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Performance analysis of mooring hawser prototypes manufactured with different kinds of constituent materials

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Abstract

This work aims to investigate the performance of double-braided hawsers manufactured with different kinds of raw material in order to achieve experimental results to confirm that hybrid ropes – a polyester jacket and a polyamide (nylon) core – may potentially present a service life time longer than 100% polyamide ropes and improved performance compared to 100% polyester ropes in mooring applications as well. This goal may be achieved by means of a construction which counterbalances the elongation between core and cover, combining the physical and mechanical properties of these two raw materials. Polyamide is a raw material with high mechanical shock absorption due to its quick elastic recovery. On the other hand, polyester has excellent resistance to ultra-violet radiation as well as abrasion and presents no water absorption. Polyester has excellent resistance to fatigue and to traction while exposed to high loads. Therefore, a balanced construction between these two materials may result in a product with distinct quality and performance.

1. Introduction

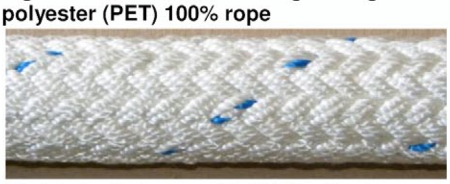
Based on our experience and preliminary studies, we have always supported the thesis that one of the factors which could extend the service life of mooring hawsers was the use of composite hawsers: a polyester jacket and a polyamide core. Our technical argument advocated the idea of a considerably balanced structure as regards elongation, for while the rope core has long pit length, the jacket has short pit length. This blend was assumed to ensure that the hawser has a better performance towards ultraviolet rays and greater traction resistance when wet, as well as higher abrasion resistance. However, we recommended that this suggestion be tested.

By means of laboratory tests carried out in compliance with the manufacturing, inspection and testing standards from the OCIMF guidelines, our study aims to compare the performance of mooring hawsers of the same double-braided structure (2-in-1) but with different constituent materials and some parameters. For that purpose, polyamide and polyester yarns were purchased especially to be used in this study by means of which the four hawser prototypes were tested, and are specified as follows in Figure 1, 2, 3 and 4.

Figure 1 – Double-braided polyamide (PA) 100% rope

Double braided rope with 100% polyamide rope and jacket, diameter 48 mm (6" circumference). Material specification: nylon - PA 66.

Figure 2 – Double-braided high elongation polyester (PET) 100% rope



Double braided rope with 100% polyester rope and jacket, diameter 48 mm (6" circumference). Material specification: polyester - PET 1high elongation. CSL development.

Figure 3 – Double-braided hibrid 1
(PA+ high elongation PET) rope

Composite double braided rope: polyamide core and polyester jacket, diameter 48 mm (6" circumference). Material specification: nylon - PA 66 + PET 1high elongation. CSL development

Figure 4 – Double-braided hibrid 2
(PA+ high tenacity with medium elongation PET) rope

Composite double braided rope: polyamide core and polyester jacket, diameter 48 mm (6" circumference). Material specification: nylon - PA 66 + PET 2 mean elongation.

Through a graphical presentation, this work presents the hysteresis curves of tension and deformation displaying the capacity of energy absorption of each of the ropes, as well as tension and deformation resistance to breaking. The hawser displays the best proficiency in the cyclic test (TCLL – thousand cyclic load level).

Finally, we seek confirmation of the efficiency of the hybrid rope while we have the opportunity to evaluate the performance of the prototype of the high elongation polyester rope. We are simultaneously revisiting the characteristics of the traditional polyamide mooring rope.

2. Statement of theory and definitions

In the second half of the last century, because of all those technological innovations, several technical requirements were created in Europe in order to standardize the hawser manufacturing and inspection processes. The first standard which specified the double braided polyamide hawser was British Standard (BS) 4928, published in 1985. Two years later, in 1987, the Oil Companies International Marine Forum (OCIMF) published its first edition of relevant guidelines to purchasing, manufacturing, inspecting and testing double braided hawsers:

- OCIMF Guide to Purchasing Hawsers;
- OCIMF Procedures for Quality Control and Inspection during the Production of Hawsers;
- OCIMF Prototype Rope Testing.

