EXPERIMENTAL RESULTS OF SYNTHETIC MOORING ROPES JACKETS SUBMITTED TO ABRASIVE ACTIONS

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Abstract. The use of synthetic ropes in the naval sector has been increasing because of its handling simplicity. In addition, with oil field development in ultra deep waters, the replacement of steel ropes used for the floating structures *mooring by others with lower linear weight became a necessity. A very important element that composes the rope is the jacket. Although it does not contribute to the mechanical resistance analysis of the rope, it must have durability characteristics that, during the useful life of the rope, work as a protection against the action of all kinds of external agents. Usually, the jackets are made of the same material that the ropes are made of and consume approximately 20% of the weight of the rope, which implies a very high additional cost. The main objective of this work is to present the experimental results obtained in the analysis of jackets made of different synthetic materials. The specimens were submitted to the following tests: abrasion under tension in a fluid environment and abrasion under tension combined with bending, simulating real conditions of work. Through the results, it will be possible to analyze different materials and to make a comparative analysis. The abrasion tests were performed in a prototype of an abrasion machine, according to standardization procedures, preparation procedures for specimens and wearing analysis criterions previously established in POLICAB - Stress Analysis Laboratory of the Federal University of Rio Grande.*

Keywords: *abrasion, wearing, ropes, jackets, synthetic mooring ropes*

1. INTRODUCTION

The use of synthetic ropes in the naval sector has been increasing considerably over the last few years. Mooring operations and movement operations of ships using tugs have made its use very common because of its handling simplicity. In addition, with oil field development in ultra deep waters, the replacement of steel ropes used for the floating structures mooring by others with lower linear weight became a necessity.

In spite of studies about these synthetic ropes, considering the mechanical behavior (tension, elongation, fatigue and creep), little is known about the mechanical behavior of protecting jackets. It should be noticed that as much as in tug operations, as in movement operations and offshore platforms settings, the action of wearing by the contact of the ropes with abrasive elements occurs very often.

Regarding the ropes used in offshore operations, the jackets that cover them also give them a unique characteristic: the subropes are kept together by its involving action. Although the jacket does not contribute to the mechanical resistance analysis of the rope, it must have durability characteristics that, during the useful life of the rope, work as a protection against the action of all kinds of external agents. Therefore, studying the behavior of a rope when it is in use must also consider the study of its jacket.

It is also in direct contact with natural agents that contribute to their degradation (humidity, sun, drying, salt water, organic material, fragmented material, etc.), the jacket also suffers mechanical action due to the handling of the rope. The rope is rolled and unrolled, going through several positioning situations until it gets in its final work position. These situations generate the contact of the jacket with other external surfaces, which can cause wearing. The damage located in these positions transform the rope into a "weak link" and creates points of possible mechanical failure. When this situation occurs, the damaged segment is rejected and the whole rope must be also rejected in many cases for the mooring function.

Experiments in this area still have not been carried out, especially because of the lack of studies about the mechanical behavior of jackets in several work situations and the use of different materials in its manufacture. Because of this, establishing superficial wearing test procedures and analysis procedures of experimental results becomes very important.

This paper presents the experimental results obtained in the analysis of jackets made of different synthetic materials submitted to different abrasive situations and also a comparison between these results.

Groups of three specimens were submitted to abrasion under tension in a fluid environment tests and abrasion under tension combined with bending tests, simulating the real conditions of work. A group was submitted to an abrasive situation in which the number of cycles was critical and it was considered as a reference situation. Then new groups were submitted to the same situations with 80%, 60%, 40% and 20% of this critical number of cycles. This sequence of tests was made for each kind of synthetic materials.

Through the results, it will be possible to trace wearing curves for different materials, to analyze them and to make a comparative analysis. Then with future experimental results it will be also possible to choose and to reject materials, proposing a reduction of weights and costs, without losing the reliability and the safety of the ropes.

