CORDAGE INSTITUTE GUIDELINES FOR MARINE GRADE NYLON AND POLYESTER ROPE-MAKING YARNS

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Abstract – **The Cordage Institute (CI) recently published a new guideline for marine grade nylon yarn. This and an earlier, similar guideline for marine grade polyester yarn provide minimum performance criteria based on the yarn-on-yarn (YoY) abrasion test.**

The YoY abrasion test was developed by an Oil Companies International Marine Forum (OCIMF) study on the causes of failure of large single point mooring (SPM) hawsers in the early 1980s. Cyclic load tension testing of fiber ropes showed that internal abrasion was the principal cause of strength loss and failure. This problem is particularly acute in wet nylon ropes. OCIMF incorporated the YoY abrasion test into its "Guidelines for the Purchasing and Testing of SPM Hawsers". The method has also been adopted as a standard test method by CI and ASTM and is referenced in other industry guidelines.

At the request of the US Navy in the mid 1990s, CI set out to establish a definition and guideline for marine-grade yarn for use in mooring and towing hawsers. Wet YoY abrasion tests were performed on samples of four polyester and four nylon yarns which were claimed to be marine grade. All four polyester yarns exhibited very good performance. Based on this, CI published CI Guideline 2009P "Performance Requirements of Marine Grade Polyester Yarn for Fiber Rope" in 2002.

Three of the tested nylon yarns exhibited very good wet YoY abrasion performance. But one nylon yarn performed relatively poorly. CI drafted a marine grade nylon yarn guideline in which the minimum performance criteria included the three good-performance yarns but excluded the poor-performance yarn. The producer of that excluded nylon yarn objected strongly, and the draft nylon guideline was not approved at that time.

Additional YoY abrasion tests were recently performed on presently available nylon yarns. The nylon yarns used in the earlier CI tests are no longer made, at least by the original producers. Two present-day yarn producers provided samples of their regular and marine nylon grade yarns for testing. A rope producer also provided marine grade nylon yarn for testing.

The marine grade yarns performed significantly better than the corresponding regular grade yarns. The marine grade nylon yarns all exceeded the earlier established CI minimum performance criteria. As a result, CI has now approved and published CI Guideline 2009N "Performance Requirements for Marine Grade Nylon Yarn For Fiber Rope"

This paper explains the importance and advantages of using marine grade nylon yarn in ship mooring hawsers and other applications in which the rope is subjected to cyclic tension loading in wet condition. It presents the results of the OCIMF sponsored hawser study and the YoY abrasion test development trials. It describes the marine grade YoY test programs which were carried out by CI, including the results of the recent marine grade nylon yarn YoY abrasion test program.

This paper will be of interest to yarn producers, rope manufacturers, and users of fiber ropes in the marine environment.

Key Words: Marine Grade, Marine Finish, Nylon, Polyester, Yarn, Rope, Abrasion, YoY Abrasion Test

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INTRODUCTION

This paper describes the research and development programs leading to the Cordage Institute new guidelines for marine grade nylon and polyester yarns for fiber rope.

In marine service, some nylon and polyester ropes last much longer than others. This superior performance is attributed to various proprietary processes, such as oils and other finishes, applied by the yarn producers and rope makers. Yarns which possess superior performance are now called marine grade. Nylon fiber is particularly affected by water. The nylon molecule absorbs water and swells, loses strength, and becomes less resistant to abrasion. Application of a finish can protect the nylon fiber from this affect. But until recently, it was not possible to quantify and to specify performance, other than by specifying the yarn's trade-name.

The importance of marine grade yarn was demonstrated in the Oil Companies International Marine Forum (OCIMF) study of single point mooring (SPM) Hawsers in the early 1980s. The Yarn-on-Yarn (YoY) abrasion test was conceived and developed in that program. It has now been included in several standard test methods and marine industry guidelines.

