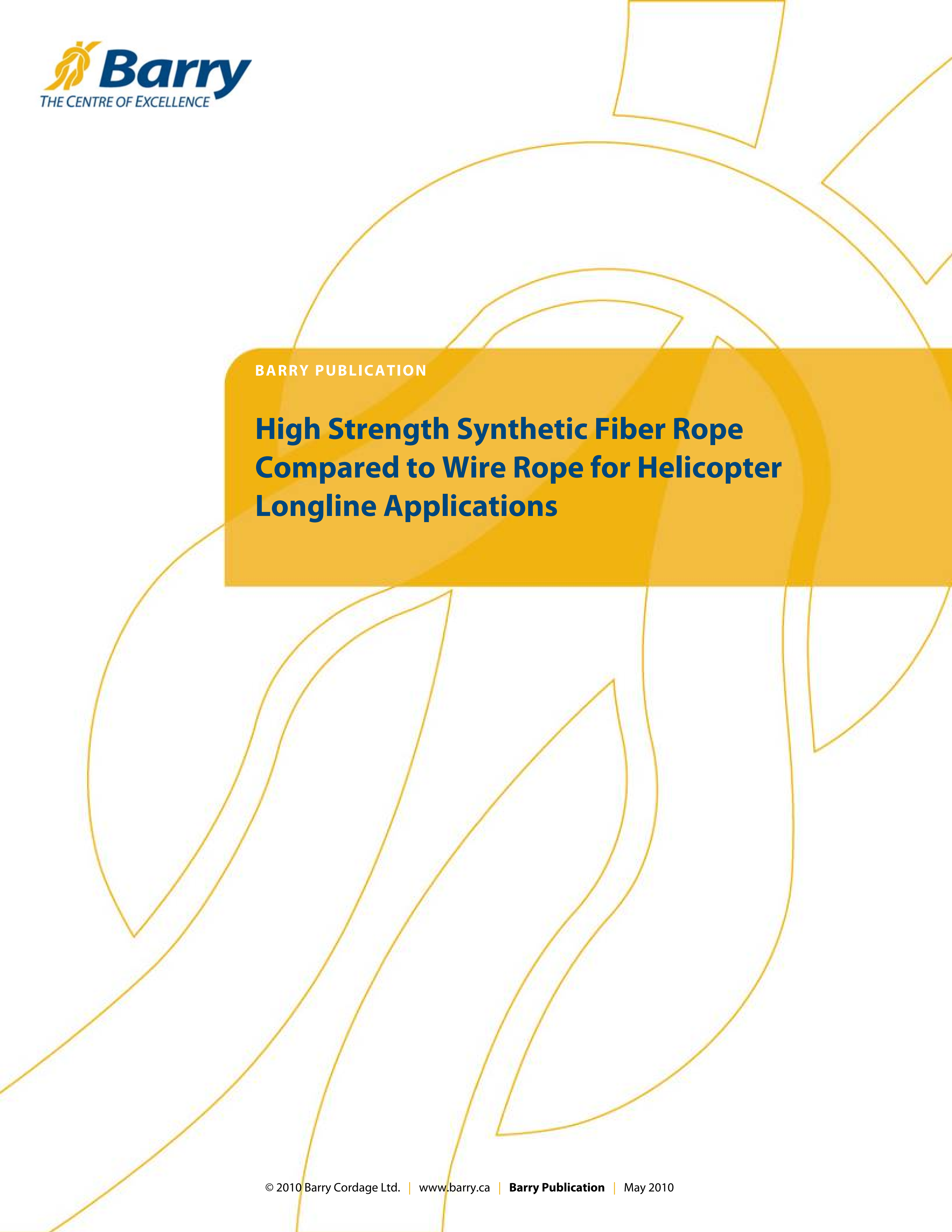
Barry
THE CENTRE OF EXCELLENCE



BARRY PUBLICATION

High Strength Synthetic Fiber Rope Compared to Wire Rope for Helicopter Longline Applications

Introduction

The use of synthetic materials for the fabrication of helicopter longlines dedicated to external load operations began some decades ago and has gained widespread acceptance as a replacement to the traditional longlines, which were made of steel cable (wire rope).

Initially, fibers such as nylon, polyester and aramid (Kevlar) were utilized. However, each of these fibers presented disadvantages that made their use problematic.

For example, nylon and polyester have too much elasticity and as the loads were being picked up, the longlines stretched much more than the electrical wires running parallel to them, which resulted in breaking of the wires and loads swinging dangerously. In addition, the recoil energy of these materials made their sudden failure potentially dangerous should they send the free end into a rotor.