2. ABRASION TEST MACHINE

In the tests, it was used a testing machine, as it is shown in Fig. 1. This machine made possible to perform abrasion under tension, abrasion under tension in a fluid environment (tension test submerged in water) and abrasion under tension combined with bending.

Figure 1. Machine used to test the materials.

The tests were made under the same abrasive conditions and the specimens were submitted to very similar abrasive surfaces.

Figure 2 shows simplified drawings of the abrasion tests, while Fig.3 shows details of the abrasion tests performed by the machine.

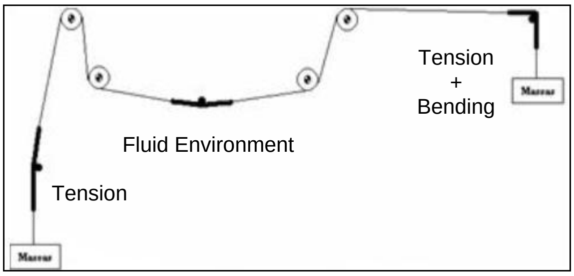

Figure 2. Abrasion under different kinds of tension situations.

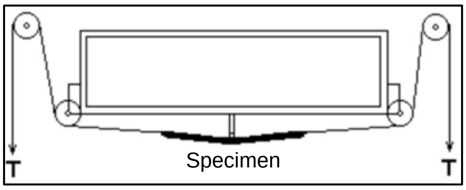

Figure 3. Detail of the abrasion under tension in a fluid environment.

3. SPECIMENS WEARING ANALYSIS

A series of precautions were taken so that all the specimens of each material could be submitted to similar test conditions. This made it possible to obtain repeatability in the tests, as well as in their preparation. In order to do this, the procedures established recently by Rodríguez *et al.* (2006) were followed.

The basic criteria adopted for the abrasion wearing determination considered the loss of mass of the specimen associated to the loss of mechanical resistance of the yarns that compose the jacket. Broken yarns and filaments were discarded for the determination of the residual mass.

3.1. Percentual loss of mass in the reference test determination

The greatest difficulty is to determine when and how the total damage of the jacket happens. So a reference test must be considered before the realization of the real tests to establish a methodology.

The specimens of a sampling were submitted to the reference test, in each kind of proof. In the moment that each one of the specimens had a sub rope exposure, without its damage sufferance, they were removed from the machine.

When the separation of all elements that constitute the jackets was finished, the criterion used to determine wearing was: all damaged components of the legs (legs, multifilaments and monofilaments) are considered as a real loss (and discarded), because of the loss of their structural function. The unbroken components of the legs were considered as constituent part of residual mass of the specimen.

For each reference specimen, the mass of the sub rope and the unbroken legs, multifilaments and filaments of the jacket were determined. This made it possible to know the residual mass, through the Eq. (1).

$$M_r = M_s + M_u \tag{1}$$

where M_r is the residual mass of the specimen, M_s is the sub rope mass and M_u is the mass of the unbroken components of the jacket.

So, in this way, it was also possible to calculate the percentual loss of mass by the Eq. (2).

$$M_{pr(\%)} = \frac{M_i - M_r}{M_i} \times 100 \tag{2}$$

where $M_{pr(\%)}$ is the percentual loss of mass of the reference specimen, M_i is its initial mass and M_r is its residual mass.

From the obtained values, the percentual average losses of mass of each sample and each kind of solicitation were calculated. These averages were used as reference for the subsequent abrasion wearing tests.

3.2. Relative wearing determination

After the analysis of the specimens submitted to the reference tests, the same analysis was carried out in the specimens of the subsequent tests. In these tests, the load was kept and the number of cycles was varied. Tests were done with 80, 60, 40 and 20% of the medium number of cycles obtained in the reference sample tests, for each sample made of three specimens and each kind of solicitation.

