- less (back) injuries and
- maintained safety (reduced lash back compared to other high elongation materials and the absence of so called “meat-hooks” or loose wires).

In the USA all towing companies use HMPE based towing ropes in the mean time. In Europe the percentage HMPE ropes is still growing and in new builds the preferred ropes are based on HMPE.

Figure 3: Harbour towing on drum winch

4.2. Ship mooring lines

In ship mooring lines HMPE is qualified by OCIMF (Oil Companies International Marine Forum) to dock LNG tankers (8).
Advantages of these ropes are:

- Good fatigue properties (bending fatigue, tension fatigue and axial compression)
- Good UV resistance
- Rope floats
- All rope constructions possible

Figure 4: Mooring of an LNG tanker with HMPE ropes

Due to:

- shorter docking times
- less maintenance on the ropes (no greasing)
- less maintenance of the ship (no painting)

- less winches necessary and
- improved safety

the value in use of these ropes made the introduction in this industry take place in a very fast pace.

4.3. Off shore mooring lines and work ropes

In the offshore industry weight reduction is again the key driver to change towards HMPE ropes. Ropes with Dyneema® are now in use for mooring of oil platforms (see figure 5), but also in a number of operations like anchoring (see figure 6), seismic surveys, pipe laying etc.

Figure 5: Mooring lines

Figure 6: Work ropes

4.3. Hauling ropes for on-land applications

For hauling of electrical wires overland and underground HMPE based ropes make smaller diameters for the same strength possible which again makes longer lengths possible on the drum winch. Furthermore abrasion and cutting resistance of these ropes over sharp edges and corners have improved in comparison with former used ropes based on industrial commodity yarns. See figure 7.

Figure 7: Hauling winch for electrical cables

4.4. Round slings

One of the latest developments is the introduction of HMPE fibers in round slings and covers. Especially in the heavy lift slings again weight reduction makes it possible to still man-handle these slings. Extended life time (number of lifts) and improved cut resistance through the development of special covers with Dyneema® are the advantages in e.g. sharp edged coils. See figure 10.

Figure: 8HMPE round slings

4.5. Conclusion

New high performance fibers have opened up new opportunities in the rope market in the last two to three decades. HMPE fibers have proven to be the best alternative for several steel wire applications where low weight, low lash-back and good environmental and fatigue performance are of importance.

Within forestry applications HMPE has shown to have the best mix of properties needed in this application field.

Nevertheless synthetic ropes will need to be handled as such and specific handling instructions will be different from steel wire ropes.

In return these ropes will prove their value in use through reduced processing time, improved safety, longer life time and less maintenance.

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