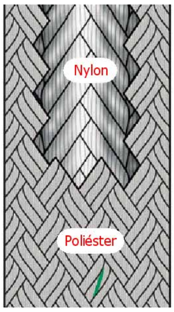
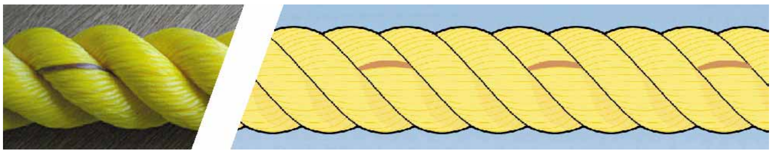
Performance analysis of mooring hawser prototypes manufactured with different kinds of constituent materials.

1. Introduction and historical background

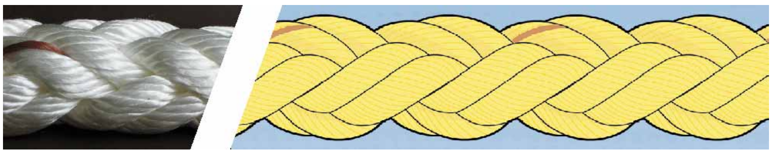


Some time ago, particularly in the early 80s, in the previous century, the double braided polyamide (nylon) hawser gained the status of the most suitable type of rope for mooring operations. Nevertheless, almost thirty years before, it was consensual that the polyamide yarn differed from man-made materials 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.

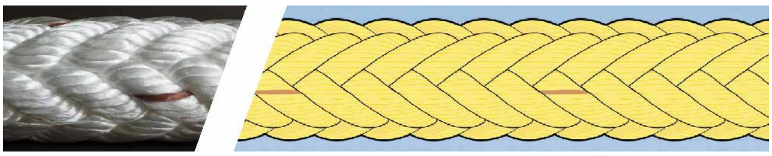
Historically speaking, it should be noted that until the 50s, vegetal fibers such as shackle were the only choice for maritime applications. However, the introduction of polyamide into the rope-making industry gave rise to a truly technological revolution at the time, and posed a unique challenge to 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 helical rope.



Ageless



Since the 60`s



Since the 70`s

Since the 80`s

However, along with the change in paradigm in the early 60s came the Braiding Machine 8 Strand, which was further developed into the Braiding Machine 12 Strand, 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.

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**.

OCIMF

In the year 2000, the guidelines abovementioned 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 braid construction;***
– **ISO 10554 - *Polyamide fibre ropes - Double braid construction***.

2. Development and Purpose of this paper

During the presentation of the technical paper entitled *Recommendation pointer for the inspection and use of polyamide (Nylon)* at the **3rd Latin American Monobuoy Operators Conference**, held in August 2007 in Rio de Janeiro, we explained 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 (nylon) 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.

The concluding remark of last year's paper was exactly the assumption underlying the study we are proudly going to present this year. By means of laboratory tests carried out in compliance with the manufacturing, inspecting and testing norms 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, CSL Ropes purchased polyamide and polyester yarns solely to be used in this study by means of which the four hawser prototypes were tested, and are specified as follows:

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

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

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

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 for 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 cycle load level*).

Finally, we seek confirmation (or not!) 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.

3. Double-braided hawser

The traditional Double-Braided rope, as its very denomination implies, 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, also, is their lay length and, consequently, the more aligned they will be in relation to the traction effort they might be submitted to.

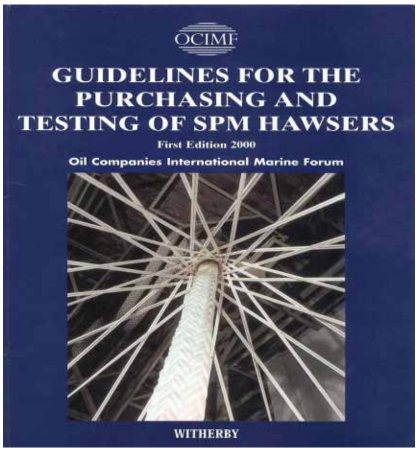
3.1 Description of the main physical and mechanical characteristics combined with their respective raw materials

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.