For each percentual band of the medium number of cycles, the residual mass was calculated using Eq. (1) and the percentual loss of mass of each specimen, using Eq. (3).

$$M_{p(\%)} = \frac{M_i - M_r}{M_i} \times 100 \tag{3}$$

where $M_{p(\%)}$ is the percentual loss of mass of the specimen, M_i is its initial mass and M_r is its residual mass.

From the obtained values, the percentual average losses of mass of each analyzed sample and each kind of solicitation were calculated.

The relation between the average values of percentual loss of mass of the analyzed sample and percentual loss of mass of the reference test is given by the Eq. (4).

$$\Delta(\%) = \frac{M_p(\%)}{M_{pr}(\%)} \times 100 \tag{4}$$

where $\Delta(\%)$ is the relative wearing.

4. TESTED MATERIALS

To make possible a comparison between materials, five kinds of jacket ropes were chosen. Their sub ropes were made of the same kind of polyester fibers, but their jackets were made of different materials as it is shown in Fig. 4

- Polyester - 10500 MIXED;
- Polyblend (60% PP + 40% PE);
- Polysteel – 1670 DTEX;
- Polypropylene – 1400 DTEX;
- Polyester – 6000F MIXED.

The Polyester, Polysteel and Polypropylene jackets have legs consisting of multifilaments, while the Polyblend jacket had legs consisting of monofilaments. Some of the mechanical properties of those materials are shown in Tab. 1. All specimens have 250 mm of length.

(a) Polyester - 10500 MIXED.

(b) Polyblend (60% PP + 40% PE).

(c) Polysteel – 1670 DTEX.

(d) Polypropylene – 1400 DTEX.

(e) Polyester – 6000F MIXED.

Figure 4. Materials submitted to abrasion tests.

Table 1. Materials properties (YBL = Yarn Breaking Load).

Jacket	Linear Weight (dtex)(1)	YBL (N)	Tenacity (N/dtex)
Polyester 10500 MIXED	10500	738.40	0.070
Polyblend (60% PP + 40% PE)	598	32.77	0.055
Polysteel 1670 DTEX	1670	114,10	0,068
Polypropylene 1400 DTEX	1400	50,03	0,036
Polyester 6000F MIXED	6000	367,58	0,061

(1)dtex = weight related to 1,000 m of yarn (multifilament or monofilament).

The ropes from which the specimens were extracted from, were provided by the CSL, with diameters of 14 mm.

5. RESULTS

The following wearing curves show the tendency of the wearing growth associated to the number of cycles, the kind of solicitation and the constant load. Each point represents the average value of the relative wearing associated to the number of cycles, for each sample.

In Fig. 5, it is possible to observe the results obtained in the tests performed using specimens with jackets made of Polyester - 10500 MIXED.

For the following materials the comparative curves between the tendency curves obtained in the tension combined with bending tests and in the tension submerged in water tests are shown. In Fig. 6, it is possible to observe and compare the results obtained in the tests performed using specimens with jackets made of Polyblend (60%PP+40%PE).

In Fig. 7, it is possible to observe the comparison between the results obtained in the tests performed using specimens with jackets made of Polysteel – 1670 DTEX.

In Fig. 8, it is possible to observe the comparison between the results obtained in the tests performed using specimens with jackets made of Polypropylene – 1400 DTEX.

In Fig. 9, it is possible to observe the comparison between the results obtained in the tests performed using specimens with jackets made of and Polyester – 6000F MIXED.

