Designing SPM Hawsers to today's requirements

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ABSTRACT

In offshore operations synthetic ropes are still finding new uses, partly because conditions change bringing new requirements, partly because new materials bring new possibilities to simplify operations. With these developments the understanding in the industry increases and this has two effects firstly the conditions of use are adjusted to maximise the safe working life and secondly the requirements for the ropes have changed to make the ropes perform better in a given application. An example of this are the new OCIMF Guidelines for SPM Hawsers. These new guidelines reflect the changes in the industry, both for fibre suppliers, rope makers and users. To meet the requirements in the new guidelines changes need to be made in the rope design.

Here the new design is introduced for Bexco's Ultraline Nylon SPM according to the new guidelines and the effect of those changes on the rope properties. First the basic design is discussed, then the properties and the steps taken to optimise the quality.

I. INTRODUCTION

General

For a **S**ingle **P**oint **M**ooring (SPM) system a synthetic rope, is used to connect an offloading tanker to a buoy. see also photo 1. This so-called hawser connects the relative small buoy to the large offloading tanker. In a heavy sea the hawsers needs the elasticity to compensate for the large movements of the buoy relative to those of the tanker. For this use nylon is a well established material, because of its excellent stretch characteristics, however its properties are influenced by water. Alternative materials are based on polyester composite fibres and these have a lower stretch, however are not sensitive to hydrolysis and have an excellent fatigue life.

Figure 1: SPM Hawser in use.

Bexco also manufactures SPM's based on these products, however here only nylon will be discussed.
Today the use of synthetic ropes for this application is well established and the product has become mature.

A. Fibre

Polyamide or Nylon was the first synthetic fibre discovered. It is available as a fibre as nylon 6, nylon 6,6 and nylon 6,10. These fibres have almost identical mechanical properties but nylon 6,6 is thermally more stable and nylon 6,10 is the most stable. In ropes they are generally equally suitable, however for cost reasons nylon 6 is usually selected. See also table 1 for a comparison with other materials.

The melting point of Nylon is 215°C, however properties start to change at lower temperatures. For short periods nylon can be used up to 140° C, for long exposures the maximum temperature should not exceed 80°C. The UV resistance is acceptable. Also the behaviour of nylon is affected by water. Water has a softening or plasticizing effect on nylon and typically the fibre strength in fully wetted is some 5-10 % lower than the dry strength. Although the effect in itself is reversible, hydrolysis can accelerate the effect of fatigue and abrasion.

	Tensile strength N/mm²	Elongation to break %	Melting Point °C	Density kg/l
Aramid HT	3 600	4.0	480	1.44
Aramid Copolymer	3 500	4.0	480	1.39
Aramid SM	2 760	3.7	480	1.44
Gel spun PE	3 300	3.5	145	0.97
LC Polyester	3 000	3.8	330	1.41
Steel wire	2 160	1.1	1600	7.86
Polypropylene	500	12	165	0,91
Bexcoline Composite	650	15	165 - 260	1.14
Polyester	1 050	12.5	260	1.38
Nylon	850	18.0	215	1.14

Table 1: Overview of the different fibres.

B. Rope

Typically three rope design are used for SPM Hawsers, namely eight-strand plaited, double braid and parallel-strand, see also figure 3.