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.

4. OCIMF Rule - *GUIDELINES FOR THE PURCHASING AND TESTING OF SPM HAWSERS* - First Edition 2000



Sampling for tests

In accordance with section F *Prototype Rope Testing* of the OCIMF Guide, the tests listed below were conducted for the assessment for each one of the projects of 48mm diameter (6" circumference), with allowance to extrapolation of results up to 112mm in diameter (14" circumference):

- **2 dry rupture tests;**
- **5 wet rupture tests;**
- **2 cyclic load tests.**

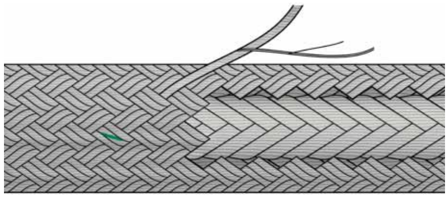
4.1 Technical Specification of ropes in accordance with International Standard

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.

5. Dimensional and rupture tests

Dimensional and breaking strength results

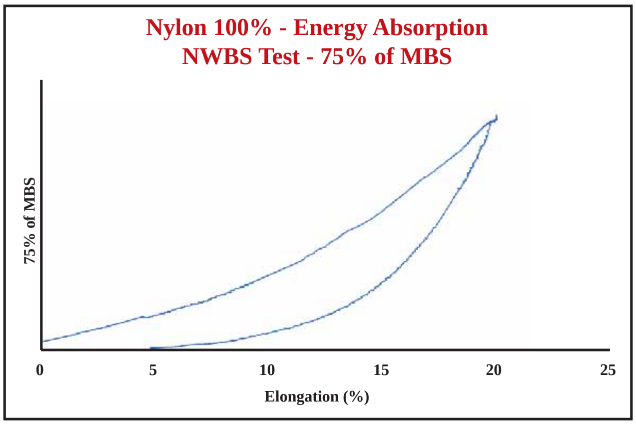


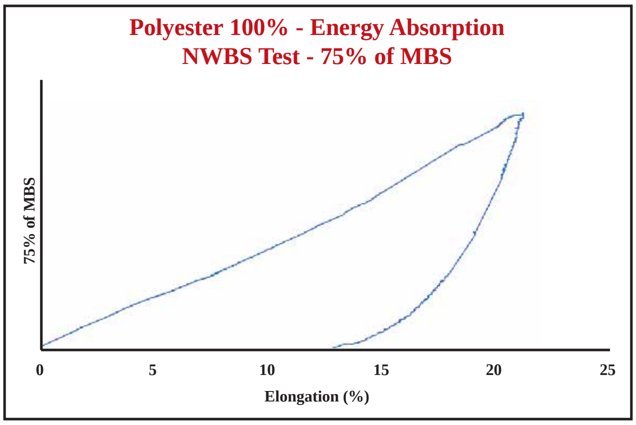
DOUBLE-BRAIDED	DIAMETER (mm)	LINEAR DENSITY (kg/m)	DRY BREAKING STRENGTH (kgf)	WET BREAKING STRENGTH (kgf)	% OF DIF. BETWEEN (dry and wet)
Polyamide 100%	49	1,50	47.330	44.400	6.6
Polyester 100%	47	1,50	44.500	44.100	0.9
Hybrid 1 (PA+PET)*	50	1,50	43.540	43.540	11.7
Hybrid 2 (PA+PET)**	50	1,50	47.570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

