



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0934 CHARACTERIZATION OF THE POLYAMIDE ABRASION RESISTANCE CURVE

Nícolas Vannucchi Nadalin
Eduardo Schultz Laux
Carlos Eduardo Marcos Guilherme
Fernanda Mazuco Clain

Universidade Federal do Rio Grande, Engineering School, Stress Analysis Laboratory, Rio Grande, Brazil
nvnadalin@outlook.com eduardolaux@furg.br carlosguilherme@furg.br fernadaclain@furg.br

Abstract. *In the various application of cables and lashings, synthetic materials are increasingly being used to replace steel. From platform anchors and floating turbines on offshore environment to the onshore use of cables, polyamide stands out as a synthetic fiber capable of supply the proposed requirements and serve as a cheaper alternative to steel. Seeing the polyamides importance on various applications, the present work has as main objective compare the characteristics of virgin Polyamide 6 abrasive resistance in dry environment and submerged in water. Therefore, the supported number of cycles by the material is sought when requested by different previously established loads. In both types of test, dry and wet, the equipment follows the specifications of the CI - Cordage Institute and ASTM Standards. The YoY (Yarn-on-Yarn) abrasion test is used to obtain the qualitative values of the abrasion resistance. At the end of this work, the characteristic abrasion resistance curves of Polyamide 6 were obtained.*

Keywords: *abrasion, polyamide filaments, yarn-on-yarn, synthetic cables.*

1. INTRODUCTION

Many of the changes that occurred during human history came from the availability and use of materials found in nature. Humanity has passed through the age of stone, bronze, steel, etc. In all, significant changes in technology and in the way engineering was made changes happened.

In the last century, in turn, much of the technological changes made by man are due to the emergence of polymers as an alternative material (metals, ceramics, etc.). This premise of Hage (1998), even though it was supported in the last century, is increasingly devoted to the research and use of synthetic polymers has been increasingly common.

The synthetic fibers use for cable manufacture, mainly for maritime applications, for an example, has hit records in the last two decades. Worldwide annual production is not easily quantified, but in 2004 it was estimated to be worth around \$ 1.6 Billion (McKenna et al, 2004).

Kenney et al., 1985 justified its use in the 1980s as component with a good mechanical axial characteristics and low specific weight. As one of the main users of ropes for permanent mooring systems, the oil and gas industry has opted for these components because they possess performance characteristics and economies of scale which are in many respects superior to steel components (Samuel et al, 2015). In addition, according to Duarte(2019), the synthetic systems were designed to work for at least 20 years without showing substantial loss in tensile strength or in the mechanical behavior along this period.

When compared to steel, polyamide has very similar tensile strength, lower mass and smaller occupied submerged area for the same required loads. Dorna 2016 in her study, complements some fiber characteristics such as: low flow, high abrasion resistance, good fatigue resistance and high barrier properties. Her also emphasizes that this set of characteristics is a direct result of peptidic bonds of the manomers.

The present work used Polyamide (PA 6), from polyamides family. When rubbed between the filaments, this material breaks part of the large polymer chains showing appearance with loose wires and a decrease of the cross section of the specimen. This material loss process is called abrasion.

In order to understand this phenomenon on polyamide 6, the present work chose Yarn-on-Yarn abrasion test as a standard method for testing inter-yarn abrasion of synthetic fibers and provides a qualitative value of the abrasion resistance (Chevillotte et al, 2018).

2. MATERIAL AND TEST METHODS

2.1 Experimental Procedure

Before subjecting polyamide fiber to any test environment, the present study performed the collect of the essential virgin filaments data. Mechanical characteristics were collected, information about its monomer chains, melt temperatures, manufacturer specifications, water absorption rate and other equally important information with help of the CIA(Integrated Center of Analyzes).

The first step after collecting the basic data is to investigate the rupture load of virgin filaments, or also called the polyamide 6 YBL (Yarn Break Load). Therefore, Instron equipment available in Stress Analysis Laboratory (POLICAB) was used for rupture tests. This is a quick and very common test in synthetic materials research. This test provides the polyamide average rupture load in addition to the total elongation and its behavior curves.