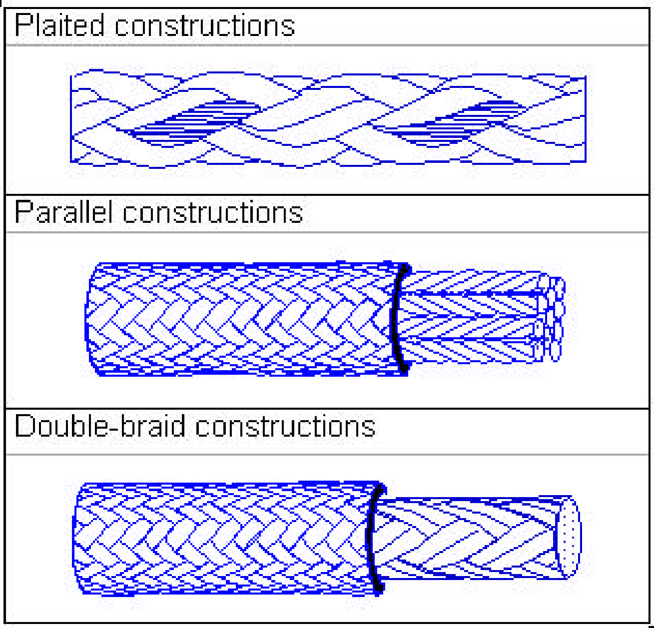


Figure 3: Rope designs used in SPM Hawsers

Bexco has both the eight-strand and the parallel-strand design in its production range. For nylon it uses the parallel-strand or Ultraline® design. This construction has been developed to give a rope extra protection against wear and tear without significantly changing the primary characteristics. This has been achieved by braiding a cover over the load-bearing cores. Each of the strands or cores consists of a three-strand rope that will be produced in both right-hand lay and left-hand lay. The sub-ropes will be laid parallel to each other. The lay-up of the sub-ropes is such that the finished rope will have a torque-neutral construction.

The cover is a circular braid design, it is optimised for wear and abrasion resistance. Only after the cover has been worn through and the cores start to abrade the strength will be affected. Also the cover can be coated with an additional, two-component PUR in those areas where wear may be expected, for example near the terminations. The design is well established at Bexco and is used for other fibres as well (such as polyester, aramid and Dyneema).

One pronounced difference between an parallel-strand rope and other, more traditional, designs is the efficiency. For most all rope constructions the efficiency reduces with size, however for Ultraline® ropes the efficiency is independent of the size over a practical range, see also figure 4.

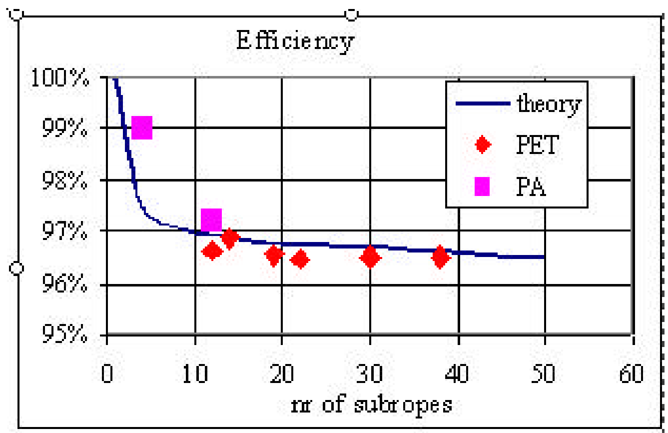


Figure 4: Strength efficiency of the Ultraline® design

The efficiency of a parallel-stand rope is a function of the sub-rope strength and splicing. The initial decrease in strength can be explained by the few number of sub-ropes, the assembled strength is close to that of the single core, whereas for ten cores or more it tends to be at the minimum strength. In Bexco's view the splicing will become difficult if the number of cores is very large, although an exact limit can not be given without testing internally estimates range from 50 to 56 sub ropes as a maximum. With too many sub-ropes handling and splicing the individual components can no longer be done in a reproducible manner. This will reduce the performance. However, total rope strength is then above 1800 tf, higher values are not very frequently needed for the polyester Deepwater lines.

II OCIMF 2000

The type approval for the nylon SPM Hawsers is conducted under the **O**il **C**ompanies **I**nternational **M**arine **F**orum (or OCIMF) “Guidelines for the purchasing and testing of SPM Hawsers”, first Edition 2000. OCIMF is the abbreviation for the Oil Companies International Marine Forum. This Part is a revision of the 1987 standard. Bexco has type approval under the previous guideline.

One aspect which has made rope testing an confusing exercise for those not familiar with the subject is the terminology. Most often it has a historic background and one needs to be aware of that to understand definitions. An example of this in the new OCIMF is the size or circumference of the rope.

Traditionally the size is expressed in inches and with the diameter this gives:

$$size\ ('') = diameter\ (mm) * \frac{25{,}4}{\pi} \approx diameter / 8$$

However, under the new OCIMF Guidelines the size is related to weight of the rope. This has been done, because historically diameter is not well defined for ropes, whereas weight is. Thus under the OCIMF size is defined as:

$$size\ ('') = \sqrt{\frac{weight(kg/m)}{k}} \quad with\ k = 0.0415\ for\ nylon$$

Other standard avoid this by referring to the Minimum Breaking Load or the weight.

