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Experimental study on the behavior of polyamide multifilament subject to impact loads under different soaking conditions

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A B S T R A C T

This article studies the mechanical characterization of impact loads on polyamide fibers. Using synthetic ropes in mooring systems, these are subject to static loads, but dynamic loads are also expected. One of the dynamic loads that can occur on cables are sudden loads, which makes the analysis of impact loads important. In this study, impact cycles were applied to polyamide multifilaments until rupture with different impact masses, and considering the conditions: dry, after 6 hours of immersion in water and after 24 hours of immersion in water. The analysis of the immersed conditions allows us to interpret the plasticizing effect that moisture exerts in polyamide, through loss stiffness in the rupture test. The results show that the increase in immersion time represents decrease in the breaking strength, and also in the resistance to impact cycles. A curve parameterization is proposed that relates the number of impact cycles and the percentage of Yarn Break Load used in the impact, getting through the coefficient of determination the best model. For force versus time graphs, obtained in each impact cycle, the energy dissipation in the multifilament can be observed in two main mechanisms: the first is the elastic deformation in form of ricochets, the second is the plastic deformation by stretching/elongation. The force-time graphs of impact cycles and the number of impact cycles to failure are measures that show performance for impact dynamic loads. Attention should be the plasticizing effect caused by water, as it reduces the static and dynamic mechanical strength of polyamide.

1. Introduction

The area of engineering materials for a long time proved to be quite resistant to changes, making it stable with classic materials applied to structural projects or components. However, synthetic materials emerged precisely as an alternative to replace these already established materials. In the last decades, there has been a significant increase in the study, demand and commercialization in the polymer sector (Hage Jr, 1998). The use of polymers has positively leveraged the field of materials. The scientific and increasingly commercial approach allowed them to be produced, often at low cost. These synthetic polymers had properties similar and sometimes superior to natural polymers (Callister Jr & Rethwisch, 2008), such as, for example, superior mechanical and weather resistance properties, being critical characteristics for the use of these materials in offshore mooring systems. These properties made these materials gain notoriety, being used in offshore systems, mooring cables, cables for ship tugs, surgical sutures, climbing cables, among other applications. Within the naval branch, these synthetic cables have very advantageous properties because, in addition to low weight, they also have high strength, high flexibility and low coefficient of friction (Louzada, 2018).

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Polyester presents an interesting option for anchoring systems, historically being the material most successfully used in permanent anchoring systems. Polyamide, on the other hand, stands out in anchoring wind platforms, intended for shallow or intermediate waters. The main difference between the two materials is in the strain at break, with polyamide showing a higher elongation than polyester (Chevillotte et al., 2020).

Regarding the properties of polyamide, it is known that it belongs to the group of thermoplastics and has excellent mechanical properties and relatively high thermal resistance (Zhao et al., 2012). Polyamide is also self-sufficient against bad weather, exceptional resistance to successive loads, not to mention the elastic recovery along with its good elongation, which guarantees it a property of shock resistance, that is, the ability to absorb energy.

Synthetic materials in the naval industry have complemented and sometimes satisfactorily replaced mooring cables and anchoring systems (eg moorings) that were previously made of steel. In this way, satisfactory mechanical performance of the cable during the useful life for which it is designed becomes mandatory, which justifies the continuous studies of mechanical characterization of fibers for synthetic cables. Within the scope of mechanical requests relevant to naval use, in this case, the dynamic requests that occur in these applications in shallow water stand out (Hanh, 2019). The integrity of the system will be maintained by dampening the actuation of dynamic loads. Among the dynamic stresses that act on these cables, it is important to highlight impact loads, which are directly correlated with the useful life of the material. More than that, it is still important to observe the combined effect of hydrolysis, associated with sudden loads. Polyamide fibers stand out in this context due to their low cost, high tensile strength and high energy absorption capacity (Chevillotte et al., 2020). On the other hand, compared to other fibers, they are strongly influenced by water absorption (plastification effect), in addition to having their performance impacted by hydrolysis at higher temperatures.

The dynamic requests that act under these anchor cables have gained scientific focus, studying fatigue and impact loads that act on such systems. Sometimes these studies address conditions of combined loads, such as mechanical characterization after impact loading (Belloni et al., 2021). Other times they address environmental conditions such as temperature and humidity associated with dynamic loading.

It is noteworthy that polymers in general do not have a database as vast and solid as classical materials applied in engineering. In addition, they have mechanical behavior, sometimes non-linear, which makes studies a challenge for engineers (Louzada et al., 2017). For this reason, in the study of synthetic fibers, experimental approaches are commonly used (Sry et al., 2017).