The next step with the material YBL already identified is establish the percentages of load in which the specimens will be subjected. For this work, percentages from 2% to 6% of the already found YBL were chosen.

After the load choice, the Yarn-on-Yarn method was used to construct the graph that characterizes the abrasion resistance of PA6.

2.2 Fibre and material

Polyamide 6 (PA6) yarns have been investigated in this study. The fiber, remains faithful to the production standards for offshore cables being manufactured by a company specialized in the area. The length varied between the abrasion resistance and rupture load tests to suit the test conditions of each machine. Even so, the length does not interfere in obtaining data.

2.3 Yarn Break Load

To obtain the nominal rupture value, tests were performed with 48 PA6 filaments following the specifications of the ASTM D2256 standard of the American Society for Testing and Materials in the premises of the Stress Analysis Laboratory through Instron equipment that identifies the maximum supported load and the elongation of the specimen. For more information about the equipment, Duarte 2017 presents the specifications of the same also used by this study. With controlled humidity (55%), temperature at 22 ° C and 60 torsional cycles. The table below shows the values obtained and also the average used of 204.38911 N. The graph then illustrates the study model used to obtain the YBL of the material with 8 of the 48 filaments investigated.

Table 1- Experimental results of polyamide tensile test on virgin specimens
Available from: Stress Analysis Laboratory

	Maximum Load [N]	Strain [%]
Maximum	214.45	21.41
Minimum	188.15	14.91
Mean	207.37	18.75
Standard Deviation	5.30	1.27

*Polyamide 6, 500 mm (22°C).

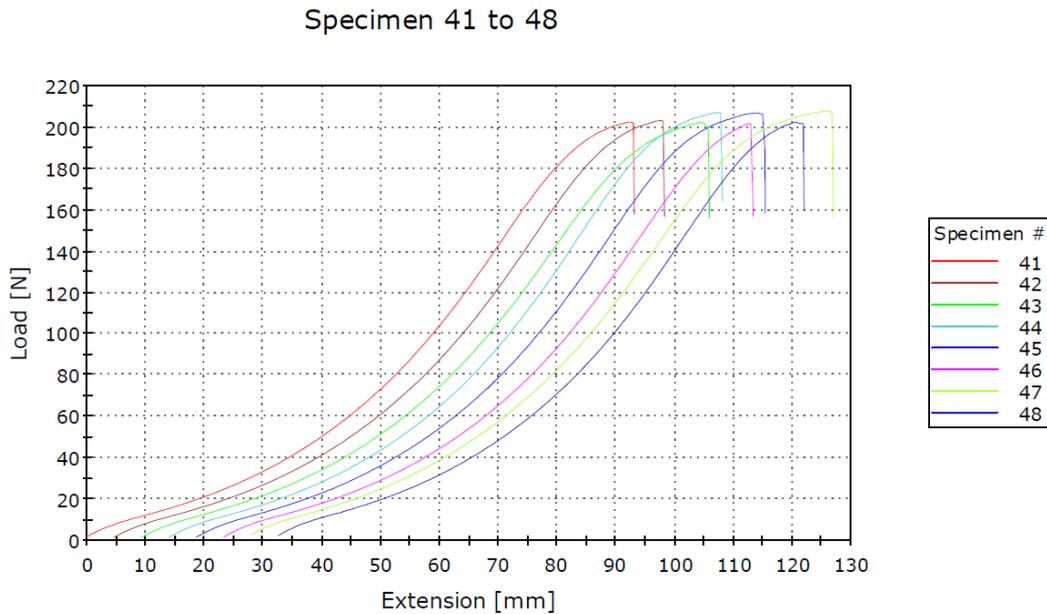


Figure 2- Polyamide 6, 500 mm (25°C)-Tensile test on virgin specimens
 Available from: Stress Analysis Laboratory

2.4 Yarn on Yarn

The yarn-on-yarn abrasion test were performed as described in CI-Cordage Institute CI 1503 “Method for Yarn-on-Yarn Abrasion” and also in ASTM 6611 “Standard Test Method for Wet and Dry Yarn-on-Yarn Abrasion Resistance”. This method consist in twist the filaments around themselves and stretch with a pre-established load. This load forces the friction between the filaments in the cycles of the machine.