At the request of the US Navy in the mid 1990s, CI set out to develop minimum criteria for marine grade yarns. Based on YoY abrasion testing of four polyester yarns, CI approved and published a guideline for marine grade polyester yarn in 2002. In similar testing of nylon yarns, three yarns performed very well but one yarn performed poorly. A draft guideline which excluded the poorly performing yarn objected was not be approved because of objections by its producer.

Recently another attempt was made to approve the marine grade nylon yarn guideline. Two yarn producers provided samples of regular nylon yarn and marine grade nylon yarn. Both marine grade yarns performed substantially better than the regular yarns and both exceeded the earlier proposed guideline. CI has now approved and published the marine grade nylon yarn guideline.

THE YARN-ON-YARN ABRASION TEST METHOD

Background of the Method

In the early 1980s, the Oil Companies International Marine Forum (OCIMF) sponsored a research program to Develop Single Point Mooring (SPM) Hawser Standards.[1, 2] Mr. Flory, then with Exxon Research and Engineering, was the principal investigator. Rope manufacturers provided specimens of twenty four different types of rope for testing, including 3-strand, 8-strand and double-braid nylon and polyester ropes

As part of this research program, a cyclic load "fatigue" test procedure was developed. In this test, the rope is first cycled 1000 times from 1% to 50% of its new wet break strength. If it survives, the peak tension is increased to 60% and another 1000 cycles are applied. If it survives, the peak tension is increased to 70% and another 1000 cycles are applied. If it survives, the peak tension is increased to 80% and 2000 cycles are applied. And if the rope survives all of these cycles, it is broken to determine residual strength. From the test result, the approximate peak cyclic tension at which the rope would fail at 1000 cycles is calculated. This result is called the Thousand Cycle Load Level (TCLL).[3]

A rope maker had provided the OCIMF test program with two 8-strand nylon rope samples made of the same nylon yarn material from the same producer, one made with a typical good yarn and the other made with a new "improved" marine finish yarn. These two rope samples were identical in nylon yarn material and rope construction, except for the yarn finish. In the TCLL fatigue test, the rope made from the "improved" marine finish nylon yarn performed much better than the rope made from the good finish nylon yarn. Similarly, another rope maker provided otherwise-identical 8-strand polyester ropes made with good-quality polyester yarns from two different producers. Likewise, in the TCLL fatigue tests, one of these polyester ropes performed much better than the other.

Examination of rope test specimens after cyclic load testing revealed that interstrand abrasion was the principal cause of rope strength reduction and rope failure. It was recognized that a test method was needed to quantify the yarn abrasion resistance of rope-making yarns.

Developing and Testing the YoY Test Method

Mr. Flory then conceived the yarn-on-yarn (YoY) abrasion test to compare the relative performance of different yarns. Figure 1 is a schematic of the YoY abrasion test machine. A length of yarn is inter-wrapped in contact with itself between three pulleys that are positioned in a defined geometry to produce a specific intersection angle. A weight is attached to one end of the yarn to apply a prescribed tension. The other end is drawn back and forth through a defined stroke at a defined speed until the yarn fails due to abrasion upon itself within the inter-wrapped region. The test can be performed in either wet or dry condition.

The Textiles Department of the University of Manchester Institute of Science and Technology (UMIST) was commissioned by OCIMF to evaluate the test method and compare the yarn performances. Samples of the good and "improved" nylon yarns and of the good and not-so-good polyester yarns were provided. PhD candidate Mustafa Goksoy performed

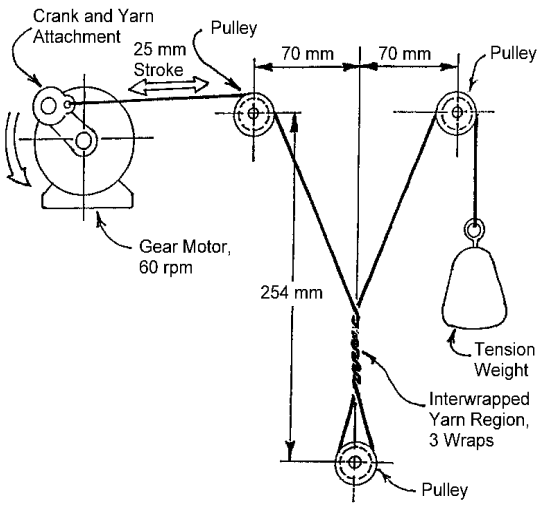

Figure 1 Yarn-on-Yarn (YoY) Abrasion Test

the abrasion testing under the direction of Department Chairman Prof. John Hearle.[4]