A. Fibre Design

Yarn behaviour is a function of the fibre selected and the yarn construction, see also figure 5 for a typical load-elongation curve.

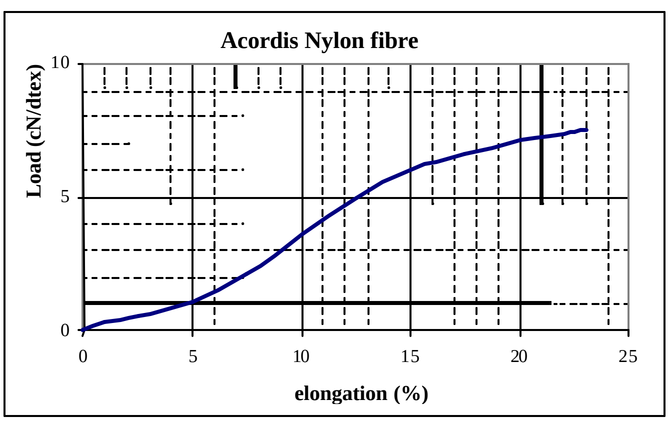


Figure 5: Static Load-elongation curve

Twisted yarn is used for two reasons, firstly to assemble the fibres to a size that allow optimal processing in the next production step and secondly to improve stability and abrasion resistance. Twist and assembly are selected as to maintain the basic behaviour of the fibre used. For this purpose an empirical coefficient, the so-called k-factor, is used:

$$k = \frac{turns / meter}{3025} * \sqrt{\frac{count(dtex)}{\rho}}$$

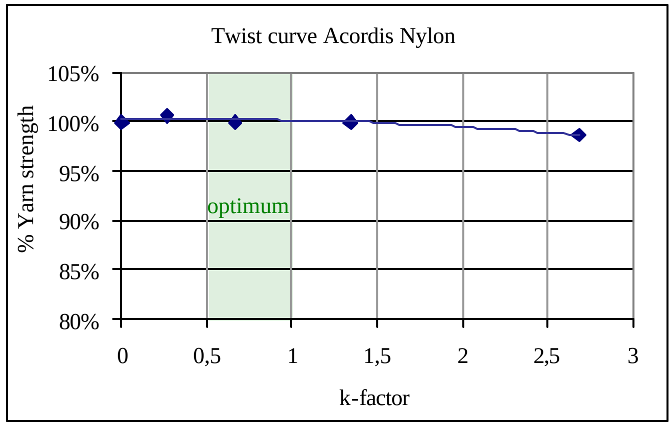


Figure 6: Strength efficiency versus twist level.

For QC not the fibre properties themselves, but their variation is important. If the difference between minimum and maximum fibre properties is high rope properties will be less predictable. For nylon there is good correlation between the elongation and the load at failure, see table 2 and figure 7

	EAB %	BS N	Spec Strength mN/tex	count dtex
Mean	21,21	148	785,5	1884
St. Dev.	1,74	2,83	12,5	15,8
Variance	8,22 %	1,91 %	1,60%	0,84 %

EAB = Elongation at Break, BS = Breaking Strength,

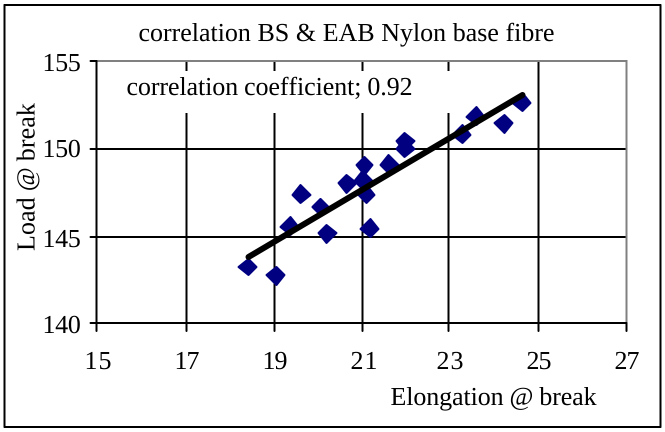
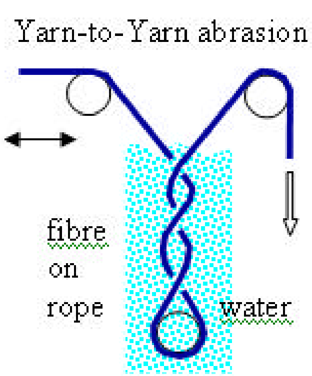


Figure 7: Elongation and Load at failure.