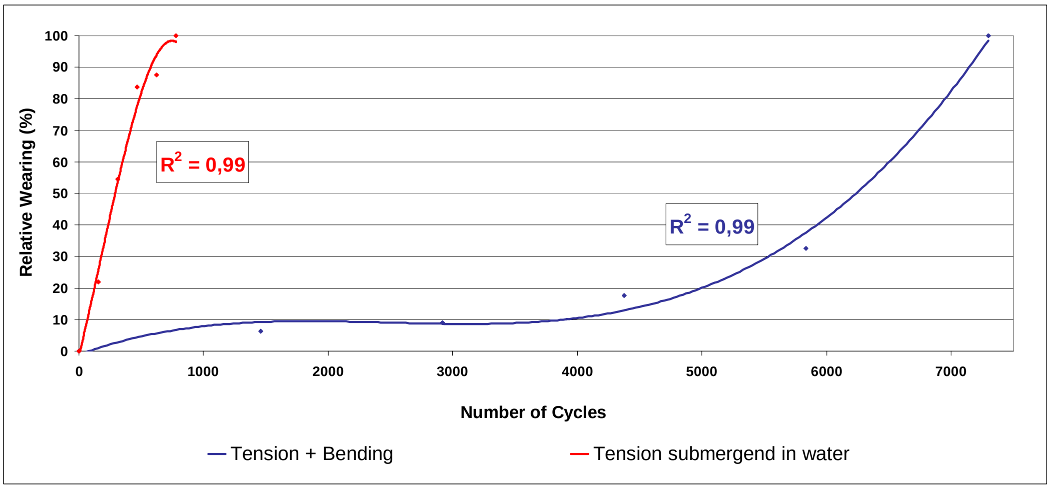

Figure 5. Curves obtained in the abrasion tests with Polyester - 10500 MIXED.

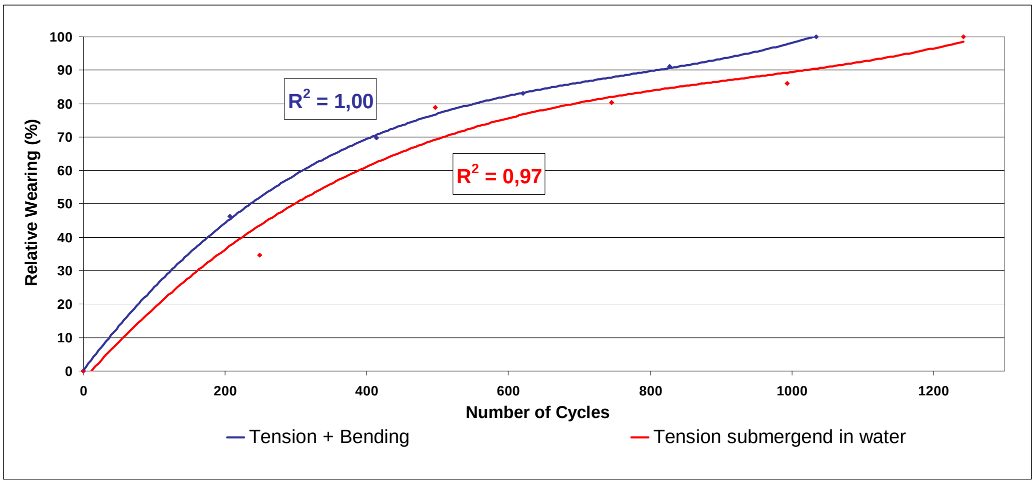

Figure 6. Tendency curves obtained in tests with Polyblend (60% PP + 40%PE).

