Some Recent Developments of Rope Technologies – Further Enhancements of High Performance Ropes

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***Abstract* - Synthetic ropes manufactured from high modulus synthetic fibers have been successfully replacing wire cables in various marine applications, such as mooring, tug and fishing for over 25 years. While there was initial resistance to these high performance synthetic ropes from users of wire rope based on reliability, appearance when used, and initial higher capital cost, experience has shown that synthetic lines provide excellent values in three main areas - safety, quality, and total cost of ownership. The substantial benefits afforded by lightweight, flexible alternatives to wire rope are becoming globally recognized by important advisories such as OCIMF (Oil Company International Marine Forum) and others.**

As these high performance synthetic lines expand into specialty applications, new technical challenges start to demand the rope manufacturers to advance their rope technologies to the next level. In this paper, we will discuss new technologies developed recently to overcome high levels of technical difficulties and challenges, including the following two areas:

1. **Requirements for a rope to perform in high temperature/fire environment;**
2. **Overcoming the low coefficient of friction nature of rope made with HMPE (High Modulus PolyEthylene) fibers.**

High Temperature/Fire Environment

The use of Aramid fibers in high temperature applications has been popular since their inception. With specially designed passive high temperature resistance coating, the thermal and flame resistance of the Aramid fiber rope can be further enhanced significantly. We will discuss the development, design and testing of this coating technology.

High Coefficient of Friction (COF) HMPE

The use of High Modulus PolyEthylene (HMPE) fiber is gaining popularity in the cordage industry due to such excellent properties as high strength, low weight, fatigue resistance, and UV resistance. However, the low Coefficient Of Friction (COF) of HMPE fiber presents a challenge when used on winches, capstans, H-bitts and other types of hardware that rely on friction for proper performance. A blended yarn, DPX, was developed to change the surface characteristics of traditional HMPE ropes. DPX is a unique blend of Dyneema® fiber and polyester that provides a "pre-fuzzed" appearance and grips better than any HMPE fiber. We will discuss the characteristics and performance improvements achieved using DPX fiber, the supporting lab data and field evaluation results.

I. Introduction

There are many advanced fibers available to the rope and cordage industry. These fibers offer many unique characteristics that serve well in various applications. However, in some instances a particular fiber alone may not provide the performance necessary to be suitable for a particular application.

Physical and performance characteristics of fibers/ropes can be modified and/or enhanced using specialized additives and/or by mechanical means. The key to manipulating a property or characteristic of any fiber is the understanding of the behavior of that particular fiber within a particular application. This behavior and subsequent reaction can be addressed by the appropriate means. Solutions exist for many scenarios, through coating technology and/or patented processing.

The following will summarize the work done at Samson to address two areas of concern with regards to the performance of fiber ropes.

II. HIGH TEMPERATURE/FIRE ENVIRONMENT

A) Application

Of interest to the petroleum tanker industry is a synthetic replacement of the Emergency Tow-Off Pendant (ETOP), commonly referred to as "Fire Wires." These pendants are required by OCIMF (Oil Company International Marine Forum) for use anytime a petroleum tanker ship is moored to a dock or berth. Its purpose is to provide a means of towing the ship away from the dock in the event of a fire. Wire rope is currently used in this application.

The ETOP is positioned along the side of the vessel and monitored to maintain a certain distance from the water. The ETOP must be adjusted as the ship's ballast changes during the loading or offloading process. This "repositioning" of the ETOP is often done manually. The handling of these heavy wire ropes has resulted in many injuries to deckhands.

An obvious solution to this would be to replace the wire rope with a synthetic rope. A synthetic rope would be much lighter and would eliminate the problem with "fish-hooks" (broken wires that protrude from the wire rope and result in many hand injuries). The problem with this solution is that the ETOP is required to be heat and fire resistant, and be able to withstand severe heat and/or direct flames for a reasonable amount of time.

B) *Product Development*

Fiber Selection

The chosen fiber for this application is a p-Aramid. This selection was due to the need for a fiber that was heat resistant and able to retain certain properties at elevated temperatures. A p-Aramid fiber has the following desirable characteristics:

1. Higher initial tenacity at elevated temperatures
2. Good heat cycling properties
3. Good abrasion properties
4. Good chemical resistance
5. Not effected by hydrolysis

Fig. 1 below shows typical initial strength characteristics of a p-Aramid fiber at elevated temperatures.