In the year 2000, the guidelines above mentioned were replaced with a single OCIMF publication entitled GUIDELINES FOR THE PURCHASING AND TESTING OF SPM HAWSERS.

Currently, the product is about to comply with international standards, as the International Organization for Standardization (ISO) has also been preparing regulatory technical standards for double-braided polyamide and polyester ropes, which will soon be published with the following numbers and titles:

- ISO 10547 - Polyester fibre ropes - Double braided construction;
- ISO 10554 – Polyamide fibre ropes – Double braided construction.

3. Description

3.1 Historical background

Some time ago, particularly in the early 80s, in the previous century, the double-braided polyamide hawser gained the status of the most suitable type of rope for mooring operations. Nevertheless, almost thirty years before, it was consensual that the polyamide yarn differed from man-made materials due to its high elongation and low value of elastic modulus, a feature that enhances the performance of this kind of hawser in operations which are subject to unpredictable natural phenomena (waves, currents, strong winds, rain storms, etc). Given these variables, which cannot be controlled by man, the prominent double-braided polyamide hawser represented a remarkable technical advance due to its excellent service life and shock absorption ability, which ensured stability, balance and a considerable cyclical harmony in relatively troublesome situations, which is normally the case for mooring operations between oil tankers and monobuoys.

Historically speaking, it should be noted that until the 50s, vegetal fibers such as shackle were the only choice for maritime applications. However, the introduction of polyamide into the rope-making industry gave rise to a truly technological revolution at the time, and posed a unique challenge to rope-making technology, which had started to envisage a new research perspective in this field: that of creating geometric shapes which could be used as improved replacements for the old format of the 3-strand helicoidal rope (Figure 5). However, along with the change in paradigm in the early 60s came the Braiding Machine 8 Strand (Figure 6), which was further developed into the Braiding Machine 12 Strand (Figure 7), a decade later, and which finally resulted in the later production of double-braid. Thus, in the late 70s, the well-accepted polyamide fiber was matched with the perfect and circular structure of the most effective naval rope: the double-braided one, also informally known as 2-in-1 hawser (Figure 8).

Figure 5 – Three-stranded helicoidal rope

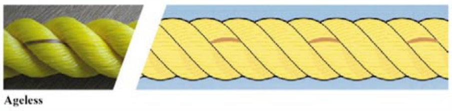


Figure 6 – Eight-stranded rope

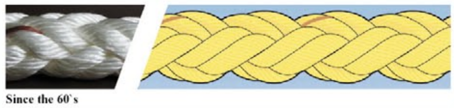


Figure 7 – Twelve-stranded rope

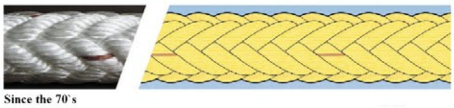
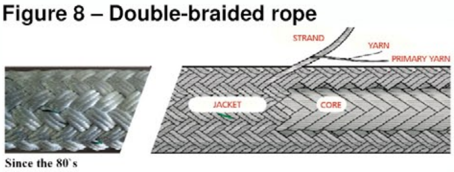


Figure 8 – Double-braided rope



3.2 Double-braided hawser

The traditional double-braided rope consists of two ropes assembled to form a single structure: an inner hollow single braid rope structure (core) is enclosed by another hollow single braid structure (cover). While a machine braids the core of the rope, with 24 strands, another one involves it with the cover braid, formed by 64 or 96 strands. The core, however, is the dominant element in absorbing the loads imposed to the rope. The distinctive and better performance of the double-braided rope, especially when compared with ropes of conventional constructions (3, 8 and 12 strands), is deeply related to the engineering of its construction, mainly because the greater the number of strands of a braid, the greater is their lay length also and, consequently, the more aligned they will be in relation to the traction effort they might be submitted to.

3.3 Physical and mechanical characteristics

The main physical and mechanical characteristics of each material of double-braided rope is summarized as follows (Table 1). If a punctuation from 1 to 5 (ranging from fair, good, very good, optimal and excellent) is preliminarily established, we will soon come to an arithmetic conclusion that double-braided hawsers – whether partially or wholly polyester – have higher potential than the 100% polyamide.

