

DEEPWATER SYNTHETIC LOWERING AND LIFTING WITH ENHANCED CYCLIC BEND FATIGUE RESISTANCE

PRESENTERS:

Justin Gilmore, *Samson*

Robert Thomas, *W. L. Gore & Associates*



INTRODUCTION

Exploration and production of offshore oil and gas is consistently moving into deeper waters. As the depths increase, performing subsea operations becomes more challenging. Applications such as pipe laying, installation of subsea equipment, and anchor placement and retrieval all require sophisticated lowering and lifting equipment. The winches used in these applications are typically very large and consume a significant amount of deck space. Winch systems, heave compensators, and tension members also add weight, and when working offshore, space and weight are precious commodities.

Traditionally, wire rope has been used as the linear tension member for lowering and lifting operations. Wire rope has good bend-fatigue characteristics; is resistant to heat; and, until the recent surge in steel prices, has been economical. The drawbacks associated with the use of wire rope are maintenance and weight. Wire rope requires frequent lubrication to prevent corrosion and to maintain performance. Weight becomes a serious concern when working in extreme depths because a significant portion of the winch capacity is used just to handle the weight of the wire. In turn, both the wire rope and winches are oversized, making for an inefficient use of power, deck space, and ship-weight capacity—all expensive components in any installation.

As oil exploration and installation moves into deeper water, the need for lightweight linear tension members is becoming more than a desire; some applications require the advantages provided by synthetic linear tension members—specifically, their light weight. Depending on fiber type, synthetics will be at least five times lighter than wire of an equal load rating. This can reduce the amount of horsepower required to drive the winch drum (for single-drum winches), and will reduce deck loads. In water, synthetics are either buoyant or close to neutral; therefore, they add no or very little weight to the lift. In recent years, synthetic ropes have replaced wire ropes in many applications, including winch lines where they have been used successfully in both single-drum and traction winches. In many cases, synthetic lines will outlast and outperform wire rope.

In cyclic-bend-over-sheave (CBOS) applications, synthetics have yet to be widely accepted. With repetitive bending, both wire rope and synthetics will generate heat—a result of friction between the strands of the rope. Wire rope generally has a lower resistance to bend fatigue than synthetics; however, because a significant amount of heat is generated with repetitive bending, most synthetics will degrade quicker.

When wire or synthetic fiber ropes are used to lower or lift a payload in deepwater, they typically utilize a heave compensation system designed to stabilize the payload prior to “landing,” or at certain depths often times in heavy seas. A heave compensation system consists of a large sheave that can move to counteract the wave action at the site of deployment. If a payload needs to be suspended at a

Weight becomes a serious concern when working in extreme depths because a significant portion of the winch capacity is used just to handle the weight of the wire. In turn, both the wire rope and winches are oversized, making for an inefficient use of power, deck space, and ship-weight capacity—all expensive components in any installation.



samson
THE STRONGEST NAME IN ROPE

CBOS TESTING

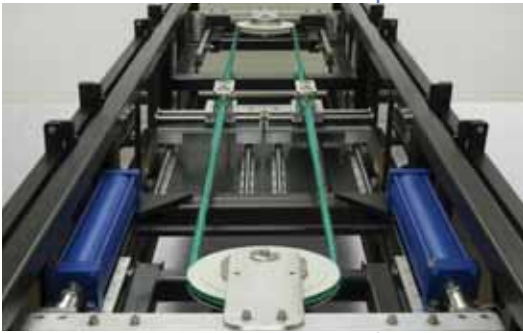


Figure 1 – Two ropes set up on a CBOS test machine.

given depth, a short section of rope will be subjected to cyclic-bending fatigue as it passes back and forth over the sheave. Depending on the job, loads can be suspended for extended periods of time.

To extend the life of synthetic lifting and lowering lines in applications with cyclic-bend fatigue, Samson has developed DeepCool™ Technology (DCT). DCT is a combination of Samson’s proprietary coatings and W. L. Gore and Associates’ GORE™ OMNIBEND™ ePTFE (expanded polytetrafluoroethylene) fiber. Ropes enhanced with DCT show an increased bend-fatigue life of seven to ten times over “untreated” synthetics. Ropes with DCT also show a significant improvement over wire rope.