The objective of this study, through an experimental approach, is to analyze the mechanical behavior of polyamide multifilaments subjected to impact loads for different conditions of immersion in water and under different conditions of load (%YBL) of impact, until the specimen reaches rupture, that is, its limiting ability to absorb external energy. The material analyzed is polyamide fiber, a synthetic polymer that particularly presents excellent mechanical properties, impact and fatigue resistance, low weight, high thermal resistance, low coefficient of friction, high resistance to oxidation, among others; this allows them to be used in the production of various products such as textile fibers, electronic components, automotive parts and many others, thus presenting great economic importance (Brydson, 1999).

2. Materials and Methods

2.1 Yarn break load test and linear density

To characterize the polyamide coil, the multifilament rupture test was performed according to standard norm, determining the breaking strength, or Yarn Break Load - YBL (EN ISO 2062, 2009), in an Instron 3365 equipment, shown in Fig. 1. And for the density linear (mass/length ratio), defined as material tex [g/km], was defined as a series of measurements to obtain the mean and standard deviation (ASTM D1577-07, 2007) using a precision balance. These data initially collected are for the characterization of the coil, and will be taken as a reference for the impact masses.

Fig. 1. Instron 3365 Equipment, Yarn Break Load

The coil characterized by Yarn Break Load and linear density, presents the information shown in Table 1. This is taken as a reference for this polyamide fiber.

Table 1. Tensile strength and tex

Material	Break strain [%]	tex [g/km]	Linear tenacity [N/tex]
Polyamide	16.61±0.81	284.6±1.30	0.74±0.01

In addition to the reference breaking load (YBL) shown in Table 1, the breaking values for polyamide fibers were also obtained under the conditions of: dry polyamide fibers, polyamide fibers after 6 hours of immersion and polyamide fibers after 24 hours of immersion in water.

During the multifilament rupture and linear density tests, the samples are conditioned during the test time with a temperature of 20 ± 2°C and a relative humidity of 65 ± 4%, conditions recommended, in which meets the standard atmosphere standard for fiber testing (LST EN ISO 139, 2006).

2.2 Multifilaments and conditions

Polyamide multifilaments were tested until they reached breakage. For the conditions of immersion in water, the following groups were admitted: dry polyamide (no immersion), polyamide after 6 hours of immersion in water and polyamide after 24 hours of immersion in water. For the impact loads, seven groups were admitted referring to the percentage of the breaking load of the virgin coil (YBL): 3%, 4%, 5%, 6%, 7%, 8% and 9%. That is, the force value in N shown in Table 1 is used as a reference to compose the impact loads in all immersion conditions.

The ratio between the force obtained in the tensile test and the acceleration due to gravity (g) makes it possible to determine the mass corresponding to 100% of YBL and, from there, the different percentages of interest. The mass that corresponds to 100% of YBL is 210.47 N divided by the acceleration due to gravity. Thus, the impact masses used for the impact tests are presented in **Table 2**.

2.3 Impact test

The impact test procedure was developed by POLICAB/FURG (Stress Analysis Laboratory/Federal University of Rio Grande) based on another norm, which standardizes impact for mountaineering ropes (EN 892, 2012). No specific literature was identified with a methodology for impact assessment at the level of polymeric synthetic multifilaments.

The impact test itself is based on the application of a mass in free fall from a certain height of fall. **Fig. 2** outlines the impact procedure and describes some variables such as: string length (L_0), free fall height (h), mass (m) and gravitational acceleration (g) (Emri et al., 2008; Nikonov et al., 2011).

Table 2. Masses used for impact

YBL percentage	Free fall mass [kg]
3%	0.64
4%	0.86
5%	1.07
6%	1.29
7%	1.50
8%	1.72
9%	1.93

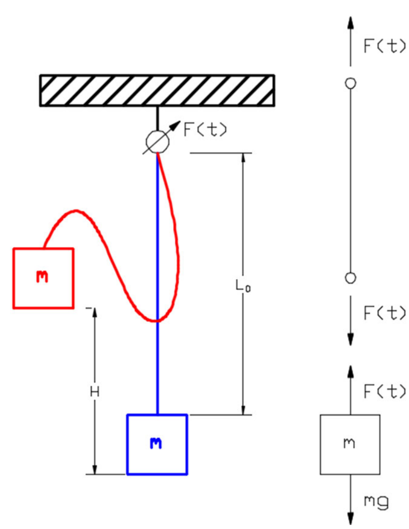

Fig. 2. Scheme application of impact mass

The specimens for the impact test are 500 mm long, corresponding to L_0 (**Fig. 2**). The impact load is released at a height of free fall of 300 mm in relation to the static length of the specimen, corresponding to h (**Fig. 2**). The equipment has a load cell at the top, where the tested multifilament is fixed, capturing force data. All specimens are subjected to successive impact cycles, under similar conditions, until rupture.