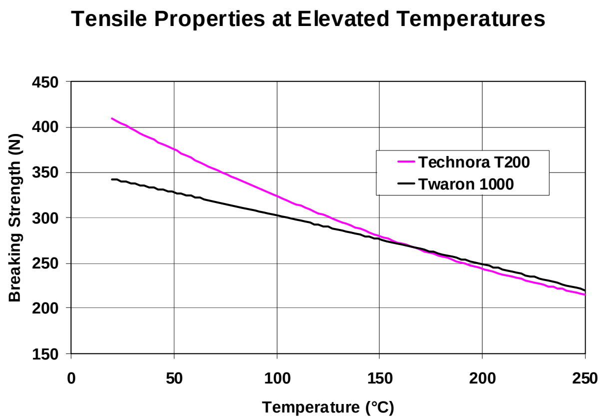

Figure 1. The p-Aramid fibers shown are products of TeijinAramid

A requirement of this application is the ability to withstand heat for an extended time period. In addition to having good strength properties at elevated temperatures, p-Aramid fibers also have the ability to retain strength when exposed to higher temperatures for extended periods of time. Fig. 2 shows the typical strength decay curve of p-Aramid fibers when exposed to elevated temperatures for a period of 1 hour.

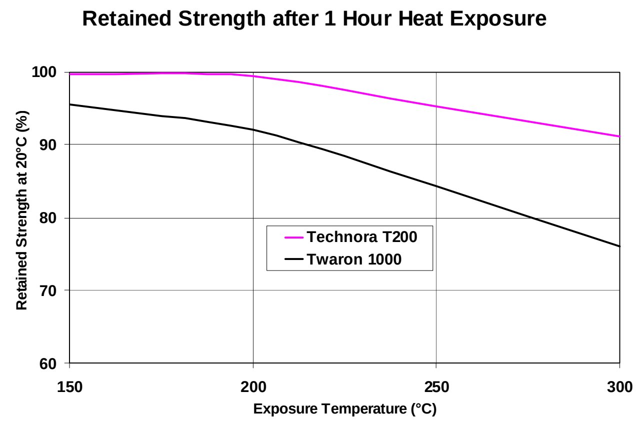

Figure 2. The p-Aramid fibers shown are products of TeijinAramid

Testing and Experimental Results

For Heat testing on ropes under load, a tubular heat chamber was build. Testing chamber capabilities are:

- Max Temperature – 500°C
- Accuracy - +/- 2°C
- Overall length of rope exposed to heat – 1 meter

Fig 3 is a schematic of the heat chamber.

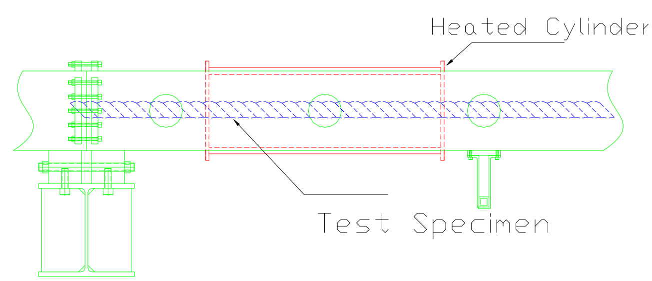

Figure 3

For Flame testing the rope was exposed to a 600°C open flame. The following measurements were taken.

- Direct exposure for 60, 90, and 120 seconds, then tested for tensile strength at room temperature. See fig. 3.
- Visual inspection after direct exposure for 60, 90, and 120 seconds.
- Measurement of internal temperature (heat transfer) at intervals of 60, 90, 120 seconds. See fig. 6.

Test was performed under lab conditions utilizing a controlled flame. See fig. 4.

Figure 4

Flame Resistance Enhancement

The p-Aramid fiber rope alone is unable to withstand direct flames as required for the ETOP application. Applying a proprietary coating containing a proprietary fire resistant ingredient can increase the damage resistance of direct flames. When applied to the rope, the coating will provide protection allowing the rope to withstand direct flames considerably longer than without the coating. Fig. 5 below shows the increased protection the coating enhancement provides. The rope with the fire retardant (“FR”) shows an approximate 3x improvement. The graph also shows that a typical polyurethane coating does not offer any improvement.

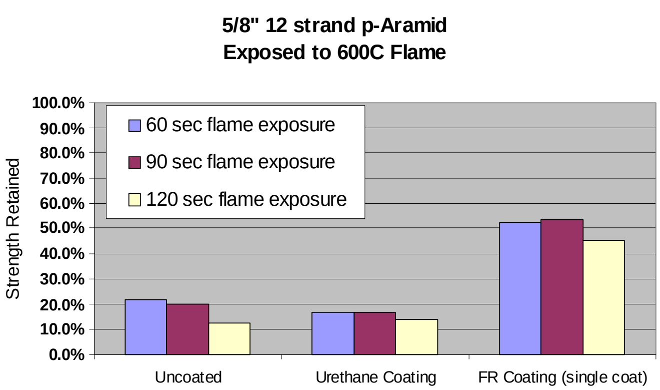

Figure 5

Another favorable attribute is the ability of the FR coating to provide insulation: therefore, protecting the inner fibers of the rope. In the 5/8” diameter rope shown in Fig. 6, the core temperature remains significantly lower than the surface (flame) temperature.