CBOS Testing

This rope fatigue can be replicated on a CBOS test machine. In a CBOS test, a rope is placed over a sheave, subjected to constant tension, and cycled back and forth over the sheave to failure.

The simplest test performed on a CBOS test machine is to count the cycles to failure (CTF), which is the number of passes a rope makes over a sheave at a given tension before it fails. The operating conditions that determine rope life are the ratio of the diameter of the sheave size (D) to the rope diameter (d), known as the D/d ratio, and the safety factor (SF) of the tension on the rope as determined by Equation 1 where MBS_{ROPE} is the minimum break strength of the rope and T_{TEST} is the test tension. Furthermore, rope life can sometimes be approximated using life factor (LF) curves established by testing a given rope construction at various test tensions and D/d ratios. Life factor is established using Equation 2 and is discussed later in this paper.

EQUATION 1:

$$SF = \frac{MBS_{ROPE}}{T_{TEST}}$$

EQUATION 2:

$$LF = SF * D/d$$

Other tests often performed on a CBOS machine to replicate real world rope usage of coefficient of friction (COF) and strength decay COF testing is not covered in this paper, but measures the friction needed to keep a rope from slipping on a sheave, which is an important variable to understand when trying to use a traction winch to drive a rope.

TECHNOLOGY DEVELOPMENT

Coating Development Background

As discussed previously, CBOS-fatigue life can be increased by reducing strand-on-strand friction. To reduce friction, a detailed study was conducted that focused on various coatings and additives. Several small-scale samples were coated and tested to failure in order to determine which coatings performed best. A summary of these tests are shown in Figure 2.

These test results show not only that the reduction of inter-strand friction by a coating can result in a greater number of bend cycles, but also that some formulations result in better rope life than others. The samples containing coatings with the lowest coefficient of friction, such as those containing silicone and PTFE performed the best.

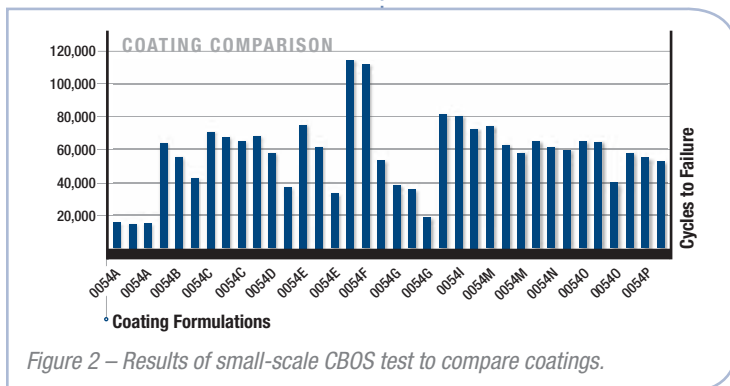


Figure 2 – Results of small-scale CBOS test to compare coatings.

Once the “best” coatings were determined, larger ropes were produced and tested, proving the superiority of the best coatings. One interesting observation was that although the best coatings remained the best as the scale was increased, the number of cycles to failure was reduced. One theory hypothesizes that this is because larger ropes require greater test tensions, resulting in greater inter-strand pressure and heat generation. Additionally, because of the larger rope diameter, heat takes longer to reach the surface and is retained within the larger core.

ePTFE Fiber Development Background

A significant amount of research has gone into developing synthetic fiber ropes that are better able to withstand the challenges of repeated bending under tension. A key wear mechanism is strand-on-strand abrasion and protecting the rope at these specific locations is critical to improving bending-fatigue life.

It is in these applications that ePTFE fiber can provide an effective solution. In fiber form, PTFE can be placed exactly where it is needed most. Furthermore, when ePTFE fiber is specifically engineered for high strength and temperature resistance, it ensures that the lubricating properties of the fiber persist through the service life of a rope.