For each combination of immersion condition and load condition, 8 specimens were impact tested to failure.

During the performance of the impact tests, the samples are conditioned during the test time with a temperature of 20 ± 2 °C and a relative temperature and humidity of 65 ± 4%, conditions recommended (LST EN ISO 139, 2006). The load cell, Instron Dynacell 2527, attached to the impact equipment captures force values over time. Due to the free ricochets, each cycle of impact was captured by the load cell with generous time for the disturbances to reverberate in the braid. When capturing this data, the objective is mainly to record the peak energy of the analyzed cycle, and how the ricochets reverberate in the multifilament. From the list of data obtained, a selection is made for the construction of the graph. A total of 61 data in sequence was selected, 10 data before the peak, the peak and 50 data after the peak. The 10 pre-peak data are for a homogenization concept, causing cycle recording to start from calibration (null load) and drive to peak power. The next 50 data points after the peak have the concept of stability, registering ricochets until they are detailed and stabilize at a load of a certain value. In the analysis of the different energy conditions, for data interpretation purposes, the graph of a single characteristic specimen per condition will be presented in this work in subsequent sections, with the specimen closest to the group mean. In **Fig. 3**, the schematic of the impact equipment is represented.

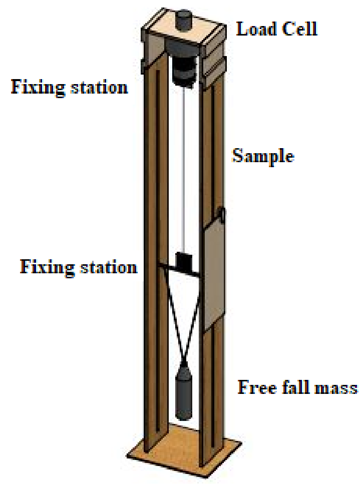

Fig. 3. Schematic of POLICAB impact equipment

2.4 Statistical filtering and curve parameterization

Due to the non-linear behavior of synthetic materials, it is difficult to generalize the data, this non-linearity still generates large dispersions in the results (Mano, 1991). Descriptive measures must be able to satisfactorily cover quantitative results and, therefore, the use of statistical tests may be necessary to be reliable and to present less dispersion (Barbetta et al., 2004). In order to filter the results of the Yarn Break Load test, the 3 values that were most inconsistent with the group mean were excluded. Thus, the 15 specimens resulted in 12 results that determine the characteristic mean validated for the group. For the number of cycles to failure, the box-plot was chosen to validate the results obtained. Values very different from the middle set are outside an accepted range. These atypical and extreme values are known as outliers and, in the treatment, the data are excluded (Hines et al., 2020). The numerical result evaluated in box-plots is the number of impact cycles to reach failure in each test condition. Outliers are excluded and validation for impact tests results in at least 5 results within an admitted zone close to the group average. The criterion to characterize lower and upper outliers were values greater than 1.5IQ, from Q1 and Q3 respectively (Morettin & Bussab, 2017). With the validated data, it is possible to propose models that relate the average number of impact cycles to failure with the percentage of YBL at impact. In this case, the models analyzed were: linear, logarithmic, power, exponential and inverse fit, **Table 3**. The mathematical resource was linearization with subsequent least squares linear regression to determine each coefficient. The measurement of the quality of each adjustment was made with the R^2, called Determination Coefficient (Gilat & Subramaniam, 2009). For curve fitting purposes, the closer R2 is to 1, the theoretically better the fit, at least for the purposes of a preliminary analysis.

Table 3. Linearized models.

Models	Nonlinear equation	Linear form
Linear	-	$y = A + B \cdot x$
Logarithmic	-	$y = A + B \cdot \ln{(x)}$
Power	$y = A \cdot x^B$	$\ln(y) = \ln(A) + B \cdot x$
Exponential	$y = A \cdot e^{B \cdot x}$	$\ln(y) = \ln(A) + B \cdot \ln{(x)}$
Inverse	-	$y = A + B \cdot (1/x)$

With the linearized models, Table 3, the values of coefficients A and B are calculated by solving the system of linear equations, Eq. (1) and Eq. (2):

$$A \cdot n + B \cdot \sum x_i = \sum y_i \quad (1)$$
$$A \cdot \sum x_i + B \cdot \sum {x_i}^2 = \sum x_i \cdot y_i \quad (2)$$

In this adjustment, it is important to remember that the variable x is the percentage of YBL subjected to impact loading, and that the variable y is the number of impact cycles that the braid will withstand before breaking. The amount of data is n, and the coefficients A and B are the results that were obtained for each of the models. This curve adjustment was done with the help of the free software Octave to be able to parameterize the best curve for each group of results.