For this type of method, the equipment used was developed in the laboratory and counts with a counting system, a drive motor, two slots for simultaneous testing, a chassis specially developed for small filaments and two coupling containers. The scheme below (Fig 2) shows in simplified form the mechanism developed for the analysis.

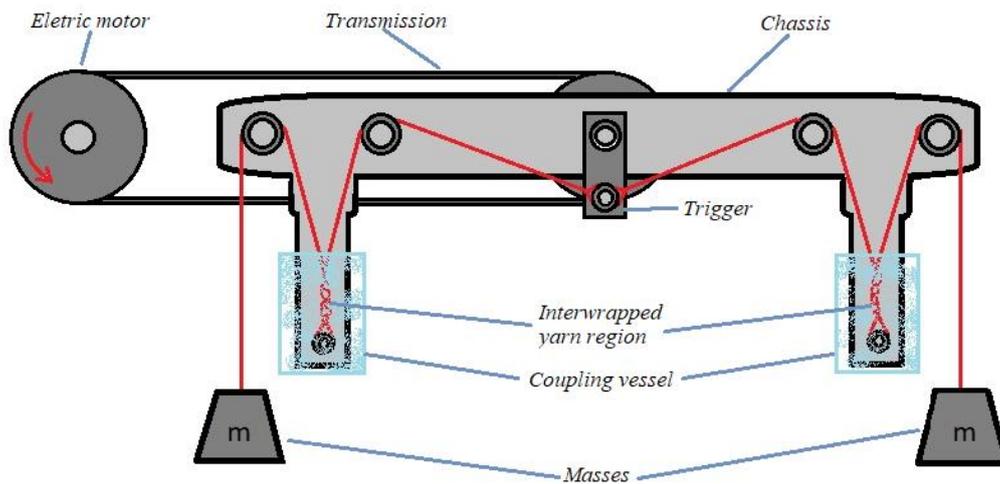


Figure 3- Yarn on Yarn machine test
 Available from: Eduardo Schultz Laux

The mechanism in full operation of a dry test on the material is shown below (Fig. 3). In tests wet with fresh water, the interwrapped yarn region is submerged with the aid of a container that surrounds the lower bearings and the region itself.