To test the effectiveness of a high-tenacity ePTFE fiber in enhancing the life of ropes used in tension-bending applications, many ropes were constructed and tested on a CBOS test machine. Several distinct ePTFE fiber variations were combined with other high-performance fibers, constructed into ropes, and cycled to failure on a CBOS machine. ePTFE fibers included variations in strength, density, titer, and modulus. In addition to varying the ePTFE fiber characteristics, fiber placement within the rope was explored. The terms homogenous or veneer refer to this placement.

In a homogenous construction, ePTFE was blended evenly throughout the cross-section of the rope. In a veneer construction, ePTFE was placed around the outside of the individual rope strands. In *Figure 3* the cross sections of two 1x7 laid ropes are shown; the green represents the ePTFE fiber. The homogenous construction is shown on the top with ePTFE fiber dispersed evenly through the rope, while the veneer construction (*Figure 3*, bottom image) finds the ePTFE fiber concentrated around the individual rope strands.

In this test, each combination of ePTFE fiber and placement offered dramatic improvements in rope performance. The testing also revealed that engineering specific ePTFE fiber characteristics and controlling the placement of the fiber in the rope construction maximizes the life of ropes used in high-tension bending applications. An ePTFE fiber optimized in strength, titer, density, and modulus in a veneer construction resulted in the greatest improvement in rope CBOS life, and was used in further testing discussed below.

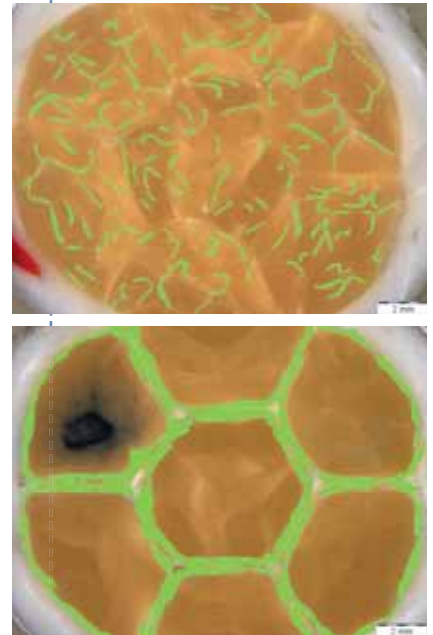


Figure 3 – Cross sections of experimental ropes. Homogenous placement of ePTFE fiber (in green) is highlighted on top, while veneer placement is highlighted below.

DEVELOPMENT OF DEEPCOOL™ TECHNOLOGY

Given the gains in rope performance granted individually by both proprietary coatings and specifically engineered ePTFE fiber, a combination of the two technologies became the next logical step. The remainder of this paper focuses on this study: the development and further exploration of DeepCool™ Technology (DCT), a combination of proprietary coatings and ePTFE fiber optimized for ropes subjected to cyclic bending.

This study focused on braided 12-strand high modulus polyethelene (HMPE) fiber ropes. The 12-strand rope construction is of particular interest because it is inherently torque-balanced; therefore, will not spin when a load is applied.

HMPE fiber was chosen for its high strength-to-weight ratio—that is, the density of the fiber is roughly equivalent to water, making it weightless in deep water lifting and lowering applications.

The first series of tests were used to compare three rope constructions: a standard 12-strand HMPE fiber rope construction (referred to as control rope), the same construction with some HMPE fiber replaced with ePTFE fiber [referred to as the GORE™ OMNIBEND™ Fiber (GOF) rope], and a third construction with both the ePTFE fiber and an optimized coating (referred to as the DCT rope). All of the ropes were tested on a CBOS test machine under the same conditions, highlighted on the next page.

HMPE fiber was chosen for its high strength-to-weight ratio—that is, the density of the fiber is roughly equivalent to water, making it weightless in deep water lifting and lowering applications.

PROCEDURE / RESULTS

Procedure and Test Conditions

SHEAVE DIAMETER (D)	20 inches
ROPE DIAMETER (d)	1 inch
D/d	20
TEST TENSION	18,500 lbs.
SAFETY FACTOR (SF)	5
LIFE FACTOR (LF = SF * D/d)	100
CYCLE SPEED	360/hour
STROKE LENGTH	48 inches

Table 1 – CBOS test conditions.