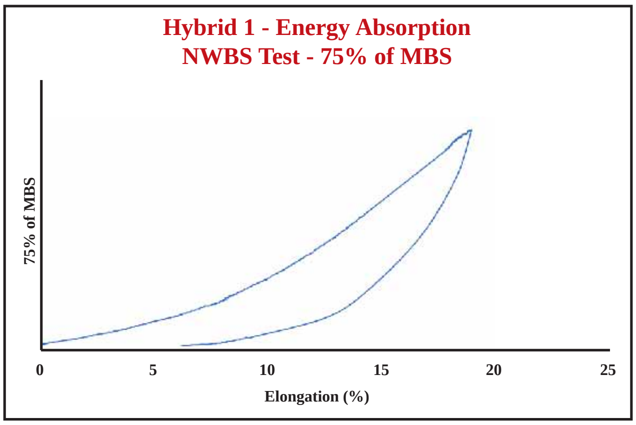
* high elongation polyester.
** high tenacity with medium elongation polyester.
Dimensional data obtained in accordance with ISO 2307:2005.

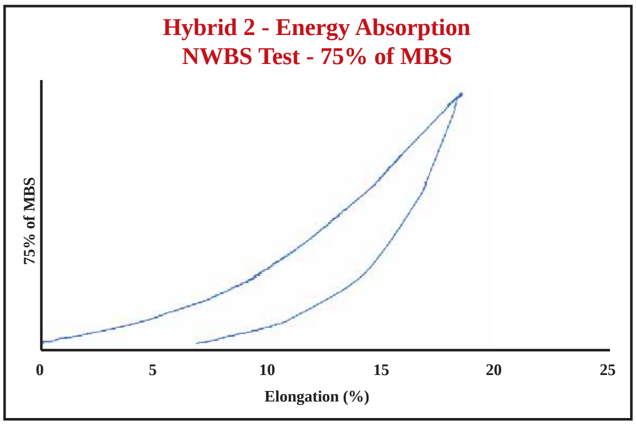
- All splices of the eyes were made by the same person. In a universe of 28 samples tested, only two wet samples of the lot of 100% nylon hawsers broke outside the splicing area, and yet, with surprising results.