The disadvantage of aramid is rapid loss of strength due to salt water, humidity and UV radiation. While this was considered a breakthrough fiber some decades ago, its use is very limited today. It has been replaced with Dyneema, a high modulus polyethylene (HMPE).

A primary advantage of synthetic fiber rope is that it is lightweight. Lightweight longlines are easier to handle and reduce ground support equipment and personnel. Additionally, the reduced weight of the longline itself can translate into greater payload and increased efficiency.

Weight Comparison

Dyneema's density is 1/8' that of steel. A 1" Dyneema® and wire each have approximately 109,000-pound average break strength. However, the weight per 100 feet is very different:

Table 1:

	Approx. weight / 100 feet
Steel (19 X 7)	185 lbs
Dyneema®	22 lbs

The payload advantage of Dyneema® compared to steel increases with the length of the longline. A 200-ft Dyneema® longline yields approximately 325 lbs of additional payload.

Fatigue Resistance

The fatigue properties of Dyneema® rope are remarkable and put this fiber in a class of its own.

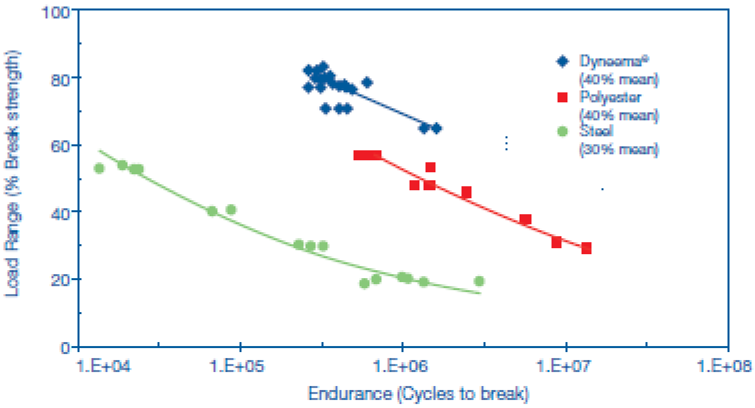


Figure 1: Tension fatigue life of various ropes.

Bend Over Sheaves

Synthetic ropes have been demonstrated to withstand 50,000 bending cycles over sheaves forty times the rope's outside diameter at 35% of the rated break strength without failure. Residual strength is 95% of the rope's original rated break strength. Thus, the synthetic rope's performance under these conditions is comparable to a 6-strand steel wire rope that is not torque-balanced.

Dyneema® ropes have demonstrated outstanding performance at a sheave diameter / rope diameter (D/d) ratio of 8:1 and a relatively high safety factor. It is more common, however, to use Dyneema® ropes at a 10 to1 D/d ratio and a 7:1 or 10:1 safety factor.

Low Stretch

Due to the high modulus of Dyneema®, there is minimal stretch and stored energy over the working load range. Figure 2 is a load elongation curve for Dyneema®.

Ropes made from other synthetic fibers, like nylon, have about ten times the stretch of Dyneema®. Low stretch gives the user better control over the load's position and faster reaction to the loads touching the ground.

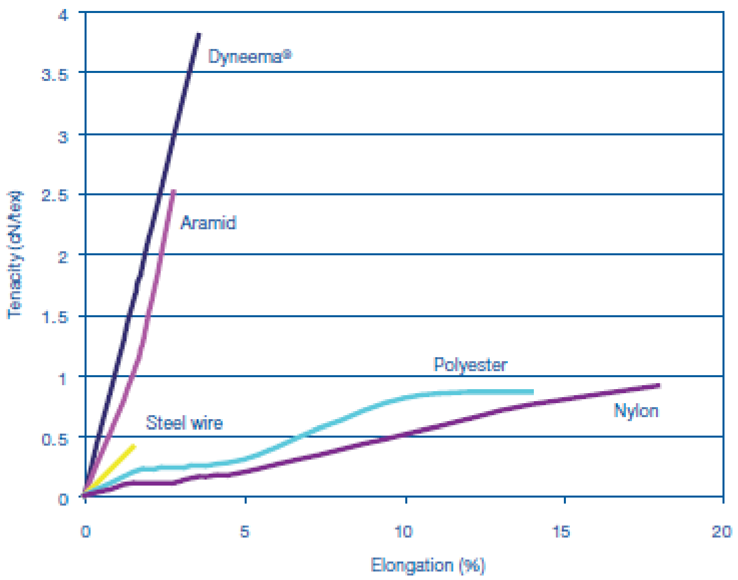


Figure 2: Tenacity elongation curves for various fibers.