	ROPE 1	ROPE 2	ROPE 3	AVERAGE
HMPE CONTROL	4,917	5,153	4,904	4,991
HMPE + ePTFE	11,425	13,506	11,920	12,284
HMPE + ePTFE + COATING	19,862	20,925	20,966	20,584

Table 2 – Machine cycles to failure for 12-strand HMPE fiber ropes.

In all tests, three lengths of the same construction of 1-inch diameter rope were run to failure by continuous bending under tension over a sheave. The first test was run with one length of rope over each sheave on Gore’s CBOS tester. The ropes were cycled until one sample failed, at which time the failed sample was replaced with the third rope. When the second rope failed, it was replaced with a dummy rope and the third rope was run to failure. The intent was that the first rope would be run continuously to failure, while the last two ropes would have discontinuous tests, and were both allowed to cool before the tests were continued.

The CBOS tension was set to 18,500 lbs. during all tests. Based on the average break strength of the control ropes (92,630 lbs.), the test tension was selected to provide a safety factor of five—an industry-wide accepted value. Because the break strengths of the ropes with ePTFE fiber varied slightly from that of the control ropes, the safety factor for the testing of those ropes may have varied up to 10 percent. Test conditions are detailed in Table 1.

Results

Given the test conditions described above, the control rope averaged 4,991 cycles to failure. With the addition of ePTFE fiber, rope life was increased to an average of 12,284 cycles to failure. The best performing ropes incorporated both ePTFE fiber and an optimized coating, as developed by Samson—these ropes performed better than the control ropes, failing after an average of 20,584 cycles. These results are illustrated in Table 2 and Figure 4.

Elongation data was also captured for each rope sample. Figure 5 illustrates the elongation data for the first rope sample failed in each construction.

Discussion

The 12-strand HMPE fiber control ropes all seemed to fail predominately due to inter-strand abrasion. There was a large amount of debris both on and around the CBOS tester and between the strands of the rope, indicating a high level of wear. Additionally, individual filaments were fibrillated and tangled with filaments from neighboring strands. All of the broken strands had very tapered ends. The tapering is indicative of the “scissoring” action caused by the relative movement of the rope strands, causing the strands to saw through each other. Also, the ropes failed rather abruptly, with all strands failing in the same region. This indicates that tensile failure occurred rapidly, most likely because all of the strands had been abraded to the same level of strength loss.

An examination of the GOF ropes (HMPE fiber with ePTFE fiber) suggests a failure mode similar to that seen in the control ropes, but delayed by the addition of ePTFE fiber. Similar to the control-rope tests, tapered and fibrillated sub-strands suggest an abundance of abrasive scissoring failure. There was also little evidence of the ePTFE consistently smearing together into a barrier that protected the strands from sawing through each other—a phenomenon seen in the DCT ropes. It appears that the rope failed in the same fashion as the control ropes, but protection provided by the ePTFE delayed the failure.

This is further substantiated by the similar elongation rates of the control and GOF ropes. The GOF ropes showed more elongation compared with the other specimens and occurred at a rate similar to that of the control ropes. The fact that the elongation rate of the GOF ropes was comparable to that of the control ropes might suggest that the individual fiber damage in the GOF ropes was more similar to that in the control ropes.

There was a slight shift in the failure mode of the DCT ropes (HMPE fiber + ePTFE fiber + coating). These seemed to fail due a combination of inter-strand abrasion and tensile loss due to both fatigue and fiber crushing.

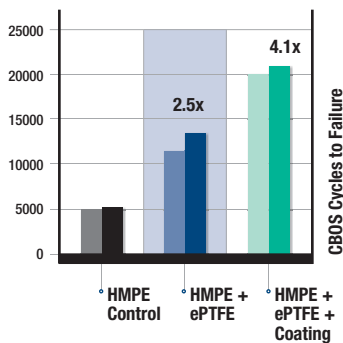


Figure 4 – CTF data for 12-strand HMPE fiber ropes.