This testing was conducted blind. The UMIST researchers did not know how the yarn identities or how they had performed in the rope tests. In the following discussion, the two nylon yarns will be designated by the blind codes assigned to them in the UMIST tests, Nylon A and Nylon B.

Table 1 summarizes the performances of the ropes made of these yarns, in the OCIMF hawser test program. The TCLL test performance of Nylon Rope A was much better than Nylon Rope B. The 19,000 kg TCLL value for Rope B means that, when cycled to a peak tension of 50% of its new wet break strength, 38,600 kg, it would survive only about 1000 cycles. Projection of the 26,000 kg TCLL value of Rope A down to this same 19,000 kg peak cyclic tension indicates that Rope A might last 5,000 cycles. In other words, Nylon Rope A might last five times longer in typical marine service!

Table 1 Summary of Nylon A and B Rope Test Results OCIMF SPM Hawser Standards Development Program

	Thousand Cycle Load Level, kg	Projected Cycles to Failure at 19,000 kg
Nylon A rope	26,000	5,000
Nylon B rope	19,000	1,000

Figure 2 is a graph of the results of the UMIST nylon YoY abrasion testing. The wet YoY abrasion performance of nylon yarn A was much better than that of nylon yarn B.

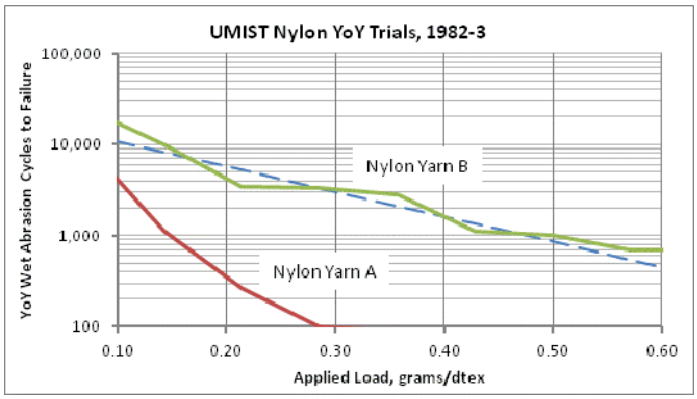

Figure 2 OCIMF Sponsored UMIST Nylon YoY Abrasion Test Trials

At the conclusion of testing, the results of the rope cyclic loading fatigue testing were revealed to the UMIST researchers. There was a direct correlation between the nylon ropes which performed very well in wet cyclic tension and the corresponding yarns with performed very well in the wet YoY abrasion testing. There was also a direct correlation between the results of the polyester rope tests and the results of the polyester YoY abrasion test results. [5, 6]

Other than the marine grade finish, the two nylon yarns were identical. The marine grade finish on the Nylon A yarn significantly improved its resistance to wet yarn-on-yarn abrasion, and this improved the rope wet cyclic load fatigue performance.

The YoY abrasion test method is now "standardized" in Cordage Institute CI-1503 [7] and ASTM D6611 [8]. It is called for in several fiber rope guidelines: OCIMF SPM Hawser Guidelines, API RP2SM Deepwater Mooring Guidelines [9] [10], ABS Deepwater Mooring Guidelines [11] and ISO Guidelines [12].

THE CI MARINE GRADE YARN GUIDELINE DEVELOPMENT PROGRAM

At the request of the US Navy in the mid 1990s, CI set out to establish minimum performance criteria for marine-grade nylon and polyester yarn used in mooring and towing hawsers.