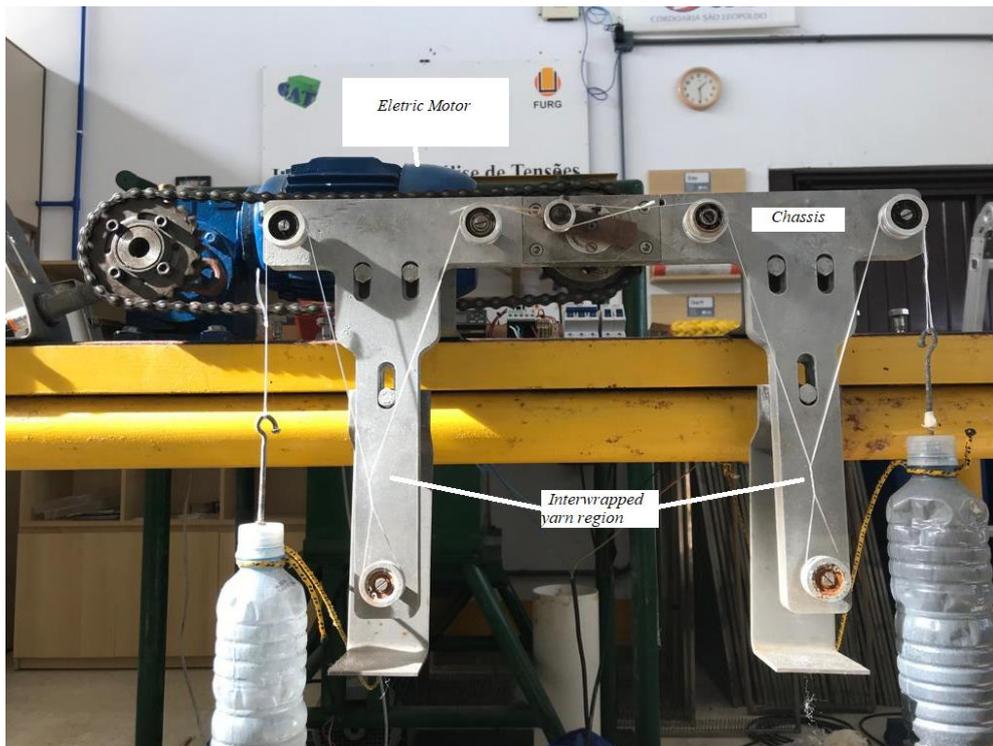


Figure 4- Operating mechanism for a dry test
 Available from: Nícolas Vannucchi Nadalin

As a final observation, this test system was also chosen as an inexpensive and reliable option. It can be observed from Figure 3 that in comparison with other cable tests this requires components that are easily accessible and consequently reflected in the high reliability.

2.5 Mathematical model

The mathematical model for this document is relatively simple in the same way as obtaining results. From the dry and wet filaments tests with the different percentages of YBL, the general mean (1), the maximum and minimum, and the standard deviation (2) of each percentage are found.

$$\{[1/n] * \sum_{i=1}^n xi\} = X \quad (1)$$

$$\{[1/(n-1)] * \sum_{i=1}^n (xi - X)^2\}^{(1/2)} = S \quad (2)$$

3. GRAPHIC CHARACTERIZATION

In all tests, for each percentage value, 20 yarn-on-yarn test were made, 10 being for dry environments and 10 for water immersed wires. In all, the interwrapped yarn region suffered a break. Absurd dispersions are disregarded and discarded.

Figure 5 represents the compilation of the data collected for dry test yarns from the graph (Number of cycles x applied load). Following all the norms and standards of reliability it was possible to obtain this characterization curve of the abrasive resistance for Polyamide 6.