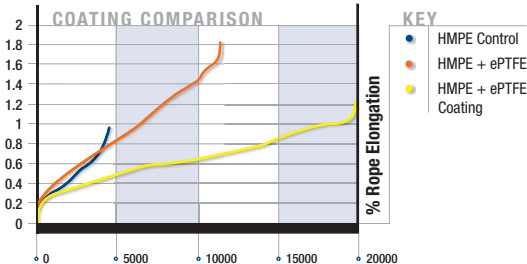


Figure 5 – Elongation data for HMPE CBOS tests.

FURTHER EXPLORATION

Inter-strand abrasion was evidenced, as usual, by the fibrillation of individual filaments of HMPE within the strands, along with the tangling of filaments from neighboring strands. Many of the broken strands had tapered ends, again indicative of the scissoring effect described above.

In addition to the failure due to abrasion, fiber crushing is evidenced by blunt, flattened failure sites that can be traced to strand crossover points. The presence of ePTFE and the optimized coating allowed strands to move relative to each other without any scissoring action, and the pressure at these points had more time to crush and weaken individual fibers, eventually leading to tensile and fatigue failure. There was also considerably less debris in the DCT test than in the control-rope test. The DCT ropes failed less abruptly than the control ropes—this is noted most easily by the fact that one strand survived when the rope failed.

It is interesting to note that the total elongation in both the control and the DCT ropes was almost identical. At the same time, the elongation rate for the DCT ropes was about 4 times slower than the control ropes. This indicates a link between individual fiber damage from creep, abrasion failure, and tensile failure (at the filament level) and the ePTFE protecting it.

Samples of all rope constructions were relatively stiff in the single and double-bend zones after failure. This indicates some level of fiber fusion, which contributes to rope failure in two ways: first, load sharing within the rope is decreased with increased fiber fusion; and second, the high temperatures associated with fiber fusion causing strength loss in the HMPE fiber.

FURTHER EXPLORATION OF DEEPCOOL™ TECHNOLOGY

As evidenced above, the synergy of ePTFE fiber and an optimized coating provided by DeepCool™ Technology greatly enhances the life of ropes in high-tension bending applications. Additional testing was completed on 12-strand HMPE fiber ropes in an attempt to model expected rope life based on the operating conditions of SF and D/d ratio. Furthermore, the testing aimed to explore the validity of the expected rope life as a function of LF, a term determined by Equation 2 in the introduction of this paper.

Procedure and Test Conditions

Testing was completed on a CBOS test machine in the same manner as the development of DCT. In these tests however, optimized 12-strand HMPE fiber ropes with DCT were compared to control ropes at a variety of test conditions, described in Table 3. Three ropes of each construction were cycled to failure under the six life factors given in the table.

Results

The ropes with DCT lasted considerably longer than the control ropes, improving five times at LF = 60 to 12 times at a more forgiving LF = 150, as evidenced in Figure 6.

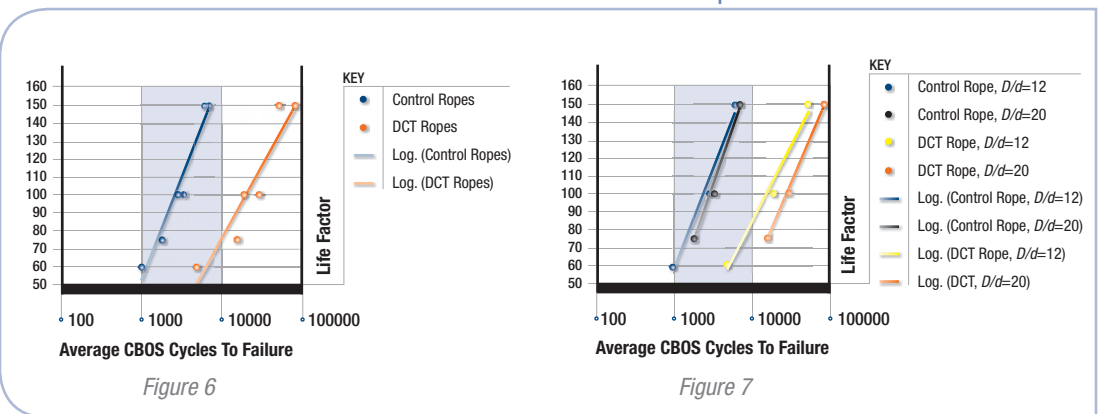
While an increased life factor corresponds to a longer rope-service life, it also appears that the D/d ratio plays a role. To maintain a given life factor while reducing the size of the sheave, test tension must be reduced. At the same life factor, ropes tested on a smaller sheave do not last as long as those tested on a larger sheave, as evidenced in Figure 7.