5.1 Hysteresis curves up to 75% of MBS

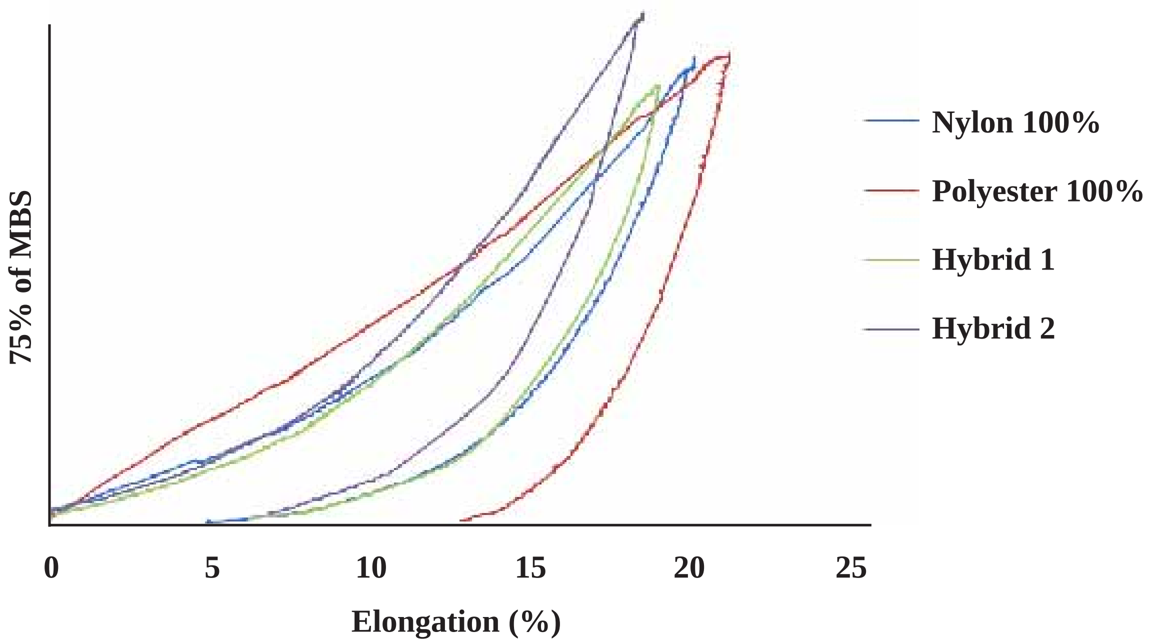






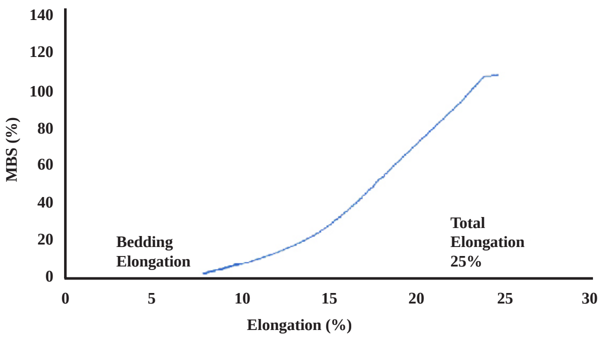


Energy Absorption
NWBS Test - 75% of MBS

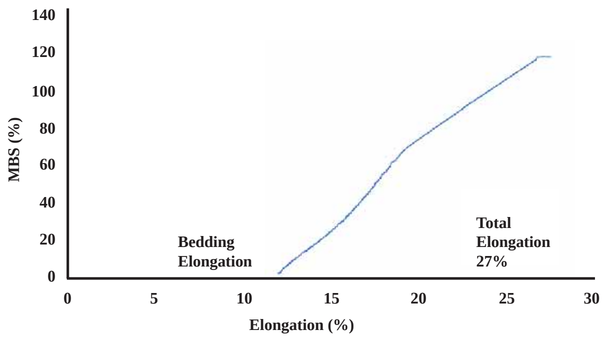


5.2 Rupture curves after bedding in

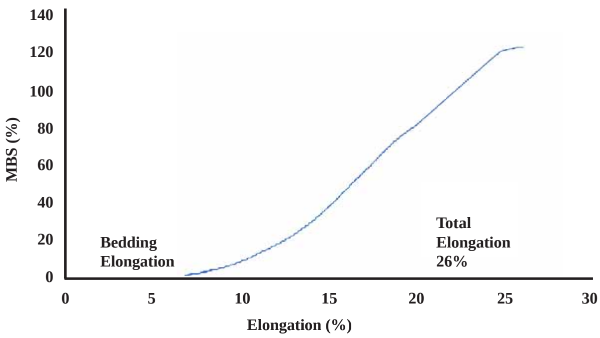
Nylon 100% - Load versus Elongation
NDBS Test



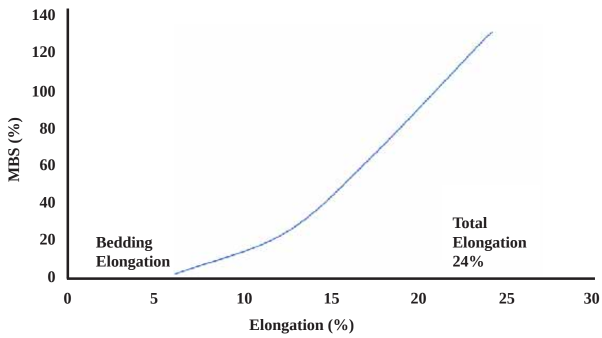
Polyester 100% - Load versus Elongation
NDBS Test