Phase 1 CI Rope and Yarn Testing

In 1997, three producers provided nylon yarns with and without marine finish. A manufacturer made these into six 3-strand rope samples. It was intended to test these ropes using the OCIMF TCLL cyclic load test method. However, that effort failed due to test machine problems.

Mr. Flory was then provided with short pieces of these six rope samples for blind testing: he did not know which yarns had marine finish. He conducted wet YoY abrasion tests on yarns removed from the rope samples and provided the results to the CI Technical Committee for comparison.

Table 2 summarizes the results of that first CI sponsored effort. It clearly demonstrated the ability of the YoY abrasion test method to identify good marine finishes.

However, because the yarns had been made into ropes before they were tested, their performances might not be representative of new yarns. Thus these results could not be used to set minimum performance criteria. A second set of tests would need to be performed.

Table 2 Summary of Result of First CI Marine Finish Guideline Tests

Applied Load	Yarn Producer 1		Yarn Producer 2		Yarn Producer 3	
200 gm	2430	53159	1773	17184	1787	17329
300 gm	845	14987	882	8487	776	9754
400 gm	349	3886	449	4714	611	5958
CTF Ratio	**10.3**		**10**		**11**	
Marine Finish?	No	**Yes**	No	**Yes**	No	Yes

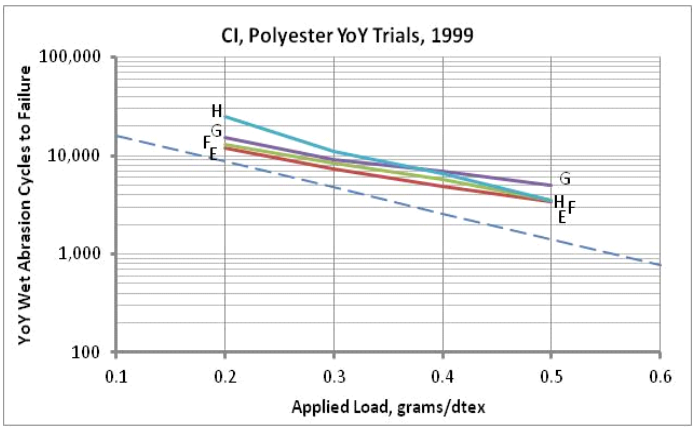

Figure 3 CI Polyester YoY Abrasion Test Results, 1999

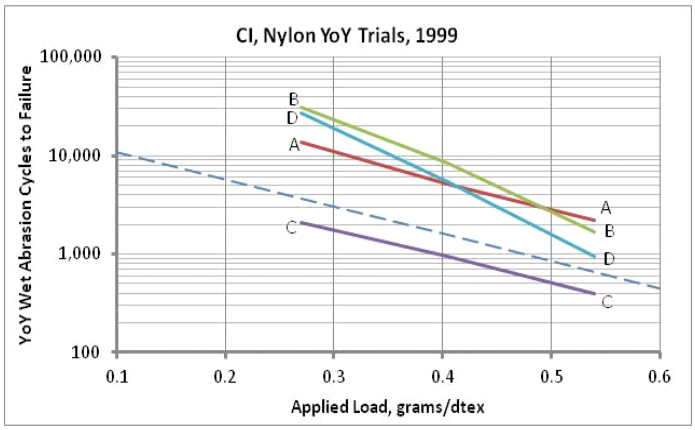

Figure 4 CI Nylon YoY Abrasion Test Results, 1999

Phase 2 CI Yarn Testing, Polyester Guideline

In 1999 CI asked producers of marine grade nylon and polyester yarns to provide samples for wet YoY abrasion testing. Four polyester and four nylon yarns were provided to Mr. Flory for testing.