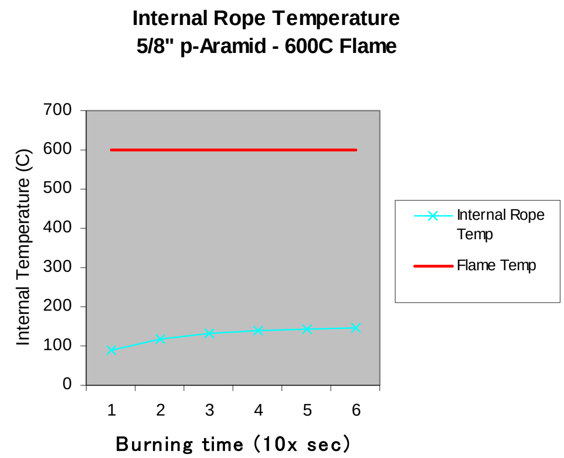

Figure 6

C) Application Modeling

Tables 1 and 2 model the system properties of both wire and p-Aramid. Wire, as expected, does have a higher retained tensile over the p-Aramid fiber; however, the p-Aramid fiber does retain approximately twice the recommended working load (20% MBL) over the same time period.

Table 1
Wire System Model

		Measured at 20°C	Measured at 300°C	Measured at 300°C (after 30min at 300°C)
Break Strength	GPa	2.37	1.8	1.74
Retained Strength	GPa	100%	75.9%	73.4%
Density	kg/m3	7600	7600	7600

Table 2
p-Aramid System Model

		Measured at 20°C	Measured at 300°C	Measured at 300°C (after 30min at 300°C)
Break Strength	GPa	3.42	1.5	1.5
Retained Strength	GPa	100%	43.9%	43.9%
Density	kg/m3	1390	1390	1390

To equal the performance of wire rope, it is possible to upsize a p-Aramid and still maintains a significant weight savings. Table 3 below shows that by increasing the diameter of the p-Aramid rope, 100% of the residual strength (compared to wire rope) can be achieved. The increased diameter still provides great handling characteristics at less than half the weight.

Table 3

p-Aramid Rope Diameter (mm)	Rope Strength at 20°C (tons)	% Strength vs 40mm Steel Rope at 300°C: 30 min	1 hr	1 day	Weight of Rope (kg/m)	% Weight vs 40mm Steel Rope
40	112	68	62	61	1.3	22.7
45	142	90	82	77	1.7	28.6
47	155	**100**	91	84	1.8	**31.2**
50	175	116	**101**	95	2.1	**35.7**
52	190	128	111	**103**	2.2	**44.2**

D) Summary

From this study the conclusion can be drawn that a rope produced from a p-Aramid fiber, along with a specialized coating can replace wire rope in high heat applications. The following have been noted:

- P-Aramid fiber has the ability to withstand and perform under high temperatures
- A FR coating is necessary to resist direct flames and to provide thermal insulation
- When compared to wire rope, of equal diameter, a rope made of p-Aramid fiber can still exceed the recommended working load after exposure to a high temperature environment.
- Upsizing will allow a rope of p-Aramid fiber to equal the performance of wire rope, at a significant weight savings.

[1]

III. INCREASING COEFFICENT OF FRICTION

A) Application

In many applications HMPE fiber is considered an ideal strength member based on the following characteristics:

1. high strength and low weight
2. superior fatigue resistance
3. superior abrasion resistance
4. superior weather resistance
5. flexibility
6. elongation characteristics similar to wire

A limitation of HMPE is the low Coefficient of Friction (COF). DPX, a unique blend of HMPE fiber and polyester, has been created to address this issue. It provides a “pre-fuzzed” fiber appearance which wears well and grips winch drums. Using this fiber, Samson has developed a series of products, to take advantage of DPX’s enhanced surface properties.

B) Testing

Coefficient of friction (COF)

COF is measured based on the principle shown in Fig. 7. A Rope is placed over a round stainless steel surface, with a dead weight applied to one side at T1. The load at T2 is then increased until the rope slips on the drum. Knowing the bending angle, T1, and T2, we can compute the COF using equation also shown in fig. 7.