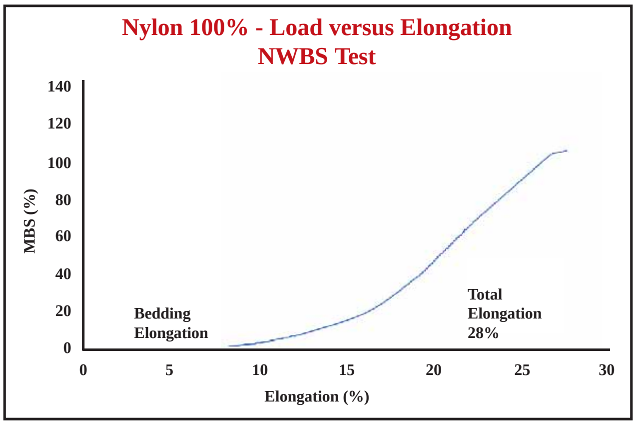
Hybrid 1 - Load versus Elongation
NDBS Test

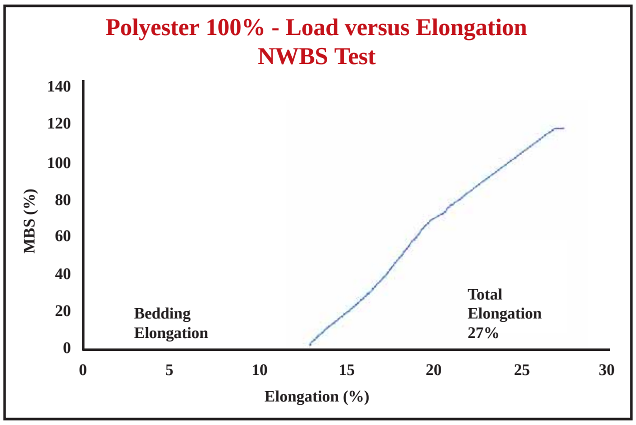


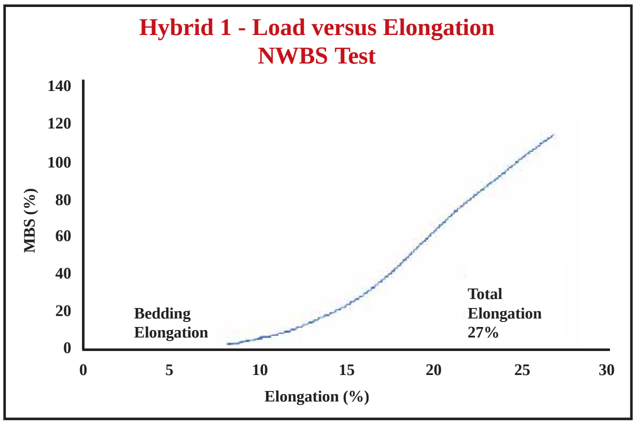
Hybrid 2 - Load versus Elongation
NDBS Test