Table 1 – Description of the main physical and mechanical characteristics combined with their respective raw materials

DOUBLE-BRAIDED POLYAMIDE (PA) 100%	DOUBLE-BRAIDED POLYESTER (PET)* 100%	DOUBLE-BRAIDED HYBRID 1 PA+PET*	DOUBLE-BRAIDED HYBRID 2 PA+PET**
– excellent breaking strength;	– optimal breaking strength;	– optimal breaking strength;	– optimal breaking strength;
– excellent shock absorption capacity;	– optimal shock absorption capacity;	– optimal shock absorption capacity;	– very good shock absorption capacity;
– optimal physical properties retention capacity after long cyclical efforts;	– excellent physical properties retention capacity after long cyclical efforts;	– optimal physical properties retention capacity after long cyclical efforts;	– optimal physical properties retention capacity after long cyclical efforts;
– very good abrasion resistance;	– excellent abrasion resistance;	– excellent abrasion resistance;	– excellent abrasion resistance;
– very good resistance to ultra-violet (UV) radiation;	– excellent resistance to ultra-violet (UV) radiation;	– excellent resistance to ultra-violet (UV) radiation;	– excellent resistance to ultra-violet (UV) radiation;
– loss of up to 10% of its resistance when wet (fair acceptance).	– loss of up to 0% of resistance when wet (optimal acceptance).	– loss of up to 5% of resistance when wet (very good acceptance).	– loss of up to 5% of resistance when wet (very good acceptance).

* high elongation polyester.
** high tenacity with medium elongation polyester.

3.4 Ropes Technical Specification

The technical specifications of double-braided ropes for each constituent material in accordance with international standards are presented as follows (Table 2).

Table 2 – Technical specification of ropes in accordance with international standard

DOUBLE-BRAIDED	NOMINAL DIAMETER (mm)	NOMINAL LINEAR DENSITY (kg/m)	NOMINAL BREAKING STRENGTH (kgf)
Polyamide 100%	48	1,43	41.600
Polyester 100%	48	1,84	36.100
Hybrid 1 (PA+PET)*	48	1,64	38.850
Hybrid 2 (PA+PET)**	48	1,64	43.360

* high elongation polyester.
** high tenacity with medium elongation polyester.

4. Presentation of data and results

4.1 Dimensional and breaking strength

Dimensional data – diameter and linear density – were determined in accordance with ISO 2307:2005. All linear densities of the double braided hawsers had their constructive distributions (mass percentage between core and cover) duly respected in compliance with international recommendations (ISO Standard and OCIMF Guidelines). All tested double-braided ropes presented constant linear density of 1,50 kg/m. Though they presented comparative coherence in dimensional results, each one of the ropes was manufactured in accordance with the constructive variables projected for each of the combination of raw materials.

The dry breaking strength results for all tested double-braided ropes comply with International Standards specifications. Moreover, none of the ropes that were tested in wet condition presented breaking strength below the one specified as minimal. It has to be emphasized that only the 100% nylon rope had linear density that fitted normative dimensional tolerance of 5%, with the 100% polyester rope performing outstanding (-22,7%), with demonstrates its extraordinary constructive efficiency. Moreover, all splices of the eyes were made by the same person. In a universe of 28 samples tested, only two wet samples of the lot of 100% nylon hawsers broke outside the splicing area.

Dimensional and breaking strength results are presented in Table 3. Rupture curves after bedding in are presented in Figure 9, 10, 11 and 12 (dry condition) and Figure 13, 14, 15 and 16 (wet condition).

Table 3 – Dimensional and breaking strength results

DOUBLE-BRAIDED	DIAMETER (mm)	LINEAR DENSITY (kg/m)	DRY BREAKING STRENGTH (kgf)	WET BREAKING STRENGTH (kgf)	% OF DIF. BETWEEN (dry and wet)
Polyamide 100%	49	1,50	47.330	44.400	6.6
Polyester 100%	47	1,50	44.500	44.100	0.9
Hybrid 1 (PA+PET)*	50	1,50	43.540	43.540	11.7
Hybrid 2 (PA+PET)**	50	1,50	47.570	47.570	6.1

* high elongation polyester.
** high tenacity with medium elongation polyester.
Dimensional data obtained in accordance with ISO 2307:2005.