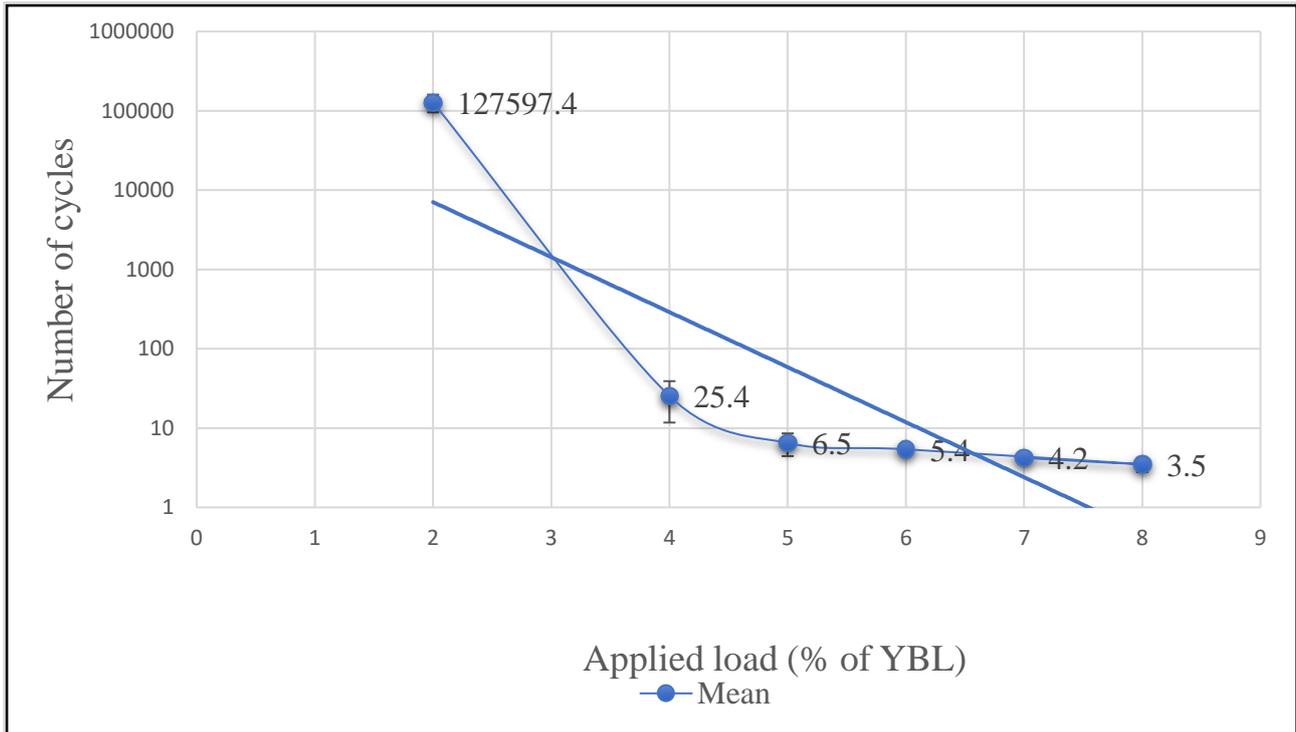


Figure 5- Abrasive strength of dry filament (polyamide 6)
Available from: Stress Analysis Laboratory

It is noticed that in higher loads the filament resists little since the tension in the small section generates high abrasive tensions. In smaller percentages of YBL, the material resists much more, showing very high numbers of cycles.

By subjecting the material to the same tests with the difference that the environment becomes fresh water, it was observed that the liquid serves as a "lubricant" to the material. The numbers for the same percentages of charges have increased considerably.

This fact, for an analysis in national waters can be definitive when one must choose its purposes. The following data were the result of this study.