3. Results and discussion

3.1 Characterization of fibers

The result obtained for the rupture (YBL) of the polyamide fiber under each immersion condition is presented in **Table 4.**

Table 4. Tensile strength and strain.

Condition	Break tensile strength [N]	Break strain [%]
Dry	208.63±2.21	18.70±0.58
6 hours in water	196.33±4.00	21.71±1.57
24 hours in water	188.48±3.82	20.65±1.04

It is possible to observe the tendency of decreasing resistance to rupture with longer immersion time in water. It should be noted that hydrolysis is the reaction of the chemical group in the polymer chain with water molecules; acidic or basic environments and with temperatures that favor hydrolysis, which leads to chain breakage and the binding of oxygen and hydroxyl to separate groups (De Paoli, 2009). The relationship of polyamide hydrolysis (and other synthetic fibers) with acidic environments and high temperatures is addressed in the literature (Liu & Reineke, 2010; Hocker et al., 2014; Duarte et al., 2019). In this study, as the immersions were made at room temperature, the hydrolysis effect is not the deleterious effect of this loss of strength. What occurs is a plasticizing effect on the chemical chain of the polyamide.

Polyamides have a general structure of alternating hydrocarbons and imide groups (–NH.CO–) (Miles & Briston, 1975). Immersion in water acts as a plasticizer in the polymer, separating the molecular chains and decreasing crystallinity. The immersion in water and the loss of crystallinity in this plasticization, modify some properties of the polymer, among them, the elongation increases subtly for immersed conditions, and the breaking strength decreases until the saturation point.

The plasticizing effect reduces stiffness for longer immersion times in water. This can be seen by comparing the stress-strain graphs of the conditions: dry, 6 hours of immersion in water, and of the polyamide in 24 hours of immersion. In **Fig. 4**, the stress-strain curves of the characteristic specimens of each group (which most closely approximates the group mean) are plotted. Knowing that stiffness is a measure of force by deformation [N/mm], the description of the comparison is precisely to realize that for the same force values the deformation is greater for polyamide immersed in water for 24 hours.

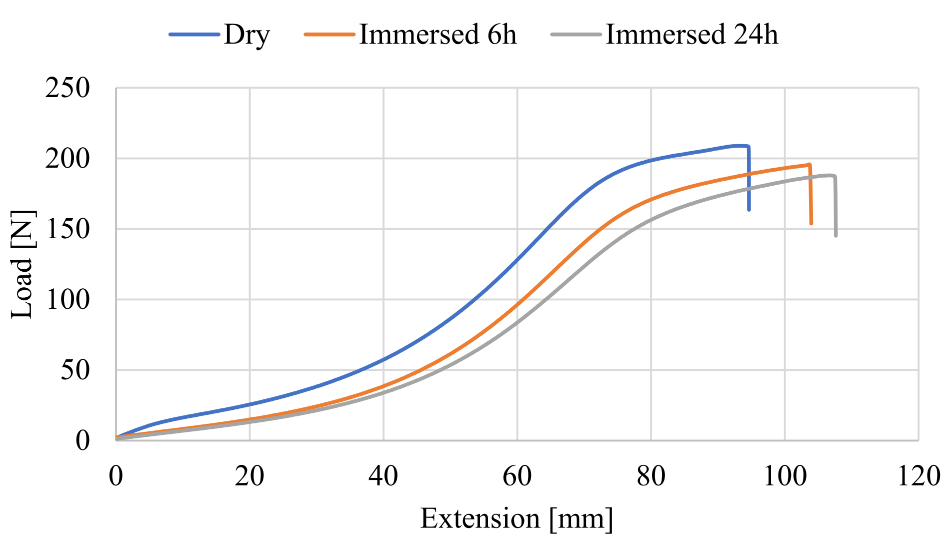

Fig. 4. Comparison of the stress-strain graph, dry and immersed conditions

3.2 Impact resistance and parameterized curves

Table 5 shows the average number of impact cycles required to bring the specimens in the given condition (immersion and load) to rupture.

Table 5. Number of impact cycles to reach rupture.