Figure 3 shows the results of the polyester yarn testing. All four polyester yarns exhibited very good performance, similar to the better polyester yarn from the OCIMF testing. Based on this, CI published CI 2009P "Performance Requirements of Marine Grade Polyester Yarn for Fiber Rope" in 2002. [13]

Figure 4 shows the results of the nylon yarn testing. Three of the nylon yarns exhibited very good YoY abrasion performance, similar to the "improved finish" nylon yarn from the OCIMF testing. However, one nylon yarn performed relatively poorly.

In preparing the draft CI marine grade nylon guideline, the minimum performance criteria was set to include the three good-performance yarns but to exclude the poor-performance yarn. The producer of that excluded nylon yarn objected strongly, and the draft nylon guideline was not approved at that time. A second attempt was made to approve a marine grade nylon guideline in 2003. Three yarns provided by producers were tested. However, again the YoY abrasion performance of one of these yarns was substantially below the other two and of the draft guideline. That yarn producer again complained, and again the draft marine grade nylon yarn guideline was not approved.

Phase 3, CI Nylon Yarn Testing, Nylon Guideline

In 2011, CI again took up the task of establishing a marine grade nylon yarn guideline. TTI had recently performed tests on a rope maker's proprietary nylon yarn to demonstrate that it met the earlier proposed marine grade nylon performance criteria.[14]

The CI Technical Committee tentatively approved the draft marine grade nylon guideline 2009N, retaining the earlier proposed YoY abrasion test minimum performance criteria. The poor-performance nylon yarn C from the earlier tests is no longer made, so no objections were raised. However, none of the good-performance nylon yarns from the earlier tests are still being made, at least by the original producers. Final approval by CI depended on another demonstration that at least one presently commercially-available nylon yarn could meet the criteria.

Two present-day producers of nylon yarn, Nexus - Icoats and Barnett, provided samples of their marine grade yarns and regular grade yarns for testing. The wet YoY abrasion testing was performed at Tension Technology International's Arbroath, Scotland facility. Figures 5 and 6 show the recent trial test results. Both marine grade yarns performed significantly better than the corresponding regular grade yarns and both exceeded the earlier established CI minimum performance criteria.

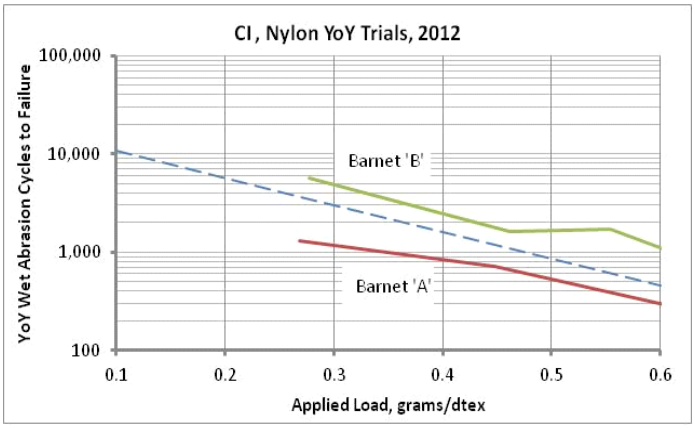

Figure 5 CI Nylon YoY Abrasion Test Results, Barnet Yarns, 2012

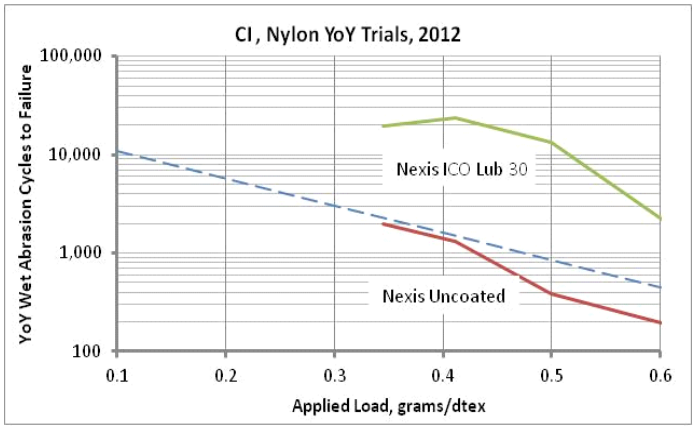

Figure 6 CI Nylon YoY Abrasion Test Results, Nexix Icoats Yarns

THE CORDAGE INSTITUTE MINIMUM PERFORMANCE CRITERIA FOR MARINE GRADE YARNS

CI has now published two separate guidelines for marine grade yarn for use in fiber ropes, one for nylon and one for polyester. The procedures to be used are the same in both guidelines.