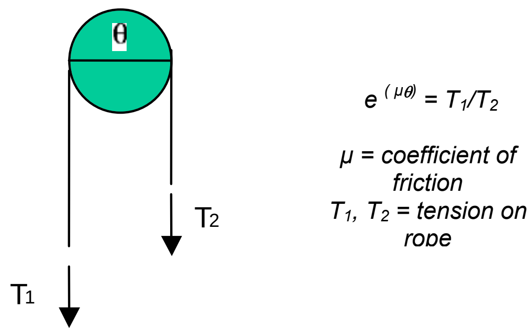

Figure. 7. COF Measurement

Abrasion Resistance

Fig. 8 is the schematic drawing of the apparatus used for comparing the abrasion resistance of ropes. Rope samples are placed under a fixed load, where the load is based on the diameter of the rope sample. The load (lbs) applied is 1600 x the diameter in inches. Thus, for a 1/2" dia. rope, the load applied would be 800 lbs. While the rope is under load, the wheel turns at a rate of approximately 15 revolutions per minute. Each revolution results in 8 "spokes" (smooth pins) abrading against the rope surface. The wheel continues to rotate until either the entire rope parts (for a single braid rope) or until the cover parts (for a double braid rope). The number of cycles or revolutions required to cause the rope to fail is then recorded as the abrasion resistance index value.

The turning rate of the wheel is slow enough to avoid heat generation to isolate the abrasion resistance from the heat resistance measurement. The fibers tested for this study included HMPE, polyester, nylon, spun polyester, DPX, and 100% polyester blend of DPX type construction.

Different coatings on polyester fiber were also evaluated to compare the improvement of abrasion resistance from coating.

The same tests were also conducted on jacketed HMPE ropes with DPX and HMPE fiber jackets to compare the abrasion resistance of the two different jacket constructions.

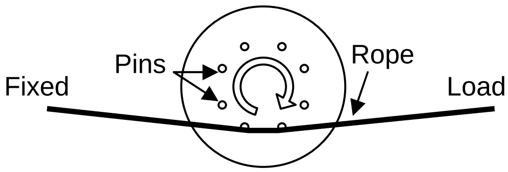

Figure. 8. Abrasion Resistance Measurement

C) Results and Discussion

Coefficient of Friction

Fig. 9 compares the COF and abrasion resistance of different fibers used for rope jackets. It is clear that DPX technology has the best combination of COF and abrasion resistance.

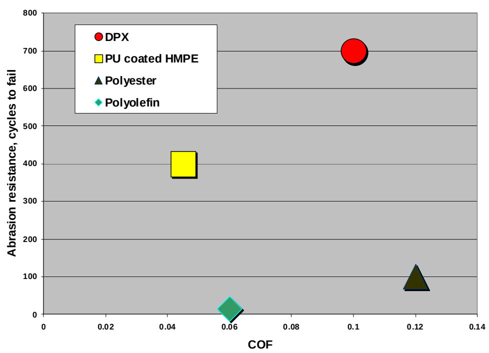

Figure 9. Comparison of Fiber Surface Properties, COF vs. Abrasion resistance

Abrasion Resistance

Abrasion Resistance of different synthetic fibers and coatings is compared with uncoated polyester in Fig. 10 and 11.

Fig. 10 shows that among all the fibers tested, HMPE fiber and DPX have the highest abrasion resistance. Tests were also conducted on polyester with various coatings to investigate if we can improve the abrasion resistance of polyester fiber to the level of DPX or HMPE fiber. As shown in Fig. 11, DPX significantly outperforms these coated polyester fibers in abrasion resistance.

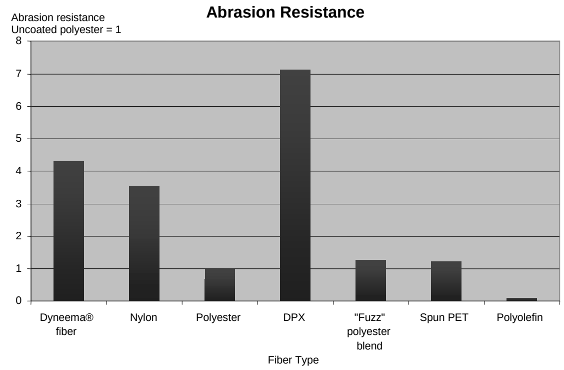

Figure. 10. Abrasion resistance of different fiber types.