Low stretch also means less stored energy in Dyneema® ropes which can be invaluable. For example, there is one tenth the recoil with Dyneema® than nylon rope.

Recoil

Recoil is the phenomena whereby the broken ends of a tensioned rope draw back rapidly after break. This may also be referred to as "snap-back".

The intensity of snap-back is in proportion to the energy stored in the rope at the point of break. The stored energy varies according to the stretch of the rope and the length of the rope. In general, a longer rope will produce greater recoil intensity and the recoil distance will be longer. Any tensioned rope, including wire rope, can recoil. The recoil energy of ropes made of more elastic fibers, such as nylon or polyester, is greater than that of wire rope. However, the wire rope twisted construction (cable-laid) creates a spring-like effect that makes the wire recoil in a sudden and unpredictable path.

Observations were made during recent preliminary testing of snap-back (recoil) of nylon, polyester, aramid, Dyneema® (UHMPE), and wire rope suddenly released under load in the vertical plane. During this testing, the UHMPE rope had the least amount of snap-back and it was observed that the stored energy of nylon, polyester, aramid, and steel cable, when a load is suddenly dropped, can bring the free end close to or beyond the anchor point of the fixed end.

Video images were analyzed at slow speed to determine the distance of travel of the recoiling part (free end), as well as to make a qualitative evaluation of the various rope types as follows:

Table 2:

Fiber	Distance Travelled / Length (%)	Observations
Polyester	+ 100	Impact beyond anchor point
Nylon	+ 100	Impact beyond anchor point
Aramid	95	Very high recoil force
Steel wire	80	High recoil force
Dyneema®	25 to 50	Low recoil force

Video on Recoil phenomena:
http://www.barry.ca/video/snap-back-phenomena.wmv
http://www.barry.ca/video/snap-back-steel-dyneema.wmv

Reduced Recoil Risk Rope

A Cordage Institute Standard (CI 1502-06 Test method for High Modulus Reduced Recoil Risk Rope) exists for the fabrication of reduced recoil risk rope. These ropes are typically used as mooring hawsers for heavy marine applications. The principle applied for the manufacture of these ropes is that any given rope will have an initial break point where only some of the strands of yarn break at a predictable point and the residual rope yarns will continue to elongate and will break during a secondary phase, thereby providing users a warning (loud sound) and time to take cover if persons are in the path of the failing line.

In the case of helicopter longlines, whereby the load is suspended in the vertical plane, this feature would not be effective since one (or both) anchor points are moving and the sound would not likely be heard. As the rope begins to fail, the load starts to fall immediately and the slack is taken up right away. The reduced recoil rope may break in successive cascading stages, delaying the time of complete rope break, but in the end, the line may soon fail entirely.

Furthermore, the reduced recoil risk rope is only effective when it is the rope itself that breaks. In a longline, the rope is connected to other components (shackles, rings, hooks, etc.). Failure of any of these components will not enable the reduced recoil function of the rope to act out and dissipate the accumulated energy.

When considering the choice of materials for helicopter longlines, one must also consider the following. Longlines are usually inserted in a protective jacket and may have heavy electrical wires, hydraulic hoses, etc. In the case of sudden failure of the longline, the jacket, wires, hoses would all act to weigh down the line and reduce greatly the recoil energy. In fact, it may be argued that the snap-back of such longlines is a moot point.

Working Load Limit and Safety Factor

When synthetic longlines are selected for a given application, it is imperative to know the total potential load that the longline will encounter during accidental dynamic loading. Recent in-flight testing of various rope types and fibers subjected to various dynamic loading conditions which may be encountered during flight, such as: pulling pitch, sudden start, sudden stop, hard banked turn, etc., has revealed interesting results. The maximum G force measured was in the range of 2 to 2.5. Under these conditions, the Dyneema SK75 had the best energy dampening profile when compared to nylon and wire rope.

The US Forest Service requires that a 7:1 safety factor be applied to longlines. In the case of a 25,000 lbs load, the maximum total potential load as a result of sudden dynamic loading could be in the range of 2.5 x 25,000 = 62,500 lbs.

A longline with minimum break strength of 175,000 lbs would have a 1.5 inch diameter x 200 ft and would weigh 104 lbs. It is important to note that rope break strength referred to is always for new rope tested under laboratory conditions. It is imperative to perform constant inspection and validation of the longline's residual strength as soon as it is put in service.