Impact load [% YBL]	Number of impact cycles to rupture, mean		
	Dry polyamide	Polyamide 6 hours in water	Polyamide 24 hours in water
3%	330.40	93.00	37.60
4%	48.80	37.80	8.40
5%	30.00	24.00	4.40
6%	22.20	8.60	2.80
7%	6.60	3.80	2.40
8%	4.20	2.40	1.40
9%	2.20	1.00	1.00

In the YBL tests (static loading), a slight tendency to reduce the breaking strength with the absorption of water was observed. In the case of dynamic impact loading, this reduction does not happen so subtly, with the decrease in resistance in dynamic loading being more drastic and imminent.

With these values of resistance to impact cycles, it is possible to parameterize the curve using the linearization methodology previously described. The curves are proposed having on the abscissa (x axis) the values of impact load, and on the ordinate (y axis) the values of resistance to impact cycles for failure. Thus, the objective is to determine three curves, one for each immersion condition. The values of coefficients (A and B) and of the coefficient of determination (R^2) for each immersion condition are shown in **Table 6, Table 7** and **Table 8**, and can be compared. The equation forms shown in **Table 3** are shown together with coefficients A and B, to facilitate the visualization of the model.

Table 6. Parameterization of curves, dry polyamide

Models	A	B	R^2	Equation form
Linear	298.60	-39.19	0.51	$y = A + B \cdot x$
Logarithmic	482.97	-242.50	0.64	$y = A + B \cdot \ln(x)$
Power	29235.60	-4.27	0.97	$y = A \cdot x^B$
Exponential	1803.50	-0.77	0.95	$y = A \cdot e^{B \cdot x}$
Inverse	-186.76	1318.09	0.77	$y = A + B \cdot (1/x)$

Table 7. Parameterization of curves, polyamide after 6 hours of immersion in water

Models	A	B	R^2	Equation form
Linear	103.01	-13.11	0.73	$y = A + B \cdot x$
Logarithmic	159.27	-77.98	0.85	$y = A + B \cdot \ln(x)$
Power	10972.05	-4.08	0.97	$y = A \cdot x^B$
Exponential	840.38	-0.75	0.99	$y = A \cdot e^{B \cdot x}$
Inverse	-52.91	407.06	0.94	$y = A + B \cdot (1/x)$

Table 8. Parameterization of curves, polyamide after 24 hours of immersion in water

Models	A	B	R^2	Equation form
Linear	35.24	-4.49	0.54	$y = A + B \cdot x$
Logarithmic	56.12	-27.65	0.68	$y = A + B \cdot \ln(x)$
Power	779.96	-3.07	0.96	$y = A \cdot x^B$
Exponential	97.85	-0.54	0.90	$y = A \cdot e^{B \cdot x}$
Inverse	-20.08	149.43	0.80	$y = A + B \cdot (1/x)$

It is observed that, in all cases, the power and exponential models seem to be the ones that best represent the trend presented by the data set. Although for the condition of 6 hours of immersion in water, the best model was the exponential, in general, it can be said that the model that best describes the results is the power model. Note that for all immersion conditions, the power model is always able to represent very satisfactorily, that is, R^2>0.95. For the dry polyamide condition, the best model is the Power model, in the terms shown in Eq. (3). The referred curve referring to the dry condition is plotted, **Fig. 5**.

$$y_1 = 29235.60 \cdot x^{-4.27} \quad (3)$$

For the polyamide condition in 6 hours of immersion in water, the best model is the exponential, in the terms shown in Eq. (4). The referred curve referring to the condition of 6 hours of immersion is plotted, **Fig. 5**.

$$y_2 = 840.38 \cdot e^{-0.75 \cdot x} \quad (4)$$

For the polyamide condition in 24 hours of immersion in water, the best model is the potency, in the terms shown in Eq. (5). The referred curve is plotted referring to the condition of 24 hours of immersion in water, **Fig. 5.**