EQUATION 2:

$$LF = SF * D/d$$

D/d	SAFETY FACTOR (SF)	LIFE FACTOR (LF)
12	12.50	150
12	8.33	100
12	5.00	60
20	7.50	150
20	5.00	100
20	3.75	75

Table 3 – CBOS test conditions.



RESULTS

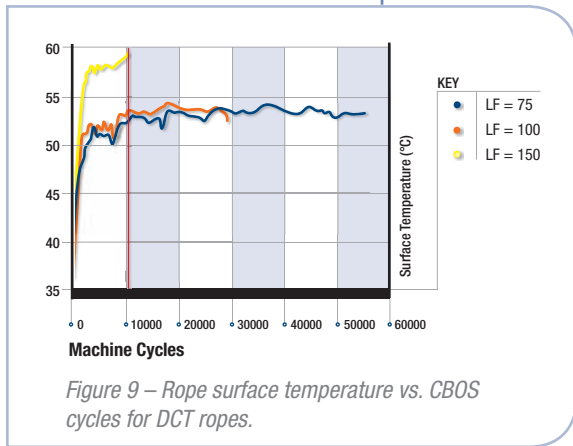


Figure 9 – Rope surface temperature vs. CBOS cycles for DCT ropes.

Statistical analysis of this data indicates that life factor can be used in a simple linear model to predict rope life at new conditions. These curves have an R^2 value above 90 percent, indicating a good fit to a linear model. Further analysis of the DCT results show that the most predictive model holds the D/d ratio constant and varies LF by varying SF only.

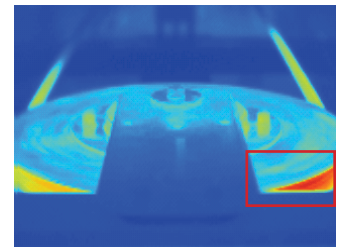
Additionally, thermal data was captured using an infrared camera for the DCT ropes tested at a D/d of 20.

Figure 8 shows the surface temperature of the DCT ropes for various life factors. It should be noted that internal rope temperatures were not recorded, but are typically much higher than surface temperatures. Below are three comparative infrared snapshots of the ropes traveling around the sheave about 10,000 cycles into the test, denoted by the red line in Figure 9. These images were all taken at the same thermal scale, and surface temperature differences are easily seen at the various life factors.

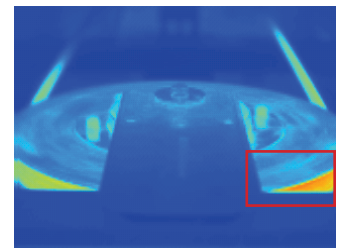
ropes traveling around the sheave about 10,000 cycles into the test, denoted by the red line in Figure 9. These images were all taken at the same thermal scale, and surface temperature differences are easily seen at the various life factors.

Note the dramatic increase in rope temperature as the life factor drops (a result of increased test tension).

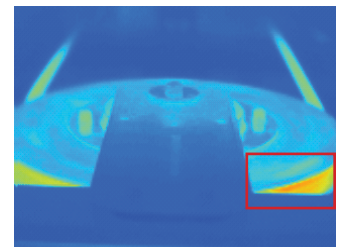
Note the dramatic increase in rope temperature as the life factor drops (a result of increased test tension).



Life Factor = 75



Life Factor = 100



Life Factor = 150

Figure 8 – Comparative infrared images of the DCT ropes at 10,000 cycles at various life factors.