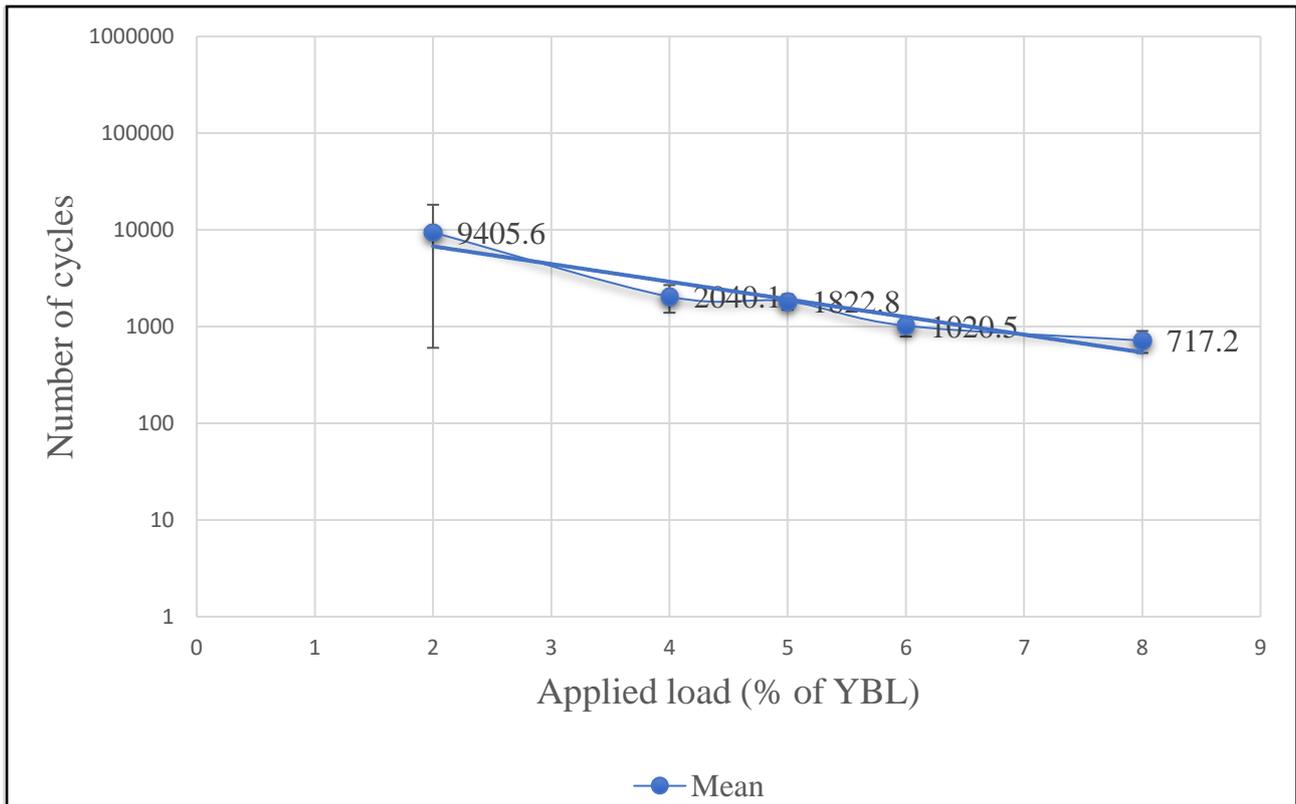


Figure 6- Abrasive strength of wet filament (polyamide 6)
 Available from: Stress Analysis Laboratory

Some other studies may still complement this work in order to obtain more accurate data and that researchers have access to the characteristics of Polyamide 6 in a more complete way. An example is the study by Chevillotte et al. (2018) which contributes by providing a comparative abrasive resistance curve between coated filaments and uncoated filaments.

4. CONCLUSION

In this work it was defined the importance of complementing the literature about the characteristics of Polyamide 6. Although this material is already well used in the offshore market and in other purposes, there are still many peculiarities that this material can present and should be studied.

The results obtained here and the characterization of the abrasive resistance curve can considerably influence the choice of their applications and substitute materials with higher costs. For example, the choice of materials for offshore and onshore applications, guide ropes, anchor ropes and many other systems using polyamide 6. In these cases, the amount of material used for various purposes is very high, so a small change in cost, can mean huge savings.

Given the results obtained, it was expected that, with the increase of the applied load, the abrasion resistance would decrease proportionally. The difference between these tests was only the environment in which they were proved. Thus, when in water, the fluid acts as a natural lubricant that decreases the effect suffered in the interwrapped region for the same applied load.

In experiments conducted in a dry environment it was noted that small percentages of loads applied as 2% resist a very high amount cycles. It is even possible to project as a tendency to infinity when applying lower percentages. Thus the filament would not break significantly for small applications.

When performing the percentage increase in the load placed on the system, however, it is noticed that the number of cycles decreases significantly as an exponential function. Thus it can be seen for example, that the filament at 8% of applied load can withstand 3.5 cycles on average, considered a low number for the experiment.

In the experiment conducted in a humid environment, the increase of the number of cycles for the same percentage of load was observed. When analyzing the 6% load for example, in dry environment the number of cycles is 5.4 on average, while in humid environment the number of cycles is 1020.5 on average. This demonstrates the lubricity of the fluid and its ability to increase its useful life.

There is also a peculiarity evidenced in the research itself. The fluid increased the number of filaments supported cycles by all percentages except 2%. This occurs because each graphic had a type of curve. In humid medium the significant curve has linear character, whereas the curve obtained in dry medium has exponential character.

It can be concluded that for small percentages of applied load, such as 2% or less, it is more advantageous to use polyamide 6 systems in a dry environment. For larger applied loads, the wet environment would be the most advantageous, increasing the filament life. Note that this analysis only takes into account the wire abrasion resistance.