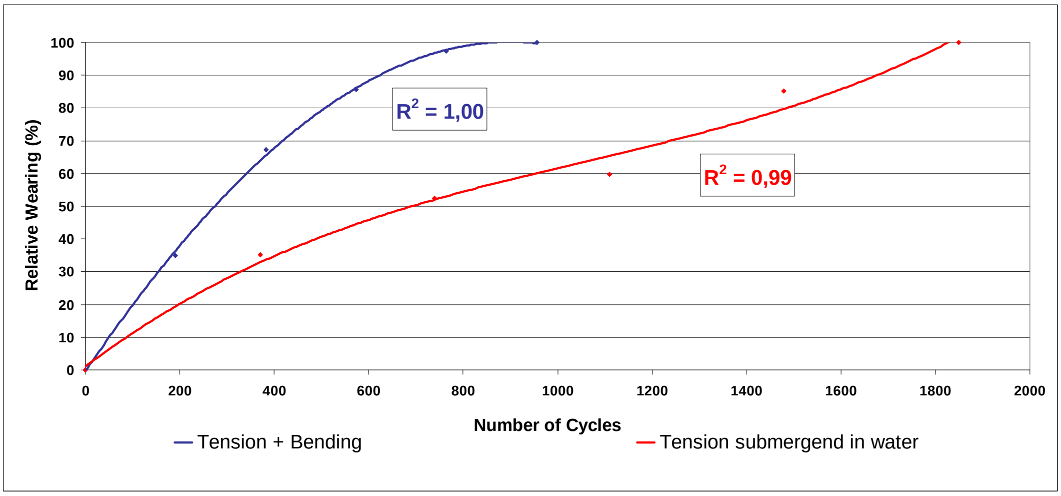

Figure 7. Tendency curves obtained in tests with Polysteel – 1670 DTEX.

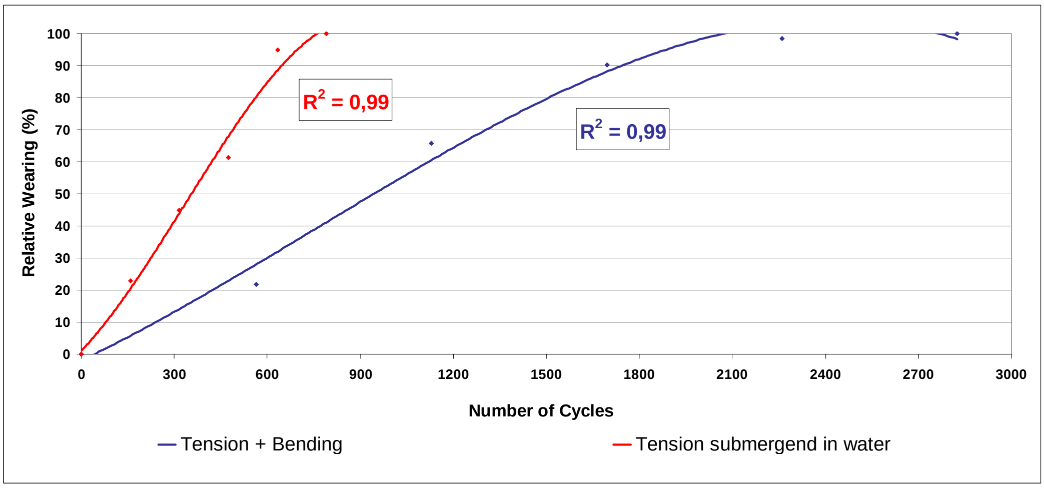

Figure 8. Curves obtained in the abrasion tests with Polypropylene – 1400 DTEX.