Figure 9 – Polyamide 100% rope tension-deformation curve – dry condition

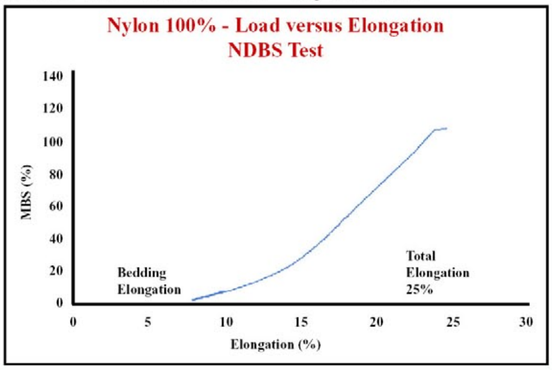


Figure 10 – Polyester 100% rope tension-deformation curve – dry condition

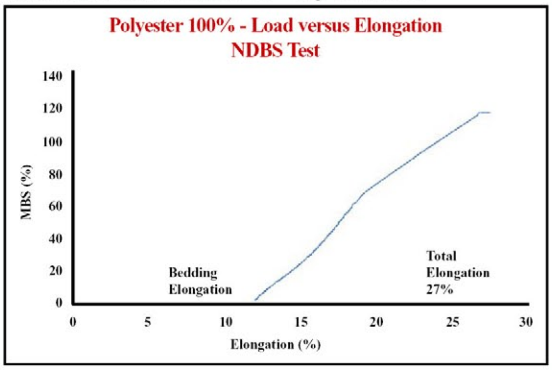


Figure 11 – Hybrid 1 rope tension-deformation curve – dry condition

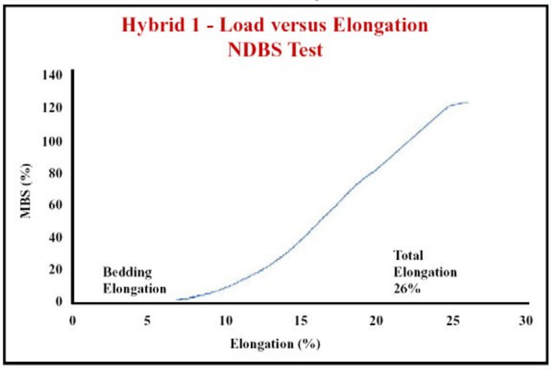


Figure 12 – Hybrid 2 rope tension-deformation curve – dry condition

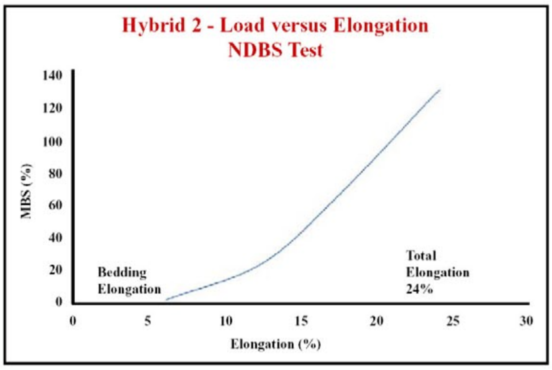


Figure 13 – Polyamide 100% rope tension-deformation curve – wet condition

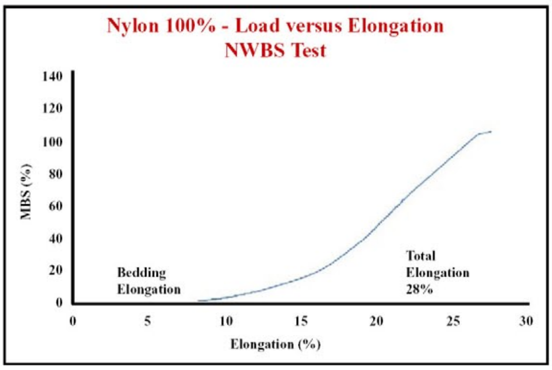


Figure 14 – Polyester 100% rope tension-deformation curve – wet condition

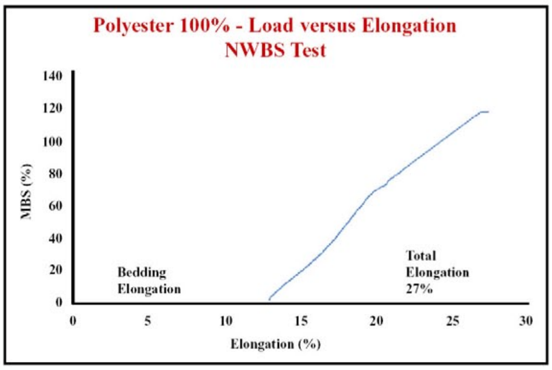


Figure 15 – Hybrid 1 rope tension-deformation curve – wet condition