Given the important conclusion, there are other types of research that can be proposed. A next step is to subject this and other synthetic materials to other environmental conditions. Different types of salinity to reproduce different oceans, seas, lakes and rivers. Catalog the content and expose it to the community. In this way, it is possible to build a solid literature of information on synthetic materials and assist the industry to become more efficient, economical and more technological.

5. ACKNOWLEDGEMENTS

This paper brings important information to complete the current bibliography of labor and academic universes. This leap was only possible with the support of people and institutions important for this research. Inside the Federal University of Rio Grande, an institution of excellence, is located the Stress Analysis Laboratory. High capacity research center for polymers and mechanical components. This center made possible all the research carried out here and the results found. The equipments are of high capacity, reliability and enable the learning and the production of knowledge. Thanks are due to this center.

The coordinator, Mr. Carlos Guilherme, is given due thanks. Due to their shared knowledge, ability to lead research and humility towards their researchers, this present work also becomes a result of this personality. It is also important to mention the work of another coordinator center, Miss Fernanda Clain. With her knowledge and expertise, she was able to deal with adversity, assimilate results and instruct research. Thanks to this personality.

Finally, this work is the result of much study and perseverance by its authors, given the importance of their information. To Mr. Eduardo Laux, due acknowledgment for his skill, knowledge and intense dedication to the creation of new content in this research.

6. REFERENCES

- ASTM D2256/D2256M-10,2015, *Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method* ASTM International, West Conshohocken, PA.
- ASTM D6611-16, 2016, *Standard Test Method for Wet and Dry Yarn-on-Yarn Abrasion Resistance*, ASTM International, West Conshohocken, PA.
- Cordage Institute. 2001. *Method for Yarn-on-Yarn Abrasion*. CI 1503 – 00
- Chevillotte, Y., Marco, Y., Davies, P., Bles, G., Arhant, M., 2018. *Fatigue of Polyamide Mooring Ropes for Floating Wind Turbines*. 12th International Fatigue Congress, Poitiers, France.
- Dorna, M.Z. 2016. *Estudo da degradação da poliamida 11 pela técnica de índice de fluidez (MFI)*. Monograph project-UFRJ- Universidade Federal do Rio de Janeiro, Departamental area of metallurgy and material. Rio de Janeiro.
- Duarte, J.P. Guilherme, C.E.M., Silva, A.H.M.F.T., Mendonça, A.C., Stumpf, F.T., 2019. *Lifetime Prediction of Aramid Yarns Applied to Offshore Mooring Due to Purely Hydrolytic Degradation*. Sage Journal, Ploymers and Polymer Composites, pp. 1-7.
- Duarte, J.P. 2017. *Avaliação do Efeito da Hidrólise no Comportamento Mecânico de Fios Sintéticos Aplicados a Ancoraagem Offshore*. Ph.D. thesis- FURG- Universidade Federal do Rio Grande, Engineering School, POLICAB, Stress Analysis Laboratory, Rio Grande.
- Hage Jr, E.,1998.*Aspectos Históricos sobre o Desenvolvimento da Ciência e da Tecnologia de Polímeros*. Polímeros No. 8.2,pp.6-9
- Kenney, M.C., Mandell, J.F., McGarry, F.J., 1985. *Fatigue Behaviour of Synthetic Fibres, yarns and ropes*. Department of Materials Science and Engeneering, Massachusetts Institute of Tecnology, Cambridge, Massachusetts 02139, USA.
- Mckenna, H. A., Hearle, J.W.S., O’Hear, N., 2004. *Handbook of Fibre Rope Tecnology*. Woodhead Publishing Limited, Cambridge, UK.
- Samuel, W., Johanning, L., Peter, D., Banfield, S.J., 2015. *Synthetic Mooring Ropes for Marine Renewable Energy Applications*. Renewable Energy an International Journal, Vol. 83, pp. 1268-1278.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.