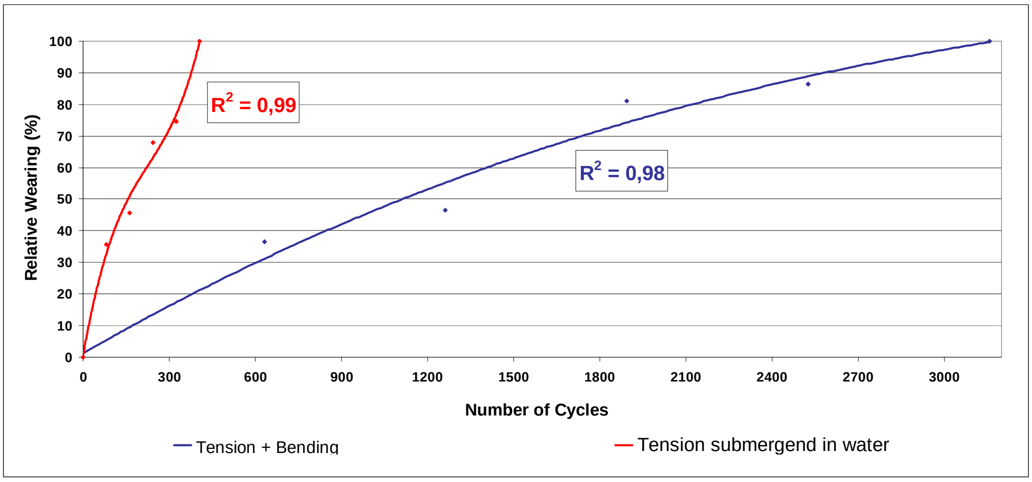

Figure 9. Curves obtained in the abrasion tests with Polyester – 6000F MIXED.

The Fig. 5 to 9 show for all the tests reasonable Correlation Coefficients, R^2. Through the results and the curves traced for each material, a comparison between all materials can be made and also an analysis of the behavior of each of them. It can be made for both situations: abrasion under tension combined with bending and abrasion under tension submerged in water. This comparison is shown in the following figures.

In Fig. 10, it is possible to observe the comparison between the results obtained in the tension combined with bending tests and in Fig. 11, it is possible to observe the comparison between the results obtained in the tension submerged in water tests.

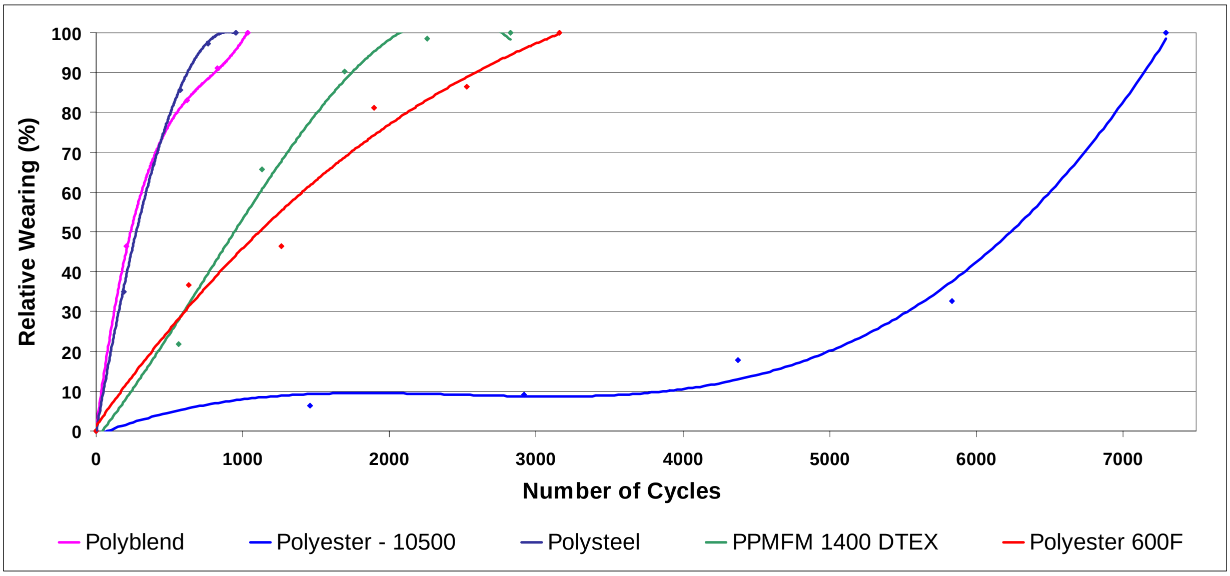

Figure 10. Comparative curves obtained in the tension combined with bending tests.