Recent testing of a helicopter longline which had a rated ultimate breaking strength of 220,000 lbs and a working load limit of 25,000 with a safety factor of 8.7 to 1, revealed a residual tensile strength of 80,000 lbs after performing a break test. This value is getting close to the total potential load value of 62,500 lbs.

The fiber used in the above example was UHMPE (Plasma), and although recoil at failure may not be an imminent threat, dropping the load poses an equally unacceptable hazard. Ongoing testing of longlines for R&D and annual recertification indicates that there is a predictable decrease in the longlines residual tensile strength as service life advances. Monitoring the longlines residual strength and re-evaluating the working load limit annually provides users a greater amount of safety and comfort. A longline may be selected at a higher initial tensile strength, using a larger diameter than necessary, so that under normal conditions of use the longline will maintain its working load limit and safety factor throughout its useful life.

Disadvantages

The main disadvantage of these materials is that they are easier to damage. Being less robust than steel wire rope, synthetic rope shows more evidence of the damages it receives. Rope damage often tends to look less severe than it really is. In particular wire rope, is frequently used even when it should be retired from service.

Materials

Several fibers are currently available for rope in helicopter operations. Physical properties of Dyneema® and steel are compared in the following table.

Table 3:

Property Comparison of Dyneema® and Steel

Physical Properties	**Dyneema®**	**Galvanized Improved Plow Steel**
Tenacity (g/den)	35	2,9
(psi)	435,000	285,000
Modulus (g/den)	2000	200
(1,000,000 psi)	25	30
Elongation (%)	2,7	2
Density (g/cc)	0,97	7,86
Melting point (˚C)	147°	>1199°

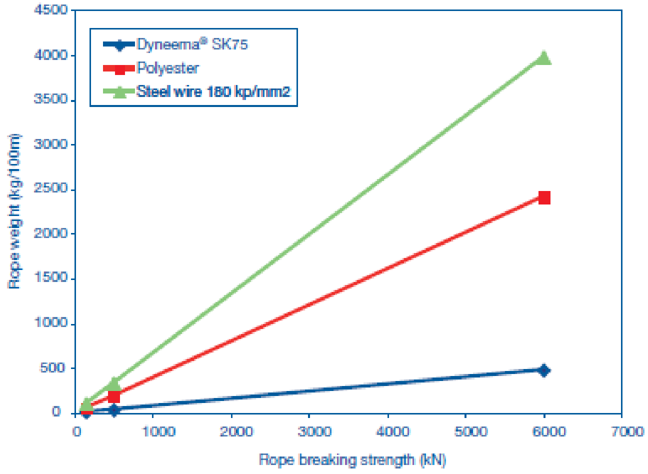


Figure 3: Typical weight and strength of various ropes.

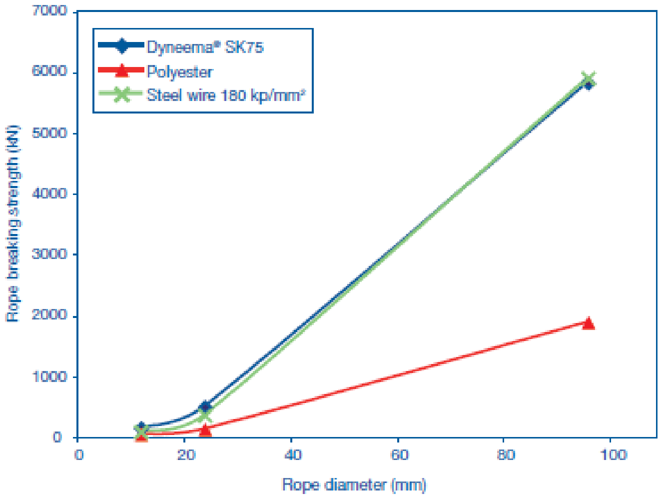


Figure 4: Typical break strength and rope diameter.

Dyneema® SK75

Dyneema® SK75 is an ultra high modulus polyethylene fiber (UHMPE) developed by DSM- Dyneema®. Dyneema® fiber combines a high degree of molecular orientation with a density that is lower than water.

Dyneema® can also be made into buoyant ropes. Dyneema® SK75 demonstrates high specific modulus, high specific strength, excellent chemical resistance and high abrasion resistance.

The disadvantages of Dyneema® are its relatively high price, its tendency to creep under constant static load and limited temperature range.