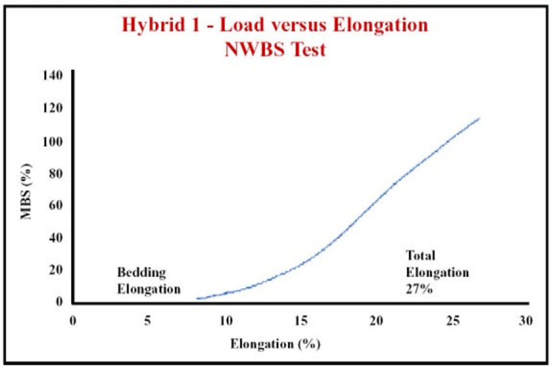
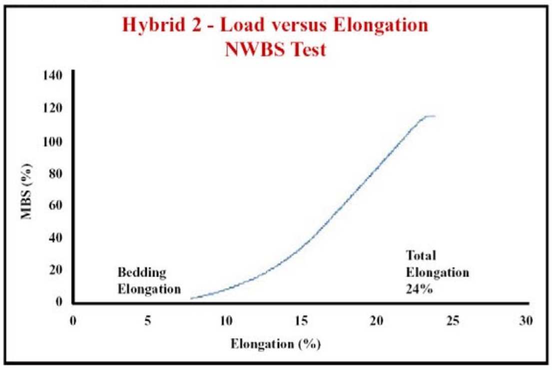


Figure 16 – Hybrid 2 rope tension-deformation curve – wet condition



4.2 Capacity of energy absorption

The capacity of energy absorption of the samples after repeated tensions was qualitatively analysed through curves of tension and deformation obtained from tests performed up to 75% of MBS in wet condition. The resultant hysteresis curves indicate the level of residual deformation and elasticity. The more elastic the material, the narrower its hysteresis cycle.

Polyester 100% showed a wide hysteresis curve. Polyamide 100%, Hybrid 1 and Hybride 2 showed similar curves and considerably narrower than Polyester 100%. Hysteresis curves are presented in Figure 17, 18, 19, 20 and 21.