$$y_3 = 779.96 \cdot x^{-3.07} \quad (5)$$

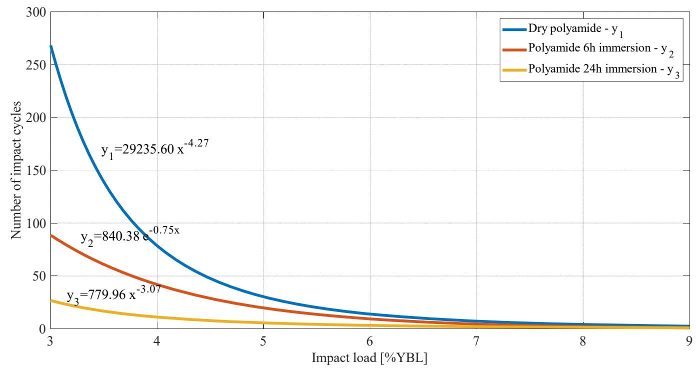

Fig. 5. Plotting parameterizations, number of impact cycles versus impact load

It is observed that the condition of fiber exposure to water is more deterministic of the material strength for lower loads (%YBL). In general, for loads greater than 7% YBL, the preliminary exposure condition is no longer critical, with a pronounced general drop in the material's resistance to cyclic impact loading. The impact cycles generate an elongation, and a gain in stiffness in the braid, thus having an effect of increasing the tensile strength and decreasing the subsequent elongation capacity. The increase in this tensile strength (static load) can be understood as mechanical improvement, the impact cycles order the chain and form these oriented lenses (Santos, 2002). You can work with percentages of 3% and 4%, with amounts of cycles that are below the curve, maintaining the integrity of the braid. Thus, it is possible that at low loads and low cycles, there is interest in the application of impact in a controlled way with the objective of gaining mechanical strength. Being the low load and low cycle, to ensure that no part of the braid is damaged in relation to the total, as the specimen must resist homogeneously for this mechanical improvement.

3.3 Graphs of force versus time in impact cycles

The load cell coupled to the impact equipment is capable of providing important results in terms of force and time. From the unit described by the area under the graph, it is known that force multiplied by time is a unit of impulse, the SI unit being N·s. In the application of impact loading, impulse terminology is appropriate, but the literature usually calls this quantification "energy". Which is not really an interpretation, however, since the impact is caused by a gravitational potential energy, and this force-time graph is able to give an indication of the energy absorption capacity. Having the force and time data, it is possible to construct the graph, as shown in **Fig. 6.** The first phase (Period A) of this graph corresponds to a zero load, since the mass is in free fall and there will be no force record in the load cell. The second phase (Period B) characterizes the cable deformation process, where this sudden load occurs. And the third phase (Period C) is a zero-loading moment, but upward movement of the mass, known as ricochet (Emri et al., 2008). After the mass drops again, the first phase is restarted, but the peak force reached in the second period is certainly less than the previous one. This is repeated continuously until there is no energy for ricochets. If the sample does not break, the charge stabilizes at a value corresponding to the product of mass and gravity.

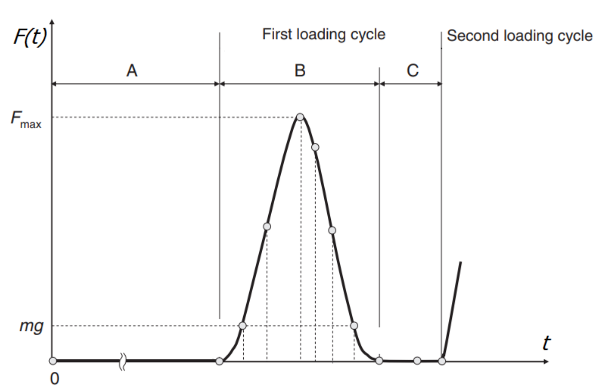

Fig. 6. Force versus time graph

The first analysis that can be done is in relation to the opening and rupture cycles. For this, the impact cycles of initiation and rupture were analyzed for a specimen characteristic of all immersion conditions and for the impact load corresponding to 6% of YBL. **Fig. 7** shows the graph for the dry polyamide condition, **Fig. 8** for the polyamide condition after 6 hours in water and **Fig. 9** for the polyamide condition after 24 hours in water.