A good correlation between elongation and breaking strength is important for a good strength efficiency. However, because of flatness of the load-elongation curve this correlation gives a relative high standard deviation on the elongation to break. In the assembly this reduces (the standard deviation is around 1), because the failure of nylon in very abrupt, when one base yarn fails the others are overloaded form the shock load and also fail.

One of the main changes for the fibre requirements in the new OCIMF Guidelines is the Yarn-To Yarn abrasion test as specified in (2), see also sketch. This test is used to quantify the abrasion resistance of materials in a marine environment. For nylon special marine finishes have been developed to improve the abrasion resistance of nylon in seawater. However by its nature abrasion is load dependent and a surface property. Thus the effect of a marine finish is more pronounced at higher loads and data from different sizes of yarn should be compared with extreme caution.

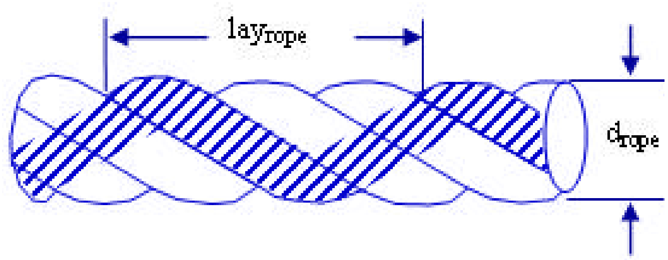


In the authors view this test should be used to evaluate the effect of a marine finish relative to that of an untreated material. For this purpose dedicated equipment has been built that allows testing of the rope yarn. Originally the test has been developed for base yarns, see (2) and (3). However it can also be used for rope yarns, which are considerably heavier. Results are significantly different, but the effect of a good marine finish is very pronounced. Thus this test can be used for QC purposes. Testing rope yarns not only for their strength, as required, but also for their marine finish content will ensure that at Bexco products meet the OCIMF requirements. Typically the difference between treated and untreated yarn is at least a factor two.

B. Rope Design

The rope behaviour for the Ultraline design is determined by the sub-rope. Size and lay angles determines strength, stiffness and other characteristics. At Bexco dimensionless parameters are used similar to the fibre to scale the sub-ropes, see equation and sketch. For SPM's two sizes of sub-ropes are used, their choice depends on the size of the final assembly

$$Const_{rope} = \frac{lay_{rope}}{diameter_{rope}}$$



For the sub-rope the same splice design is used as for polyester core, because for polyester it has proven to be an efficient splice with excellent fatigue life. As with the sub rope the method of splicing for the full assembly is copied from the DeepRope design.