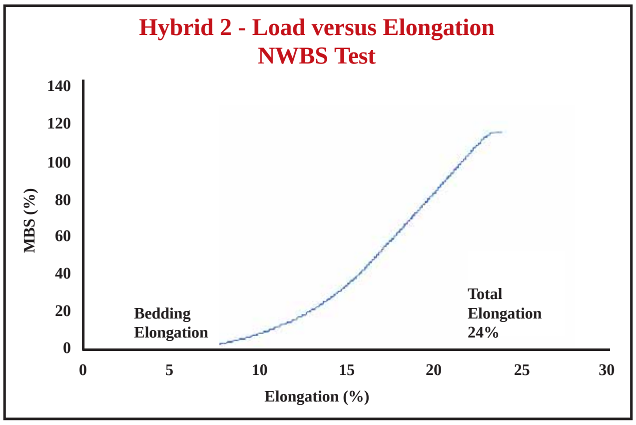


5.3 Tension and elongation curves up to rupture since bedding in

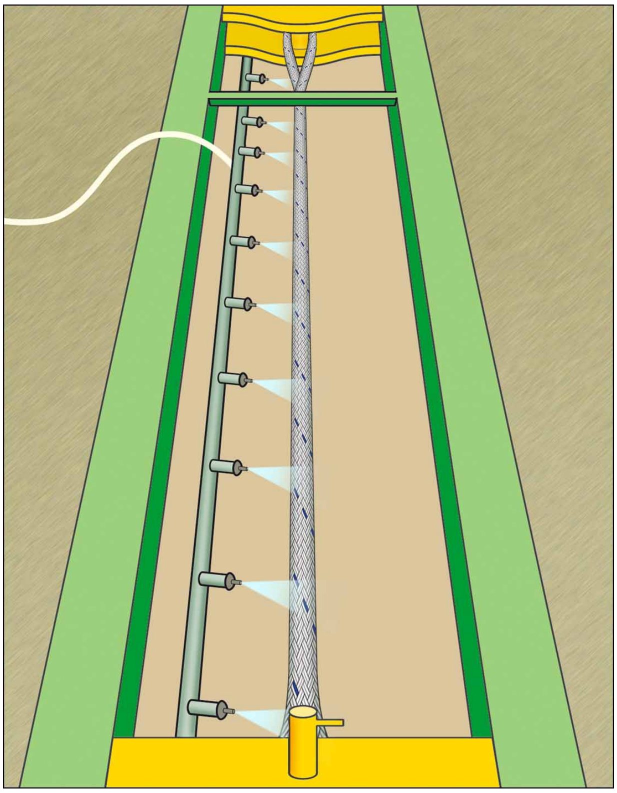






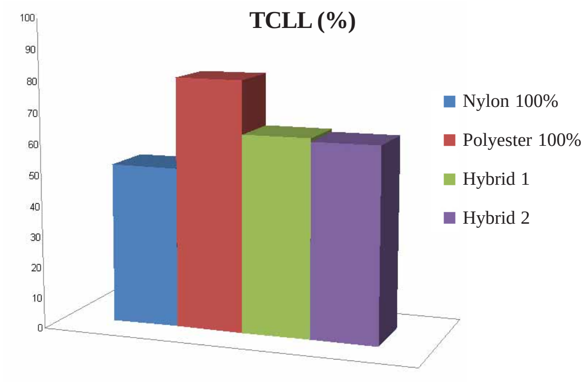


6. Cyclic tests results and TCLL (%) curve



6.1 Cyclic test results and TCLL (%) curves

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



7. Explanations and conclusions

- 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);

- 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.

- None of the ropes that were tested in wet condition presented breaking strength below the one specified as minimal. Curiously, 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%), which demonstrates its extraordinary constructive efficiency.

- The results confirm very clearly what we had empirically observed in the chart of item 2.1 - namely, the high performance of hawsers manufactured with partial or total participation of polyester. Obviously, such confirmation is based on two reasons. The first refers to the raw material researched and developed by CSL. The second reason arises from the harmony of the constructive project developed by Cordoaria São Leopoldo S/A.

Furthermore, we are glad to confirm the thesis that the hybrid hawsers we manufactured can no doubt outlast the service life of the 100% nylon 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.

Acknowledgements

I wish to thank the organizers of this event who, year after year, have worked very hard so we could have this opportunity to share and exchange our experience and, at the same time, be able to bond and get closer together both as individuals and as professionals.

I am grateful, also, to our team at CSL, who have so relentlessly devoted their time so we might comply with the deadline for the completion of this project.

My thanks to Industrial Director of our company who patiently manufactured and corrected, wherever necessary, the constructive variables of our ropes.

I want to thank, especially, the members of our Sales Department who have never ceased in their effort to seek the best alternatives for our clients. They thus have immense participation in this achievement.

Thank you all!

Leandro Haach
R&D and Quality Manager
CORDOARIA SÃO LEOPOLDO S/A.