The yarn shall use the same finish, applied in the same way as that used for all regular production of marine grade yarn. The test shall be conducted on a single yarn of size no greater than 3000 denier.

For initial classification and reclassification purposes, the test shall be conducted on a minimum of eight specimens at each of three applied loads. For manufacturing quality control, the test need only be conducted on four specimens at the applied load for which the classification test results fall closest to the minimum performance criteria line.

The yarn sample is soaked in water for 1 hour before testing. The interwrapped portion of the yarn is immersed in water throughout the test.

Figure 7 shows the minimum performance criteria for marine grade nylon yarn.[15] The criteria is expressed by the equations:

$$\textbf{Minimum CTF} = 20220 * e^{(-6.332 \times L_A)}$$

Where **CTF** = Cycles to failure, L_A is the applied load expressed in grams per dtex.*

$$\textbf{Minimum CTF} = 20220 * e^{(-7.033 \times L_A)}$$

Where **CTF** = Cycles to failure, L_A is the applied load expressed in grams per denier. *

Figure 8 shows the minimum performance criteria for marine grade polyester yarn.[13] The criteria is expressed by the equations:

$$\textbf{Minimum CTF} = 29570 * e^{(-6.093 \times L_A)}$$

Where **CTF** = Cycles to failure, L_A is the applied load expressed in grams per dtex. *

$$\textbf{Minimum CTF} = 29570 * e^{(-6.77 \times L_A)}$$

Where CTF = Cycles to failure, L_A is the applied load expressed in grams per denier. *

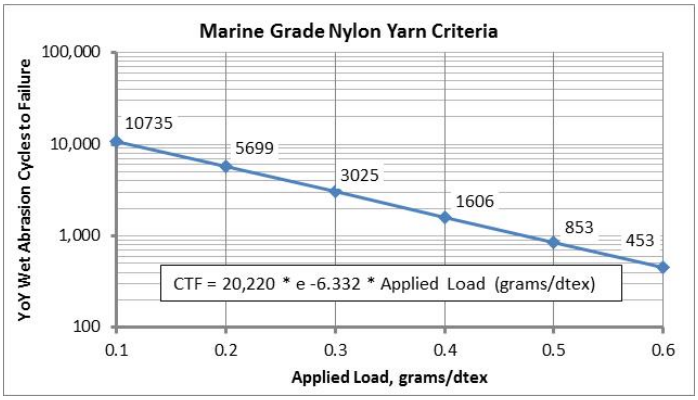

Figure 7 CI Minimum Criteria for Marine Grade Nylon Yarn

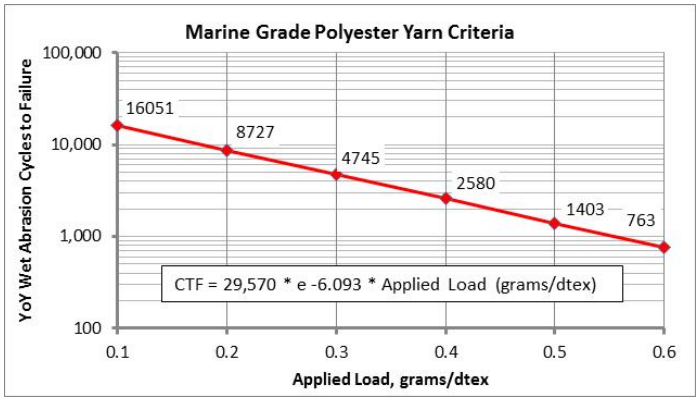

Figure 8 CI Minimum Criteria for Marine Grade Polyester Yarn

* Dtex and denier are textile industry methods of measuring yarn, based on weight per unit length.
1 dtex = grams per 10,000 m, SI unit used in most countries
1 denier = grams per 9,000 m, traditional unit used in US and UK