Figure 17 – Polyamide 100% rope hysteresis curve – wet condition

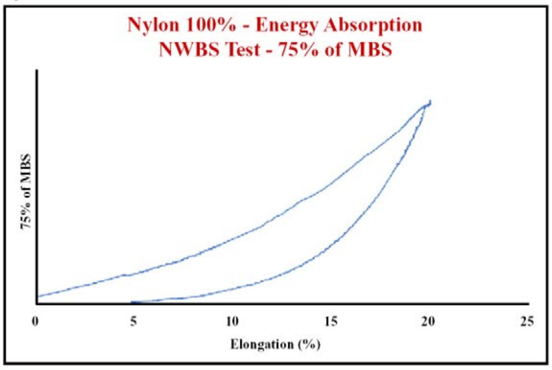


Figure 18 – Polyester 100% rope hysteresis curve – wet condition

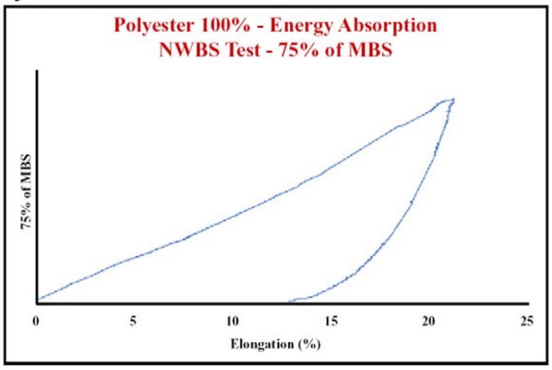


Figure 19 – Hybrid 1 rope hysteresis curve – wet condition

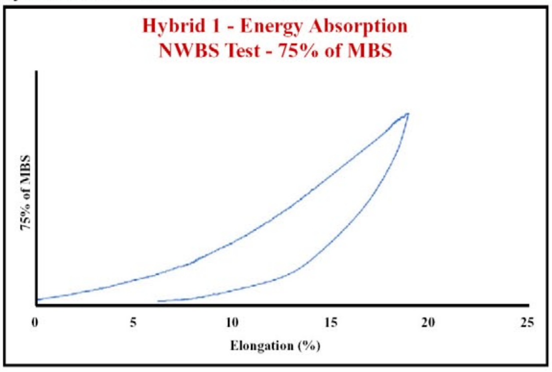


Figure 20 – Hybrid 2 rope hysteresis curve – wet condition

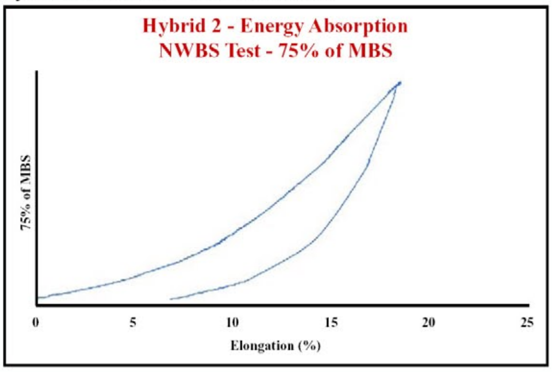
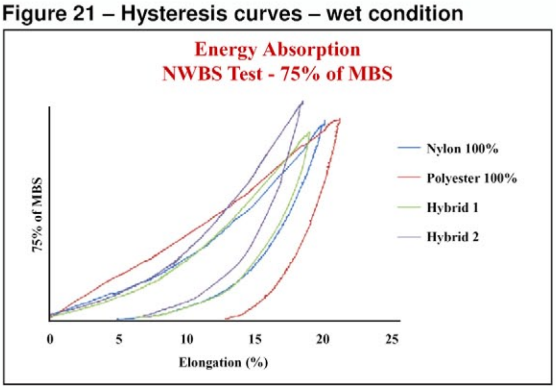


Figure 21 – Hysteresis curves – wet condition



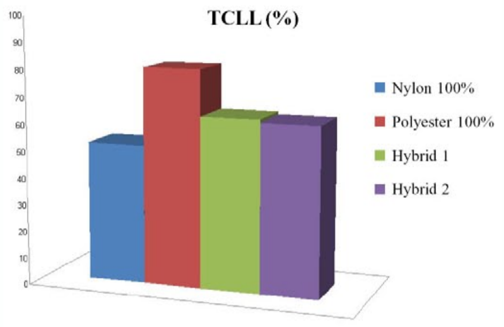
4.3 Thousand cyclic load level

Cyclic load test reflects the durability of wet ropes during cyclic loading. Polyamide or Nylon 100% hawser presented the lowest TCLL (52%) while Polyester 100% the highest (81%). The Hybrid 1 and 2 presented equivalent results, respectively 64 and 63%. TCLL test results are presented in Table 4 and Figure 22.

Table 4 – TCLL results

SAMPLE	MBS (%)	EQUIVALENT CYCLES	TCLL (%)
Nylon 100%	60	333	52
Polyester 100%	80	1449	81
Hybrid 1	70	322	64
Hybrid 2	70	281	63

Figure 22 – TCLL results



5. Conclusions

We conclude from this work that hawsers manufactured with partial or total participation of polyester present high performance, as we have empirically predicted. The results are related mainly to two reasons – the first one refers to the raw material researched and developed and the second one arises from the harmony of the constructive project developed for this work.

Furthermore, it was possible to confirm the thesis that the hybrid hawsers we manufactured can no doubt outlast the service life of the 100% polyamide hawsers. This is due not only to the superiority of their mechanical properties, but also to the physical advantage of having polyester working in the cover of the hawser.