Its principal advantages are its lighter weight (buoyant) and longer cyclic bend over sheave flex life. This fiber is also very difficult to cut and, as an example, butcher gloves and lumberjack chaps are made of Dyneema® as a protection from sharp knives and chainsaw blades.

Jackets

For use on helicopter longlines, Dyneema® generally requires protective jackets. These jackets are intended to provide protection from UV light, dust and external abrasion. The jackets can be double or triple layered and may be made with fire resistant materials such as Kevlar/Nomex in instances where they may be exposed to a nearby intense heat source.

Jackets may be closed off using Velcro or heavy duty (protected) zippers. The zipper option enables faster accessibility for easier inspection and changeovers of wires, hoses, etc.

Construction

A 12-strand braided construction is used to enable complete inspection of both outside and inside the rope's surfaces. It is also easy to splice and repair.

Terminations

The final break strength of a rope is often determined by the efficiency of the rope's termination. Some terminating techniques can increase a rope's full break strength, while others severely limit the break strength. Knots may remove as much as 60 % of the rope's strength and, in the case of Dyneema®, should never be used as they slip out and do not hold.

The actual type of splice required depends on the rope's construction. An efficient method to terminate a 12-strand braided Dyneema® rope is the eye splice. These splices are constructed by forming an eye near the end of the rope, then tucking the tails of the rope back into the rope's body. The point where the last tuck (or rope) ends, is usually where it fails at break. An appropriately sized thimble is required to support the splice and protect against premature wear.

Summary

Since there are so many uses for synthetic rope, it is impossible to have one generic material or construction to suit all applications, making a variety of ropes necessary. However, for most helicopter longlines (lifting) applications, the Dyneema® SK75 12-strand rope provides a good combination of characteristics.

These characteristics include: relative small diameter for high strength, lightweight, low-stretch, low recoil energy, torque balance with good bend over sheave and outstanding tension fatigue life. Combining this type of rope with a reliable termination translates into 100% strength.

Dyneema® SK75 Specifications for 12 strand rope

Table 4:

Outside diameter (inches)	Average break strength (lbs)	Weight (lbs / 100 ft)
3/8"	19,600	3,6
7/16"	23,900	4.2
½"	34,000	6.4
5/8"	52,800	10.2
¾"	64,400	13.3
1"	109,000	21.8
1-1/4"	165,000	36.2
1 -1/2"	228,000	51.7
1 -3/4"	335,000	78.4
2"	381,000	87.0

Chemical resistance:

Table 5:

Chemical Resistance of HMPE (Applies only to rope made of Dyneema®)		
Resistance to acids		Excellent
Resistance to alkali		Excellent
Resistance to most materials		Excellent
Resistance to water		Excellent
Aviation jet A fuel (ISO 1817 test liquid F)	RTCA DO160	Excellent
Hydraulic fluid (ISO 1817 test liquid 103)	RTCA DO160	Excellent
Lubricating oil (ISO 1817 test liquid 101)	RTCA DO160	Excellent
Solvents and cleaning fluid (Isopropyl alcohol)	RTCA DO160	Excellent
De-icing fluid (Ethylene glycol)	RTCA DO160	Excellent
Insecticide (Pyrethroid pesticide)	RTCA DO160	Excellent
Fire extinguishant (Protein, Fluroprotein)	RTCA DO160	Excellent
(Reference: Royal DSM N.V. – Dyneema literature)		

Table 6:

Heat and Chemical Resistance of Polyamide (Nylon) (Applies to whipping and lock-stitch twine, jacket and carry bag)	
Melting point	215°C -260°C
Resistance to short-term heat	130°C
UV-Resistance	Good
Resistance to alkalis	Good at low concentration
Resistance to acids	Predominantly good
Resistance to petroleum based products	Good
Resistance to bleaches and solvents	Will bleach. Degrades in mineral acids & oxidizing agents. Insoluble in organic solvents.
Creep	Slight creep under load

DSM Dyneema® is a registered trademark owned by Royal N.V.

References: Dyneema® fiber and its many applications.

If you would like more information on this topic, please contact **Peter Barry** at the Barry Centre of Excellence – pbarry@barry.ca

Barry Cordage Ltd.
6110, boul. des Grandes-Prairies, Montreal QC H1P 1A2 CANADA
514.328.3888 Toll Free: 1.800.305.2673 (Canada / USA)
514.328.1963 www.barry.ca
http://www.barry.ca/helicopter/longline.htm
http://www.facebook.com/barry.helicopter.longlines
https://twitter.com/BarryCordage