CONCLUSIONS

The CI Technical Committee operates on a consensus basis. Even though a majority might be in favor of an action, if there are major objections, an effort is made to try to resolve the conflict. Normally, CI cannot set standards or guidelines which exclude particular rope products, even those made by non-member companies. However, in this case, a new category of product, marine grade yarn, which is intended to have special, superior, desirable properties, was being established. This would allow the CI Technical Committee to make an exception and establish higher criteria, which some products might not meet. Nevertheless, it took a great deal of effort to obtain final approval of the marine grade nylon guideline.

Thirty years have elapsed since the YoY abrasion test was first developed and demonstrated by OCIMF. Fifteen years have elapsed since CI began to develop a marine grade nylon yarn criteria. During that time, several producers stopped making marine grade nylon yarn. Fortunately, other producers have now stepped in to make marine grade yarn.

We hope that the effort is worth it.

We hope that ship owners and other marine operators will now realize ropes made of marine grade yarn last much longer and that they will specify and use ropes made of marine grade nylon and polyester yarns in accordance with these CI guidelines.

July 20, 2013

References:

1. *Hawser Test Report*, Data on Large Synthetic Ropes in the Used Condition, OCIMF, Witherby and Co, London, 1982
2. *OCIMF Hawser Standards Development Program*, Trial Prototype Rope Tests, Draft Final Report, Exxon Research and Engineering, 1984
3. *OCIMF Guidelines for the Purchasing and Testing of SPM Hawsers*, OCIMF, Witherby and Co., London, 2000
4. M. Goksoy, PhD Thesis, *A Study of Yarn on Yarn Abrasion*, University of Manchester Institute of Science and Technology, 1986
5. Flory, John F., Prof. John W.S. Hearle and Dr. Mostafa Goksoy, "Yarn-on-Yarn Abrasion Testing of Rope Yarns", *Journal of the Textile Institute*, Textile Institute, Manchester, UK, 1988
6. Flory, John F., Prof. John W. S. Hearle and Dr. Mustafa Goksoy, "Yarn Friction and Abrasion Characteristics as Indicators of Rope Performance", *MTS '90 Conference Proceedings*, MTS, Washington, DC, 1990
7. CI Test Method1503, "Test Method for Yarn-on-yarn Abrasion, Wet and Dry", Cordage Institute, Wayne, PA, 2002, re-approved 2009
8. ASTM D 6611, "Standard Test Method for Wet and Dry Yarn-on-Yarn Abrasion Resistance, ASTM, West Conshohocken, PA, 2000, re-approved 2007
9. API RP 2SM, *Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring,* American Petroleum Institute, 2001
10. API RP 2SM, *Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring,* DRAFT Second Edition, American Petroleum Institute, 2012
11. ABS Guidance Notes on The Application of Synthetic Ropes for Offshore Mooring, American Bureau of Shipping, 1999, 2011
12. ISO 18692, Fibre ropes for Offshore Stationkeeping -- Polyester, 2011
13. CI Guideline 2009P, "Performance Requirements for Marine Grade Polyester Yarn for Fiber Rope", Cordage Institute, Wayne, PA, 2002, 2010
14. "Report on the Wet Abrasion Resistance of a Nylon Yarn, for US Rigging - Pelican Rope", TI-JN-2012-993-R, Tension Technology International Ltd., Eastbourne, UK, 2012
15. CI Guideline 2009N, "Performance Requirements for Marine Grade Nylon Yarn for Fiber Rope", Cordage Institute, Wayne, PA, 2013