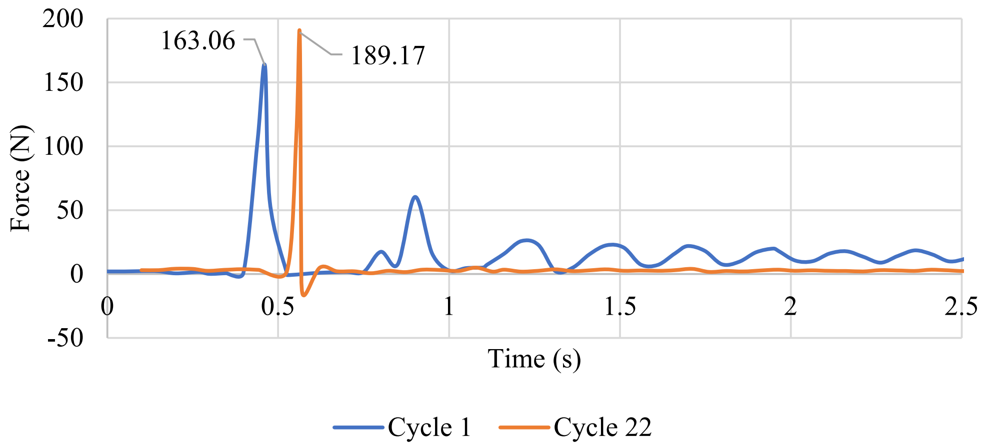

Fig. 7. Opening and breaking cycles, dry polyamide, 6% YBL

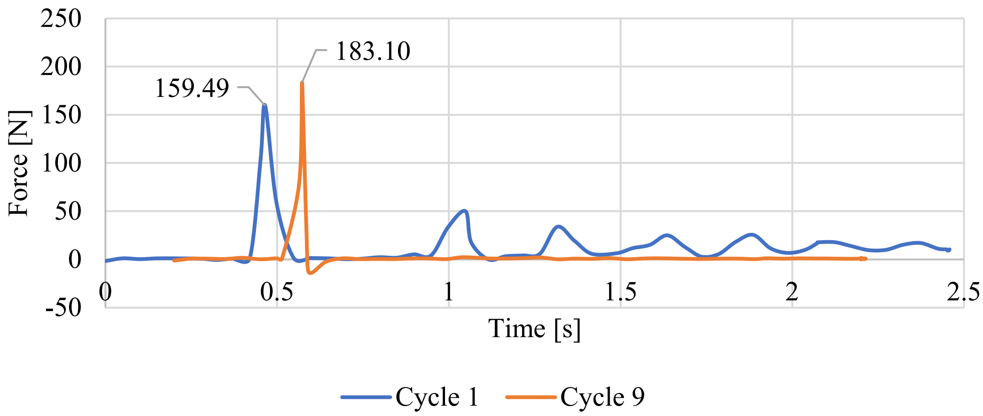

Fig. 8. Opening and breaking cycles, polyamide 6h in water, 6% YBL

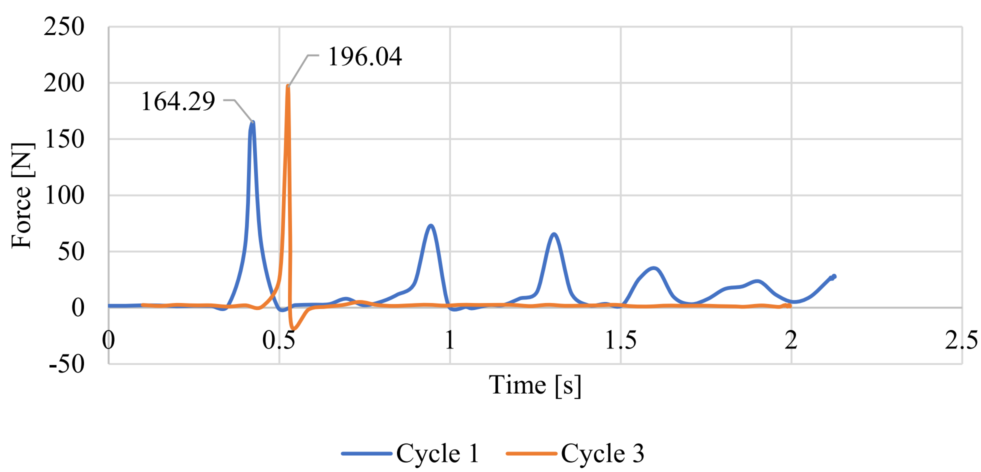

Fig. 9. Opening and breaking cycles, polyamide 24h in water, 6% YBL

As can be seen from the graphs (**Fig. 7, Fig. 8, Fig. 9**), the peak force values for the opening cycle, although showing variations, even due to the experimental deviation, still show similar values and show repeatability of the procedure. This is because the peak force essentially depends on the impact mass and free fall height, which are constant for the three plots plotted for the first impact cycle, as the impact masses are based on the virgin reference coil. As for the rupture cycle, there is no repeatability, each sample in its immersion condition will cause the multifilament to elongate differently until it reaches the rupture. It should be noted, of course, that for the opening cycles there are ricochets, since when there is a rupture the value returns to zero because there is no longer an active load on the load cell.