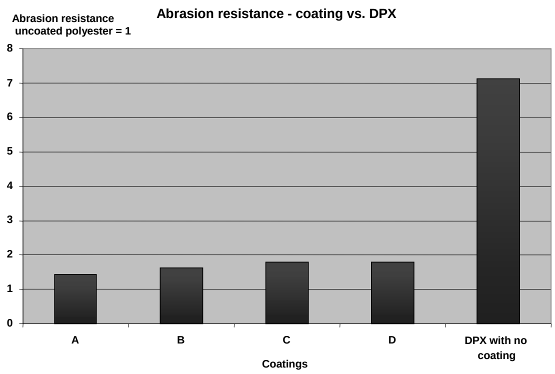

Figure. 11. Abrasion resistance improvement through coating on Polyester.

Abrasion tests were also conducted on HMPE jacketed ropes with DPX, and with 100% HMPE fiber jackets. As shown on Fig. 12, both showed comparable cover strand integrity after 5000 abrasion cycles.

Quantitative analysis of the covers was conducted by identifying the percent of original fiber intact at the end of the test, as shown in Fig 13. This showed very similar abrasion performance between DPX and HMPE fiber.

Figure. 12. Visual comparison of the Dyneema® fiber jacket (left) and DPX (right) showed similar wear.

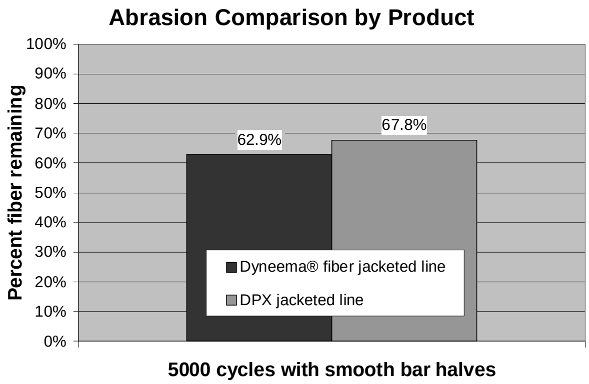

Figure. 13. Remaining cover fibers after 5000 abrasion cycles DPX vs. Dyneema® fiber, showing comparable abrasion resistance

D) Field Performance

DPX-75, a jacketed HMPE rope, as shown in Fig. 14 compares new line to a line after 6 months in service. There is little wear shown after 1800 hours of mooring operations. It was also observed that utilizing a DPX jacket improves the grip on the working side of the winch drum, reducing the slippage and load transfer from the working to the storage side of the drum.

Figure. 14. DPX-75 new (left) vs. 6 months in service (right)

Quantum 8, as shown in Fig. 15, is a non-jacketed HMPE line incorporating DPX technology. Like a jacketed rope, the DPX provides the surface enhancements of better grip and excellent abrasion resistance, while still retaining the benefits of a non-jacketed rope such as easy inspection of the inner yarns, easy splicing, and flexibility.

Figure. 15. Quantum 8 tug assist line

DPX technology has also been extended to 12 strand ropes. Quantum 12 is a 12 strand single braid with DPX enhanced surface. Fig. 16 shows Quantum 12 being used on an “H-Bitt” that without DPX technology would be nearly impossible for a HMPE rope.

Figure 16. Quantum 12 tug assist line

Another area where DPX technology has increased the use of HMPE products is with traction winches, as shown in fig. 17. A traction winch works on friction. Sufficient grip must be maintained between the “bull-wheel” grooves and the rope.

Figure 17. Quantum 8 on a turret pick up winch.

E) Summary

DPX, based on Samson manufacturing technology, provides:

1 COF comparable to polyester and superior to pure HMPE fiber and
2 Abrasion resistance comparable to HMPE fiber.

DPX has received good reviews as a surface enhancement

for both jacketed and single braided ropes. This technology has the potential to be utilized with many fibers, allowing the option of engineering yarns to create unique surface characteristics based on the requirements of specific applications.
[2]

IV. CONCLUSION

Technologies created at Samson have created product lines that offer alternatives to traditional synthetic ropes. These product evolutions have created potential for synthetic ropes to be utilized in applications that have been considered “off limits.”

Samson is continuing the effort to create innovative products, though the use of additives and unique manufacturing processes.

V. REFERENCES

[1] D. Stenvers, R. Chou, L. Padilla, O. Grabandt, P. den Decker, and B. van Berkel; “Consideration factors of rope design in high temperature applications.” Presented at MTS Rope Technology Workshop, 2007.

[2] J. Miller, D. Stenvers, R. Chou, and J. Gilmore; “Emerging technology: DPX jacketed mooring lines.” Oceans Conference 2005