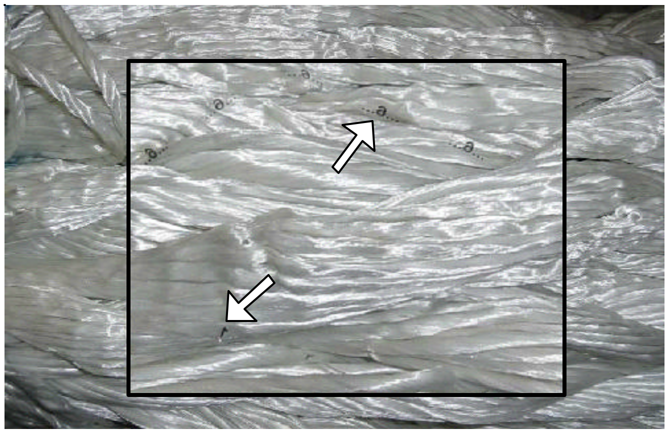


Figure 8: Every sub-rope is splice into itself

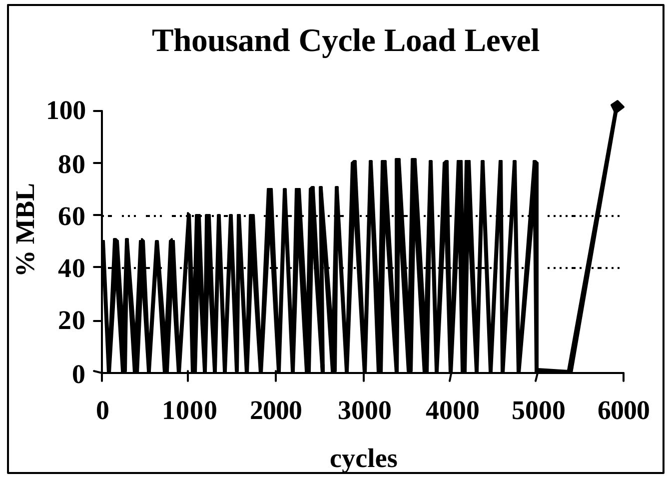


Figure 9: Schematic of the TCLL test.

Every sub-rope is spliced into itself, making the design more damage tolerant, for this purpose every core has a special marker tape allowing easy identification, see photo. The technique has been developed to splice with minimal tools. This allows splicing on site, requiring only a few tools and a clean, dry workspace. With the more accurate splicing technique variation has reduced, giving a higher reproducibility when the ropes are tested. This has resulted in a high, consistent strength efficiency of the sub rope in the final assembly.

This method has resulted in a consistent splice behaviour, almost always giving good failures (A good failure occurs when more than 2/3 of the material fail at the first break).

C. OCIMF

The new OCIMF Guidelines deviates from the old guideline in the number of test required and the fact that it should be repeated every five years. Also if rope sizes larger than 20" are to be manufactured then the biggest size also has to be tested.

Rope		Dry break test	Wet Break test	Cyclic load test
Size	dia			
6	48 mm	2	5	2
15	120 mm	2	2	
>20		2	2	

Table 3:Required prototype tests

The wet and dry test are comparable to the requirements from other standards. However, here only the average, spliced strength is defined, not the minimum spliced strength. The cyclic test is an accelerated fatigue test, see figure 9.

Also the OCIMF uses an interpolation to estimate the breaking strength for sizes between 6 and 20", based on a monotonic decrease with size. Here in the view of the author an inaccuracy is allowed that is atypical for the rest of the standard. The interpolation is linked to the rounded-of size. In the view of the author at least three significant digits should be used for the size when the breaking strength is calculated. Otherwise significant differences can occur between actual strength and calculated breaking strength according to OCIMF, see also table for example.

Rounded off size	BL accord OCIMF kN	Min			Max		
		Size "	Weight Kg/m	BL kN	Size "	Weight Kg/m	BL kN
18"	4818	17.5	12.71	4456	18.4	13.45	5030

Table 4:Example of a possible calculation

III. TEST RESULTS

A. Static Test

The results from the static test are well within expectations, see also table 5 and figure 4.

Rope		Dry break test	Wet Break test
Size	dia		
6	48 mm	562	535
15	120 mm	3308	3150

Table 5:Test results Nylon ropes following OCIMF.

There is about 5% difference between dry and wet strength, which is slightly smaller than the difference for the fibre. This is also expected, because the Marine Finish delays the effect of the hydrolysis for the rope.

However, the strength efficiency according to OCIMF does not correlate well with that for the parallel-strand ropes, see figure.10. This is caused by the parallel-strand design. Other, traditional rope design use scaling parameters for increasing rope sizes, which as previously mentioned, give a monotonic decay of the strength. In the parallel design there is a step-wise change in the size of the sub-rope. At this changing point there is a reduction in efficiency of the sub-rope. For a well-designed rope the efficiency of the full-assembly is a function of the number of sub-ropes. Therefore a step-wise change can be expected in the overall efficiency.

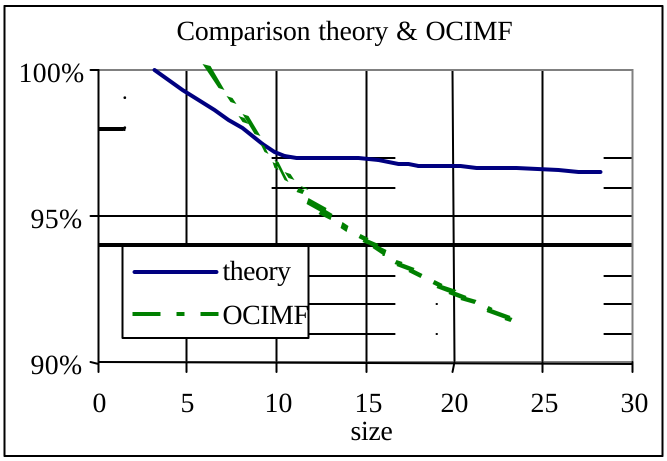


Figure 10: Theoretical efficiency & OCIMF

This issue can be addressed by conducting an additional test at a larger rope size as allowed in the standard, see also table 3. If the behaviour is comparable to that of the polyester, parallel-strand rope then the result will be on the theoretical line. If the behaviour follows that of other, traditional nylon rope designs then the OCIMF line will be followed.