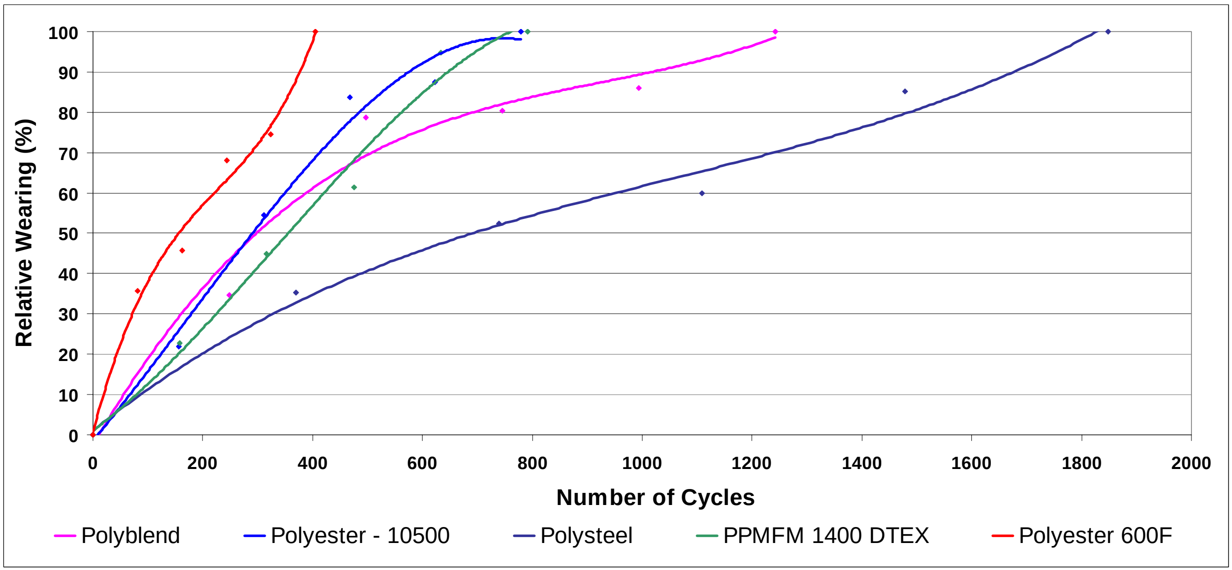

Figure 11. Comparative curves obtained in the tension submerged in water tests.

As it can be seen in Fig. 10 and Fig. 11, materials like Polysteel 1670 DTEX and Polyblend had better wearing behavior in tension tests submerged in water, but also the worst wearing behavior in tension tests combined with bending.

Although Polysteel presents the best conditions of work in submerged environments it still is not considered as a very resistant material since the difference between its behavior and other materials is not considerably.

An opposite situation happened to Polyester 10500 MIXED and to Polyester 6000F Mixed. Polyester 10500 MIXED presents a much better behavior when it is submitted to tension combined with bending tests, but when it's submitted to tension tests submerged in water it presents a behavior very similar to the others materials.

Polypropylene 1400 DTEX had the most regular behavior in both abrasive situations, but it would not be recommended since the obtained results show a low wearing performance.

Through a preliminary and qualitative analysis, the selection and the use of each material must consider the work conditions in which they will be submitted to.

6. CONCLUSIONS

In this work, results and curves obtained in abrasion tests were presented. Through the comparison between the behaviors of the analyzed materials submitted to different kinds of solicitations it was possible to make a comparison between them.

Choosing a material for a specific situation will depend of the kind of work situation and also of additional studies about the relation between wearing and environmental conditions. For example, for ropes which will be submitted to abrasive situations in submerged environments polyester jackets would be the best choice since they present better advantages in comparison to other materials tested in the present work.

The continuity of this research points to the analysis of the same materials after a period of exposure to environmental and climatic modifications during several months. They will be also submitted to tension combined with bending tests and tension submerged in water tests. After their behaviors analysis, it will be possible to compare the results with the results presented in this research and to evaluate the influence of the climatic variations in the ropes behaviors.

In addition, the variation of other parameters to determine other wearing curves will be done and analyzed. For example, the wearing curves associated to the applied load variation with a constant number of cycles.

7. ACKNOWLEDGEMENTS

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