FUTURE TESTING

While it is obvious that the use of proprietary coatings and ePTFE fiber in synthetic ropes can greatly increase their life in CBOS applications, additional testing is currently scheduled, and in some cases underway, to further understand rope behavior and the improvements offered by DCT. Testing will include, but may not be limited to:

- > **Strength decay testing:** *this aims to model rope strength as a function of CBOS cycles to which a rope has been subjected. This information will be essential in establishing retirement criteria of synthetic ropes being used in the field.*
- > **Effects of “cool-down” periods:** *ropes will be run in CBOS to a given number of cycles, the cycling will be stopped, the rope will be allowed to cool, and then the cycling will resume. This process will be repeated to rope failure, and will help determine if cycles to failure are either exaggerated by continuous testing or are cumulative regardless of “stop-starts.”*
- > **Effects of rope diameter:** *ropes will be tested at larger diameter to better understand rope life and behavior in applications where large payloads may be deployed.*
- > **Effects of bend frequency:** *ropes will be tested on a CBOS machine, but at different rates of cycling. This data will be useful in understanding rope behavior in the field, especially in unpredictable and changing sea conditions.*
- > **Variations in synthetic rope fiber:** *ropes will be constructed with other blends of synthetic fibers and other constructions to map their effect on CBOS performance.*

While it is obvious that the use of proprietary coatings and ePTFE fiber in synthetic ropes can greatly increase their life in CBOS applications, additional testing is currently scheduled, and in some cases underway, to further understand rope behavior and the improvements offered by DeepCool™ Technology.

CONCLUSIONS

From this study, the following conclusions can be drawn:

- > **Bending fatigue life for synthetic fiber ropes can be dramatically improved by the addition of ePTFE fiber and proprietary coating technology.**
- > **Life factor can be used to make predictions about rope performance under given CBOS conditions such as rope tension and sheave size.**
- > **Tension and sheave diameter variation influence the thermal response of a rope.**
- > **Improved rope performance can translate into meaningful operational benefits, such as:**
 - 85-percent rope-weight reduction.
 - reduced power consumption.
 - smaller winch equipment.
 - reduced deck footprint.
 - less frequent rope replacement and lower maintenance cost.
 - reduced equipment and schedule risk.

TECHNOLOGY PARTNERSHIPS



SAMSON

THE STRONGEST NAME IN ROPE

2090 Thornton Street
Ferndale, WA 98248 USA

(T) 360.384.4669 (F) 360.384.0572

www.samsonrope.com



GORE
Creative Technologies
Worldwide

www.gore.com

Partnering for innovation and performance: another aspect of The Samson Advantage

Developing new solutions to challenges faced in critical applications is precisely why Samson maintains the most advanced R&D organization in the industry. But working in a vacuum is not always conducive to arriving at the best solution. The concept of partnering has become central to The Samson Advantage. Working with customers to better understand the problems encountered in critical applications; and partnering with fiber and coating suppliers to determine how best to exploit their achievements in developing new products to overcome traditional limitations.

Samson engineers worked closely with fiber producer W. L. Gore & Associates to develop and test fibers, constructions, and coatings. The goal was to determine the optimum combination to provide the longest service life in situations where CBOS is a problem. The result is a product that enables extremely deep lifting and lowering operations while significantly extending the service life of the winch line. It is a prime example of The Samson Advantage in action.

W. L. Gore & Associates

W. L. Gore & Associates, Inc., a technology solutions provider with over \$2 billion in annual sales and more than 8,000 associates, specializes in fluoropolymer innovations that improve quality of life. Over its 50 year history, Gore has applied its world-renowned expertise with membranes, fibers, and laminates to thousands of products in performance-driven markets. Perhaps best known for its consumer products brands such as GORE-TEX® Fabric and ELIXIR® Guitar Strings, Gore products can be found solving complex technical problems in industries such as automotive, energy, electronics, medical, and industrial filtration. The company operates in more than 45 facilities worldwide with headquarters in Newark, Delaware, USA.

THE SAMSON ADVANTAGE TECHNOLOGY PRODUCTS SERVICE MANUFACTURING EXPERIENCE