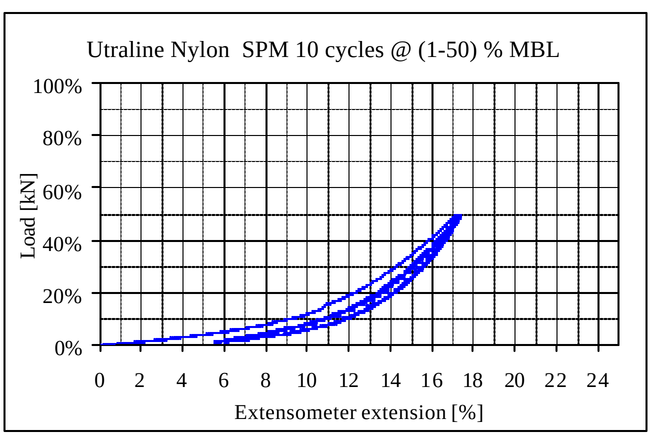


Figure 11: Load-elongation behaviour.

The load elongation behaviour has not changed significantly from the old to the new design, see figure 11 for a first loading curve.

A. TCLL

The value achieved in the accelerated fatigue test is 75%, this is significantly higher than the previous value (68%), see also figure 12. In the view of the author this can be greatly attributed to the splice used. In the new splice particular attention has been paid to reducing movements. Movement leads to imbalances in the rope, giving a higher variation and abrasion. In the cyclic experiments it was noted that the rope made little, to no noise. This indicates that there is little to no movement. The high TCLL value confirms this.

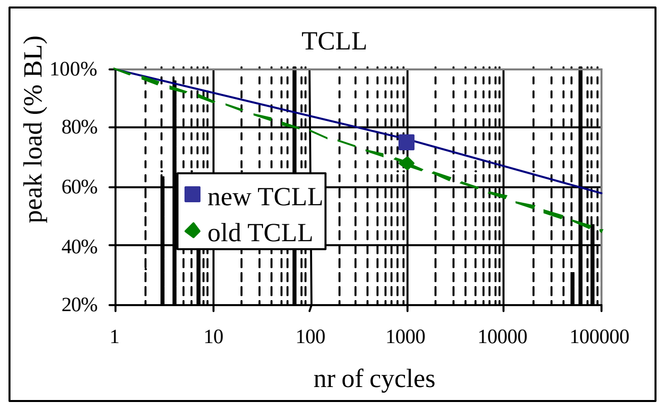


Figure 12: Old and new TCLL curve

The practical implication of the Thousand Cycle Load Level test can be seen from the curve: at normal load levels (peak loads <40% of the strength of the rope) fatigue will not be limiting. However a few overloading peaks could reduce the safe working life significantly. With an 8% difference in TCLL the difference in life is more than a factor ten.

CONCLUSIONS

The old OCIMF Guidelines for purchasing Hawsers is a well established and recognised standard. The new standard builds on giving clear targets and checkpoints both for testing and manufacturing. At Bexco the new standard has been used to bring the design and manufacturing for nylon inline with the other parallel-strand ropes.

An important addition to the guideline is the quantification of the behaviour of the marine finish. In the view of the author this test should also be included in the QC procedures required for manufacturing, because of the importance of the marine finish for the life of a nylon hawser.

The new OCIMF Guideline uses size to interpolate breaking strength for ropes tested between 6 and 15". By rounding off the size significant differences between actual and calculated strength are possible.

Experience from other applications has played an essential part in improving the fatigue performance of the rope.

FUTURE WORK

To establish the efficiency of the Ultraline design for larger sizes than 20" additional break tests will be conducted.

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2. Cordage Institute standard 1503-99, "Test method Yarn-on-Yarn abrasion, wet and dry". CI Hingham, MA.

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