Another observation that can safely be made based on the graphs presented is that the value of the force at the peak of rupture being always greater than the value of the peak opening is a result of the energy dissipation that the polyamide multifilament is capable of doing during the cycles. of impact and successively the repetition of the procedure. That is, when applying the first impact, the multifilament still virgin has the capacity to dissipate energy, when the impact is suddenly placed, the multifilament dissipates gravitational potential energy, a substantial part of this dissipation occurs through the stretching of the multifilament or plastic deformation. When the second cycle is performed, there is still energy dissipation capacity, but it is now lower than in the previous impact, as it allows less elongation. In the method itself, the same procedure is repeated, which means that now the braid is no longer released at the same height of free fall, in fact it is released at the height of free fall of the previous cycle, adding the length of plastic deformation that it had effect on the specimen in the previous cycle. And this is repeated cycle by cycle, until the sample reaches the rupture and, therefore, there is a tendency for the last cycle to present the highest peak force in relation to all the others.

Thus, immersion in water, which causes plasticization in the polyamide fibers, reduces the specimen's resistance to impact. When performing the impact cycles, there is a gradual gain in stiffness, causing the maximum elongation to reach higher values for longer immersion times in water.

It is also possible to verify the evolution of the impact cycles from the opening to the rupture cycle. It would be expensive and confusing to do this analysis for specimens that had withstood more than 20 cycles. The impact cycle evolution graph was constructed for a load of 5% YBL and 24 hours immersion condition in water in a sample that reached rupture in the fifth cycle, and is shown in **Fig. 10**.

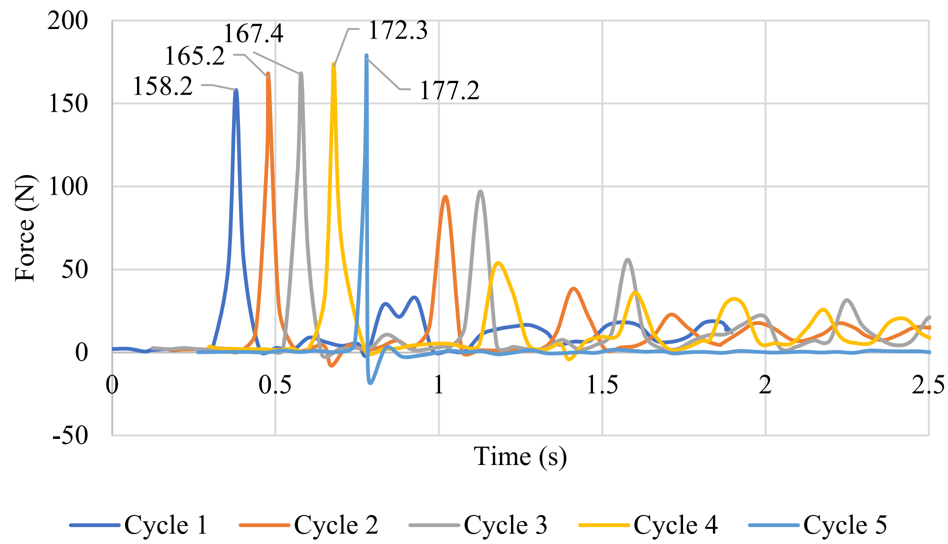

Fig. 10. Evolution impact cycles, polyamide 24h in water, 5% YBL

What can be verified is the reduction of the area under the peak that is decreased cycle by cycle, in a unit of N·s this represents a gradual decrease of the impulse. In addition, the maximum peak force is gradually increased with each cycle, until it reaches its apex in the rupture cycle. This reinforces the effect of the multifilament in dissipating energy at each cycle, gaining plastic deformation and stretching with each sudden load applied and in the repetition of the impact procedure, increasing forces are captured in the load cell. Each impact cycle makes the braid stiffer, allowing less thrust until it breaks.

If observed the results, specimens were obtained under certain conditions that broke sometimes even with more than 300 cycles of impact. The graphical representation of all cycles applied to the specimen is quite confusing for these cases. It was found that for practically all specimens that ruptured with more than 12 cycles of impact, approximately in the tenth cycle they reached strength values very close to the impact cycle of rupture, indicating proximity of elongation (plastic deformation) with the rupture condition. This stabilization behavior until the tenth cycle for a force similar to that of the rupture cycle was only not verified for the groups of impact load of 4% and 3% of YBL, in these this stabilization occurred at different times through the immersion condition in Water.

3.4 Surface with immersion time, applied load and number of impact resistant cycles

Considering the relationship of the variables: impact load, time of immersion in water and number of resistant cycles, it is possible to similarly appropriate the x, y and z axes of R3 representing each of the variables. Part of the behavior of this proposed surface was already acquired in the parameterization of the curve. At the time, parameterized curves were determined for each of the immersion conditions and the curves were parameterized according to the best model based on the coefficient of determination (R^2), which can be seen in item 3.2, in **Fig. 5.** Can plot all results shown in **Table 4** as discrete data, in addition to parameterized curve compositions. The composition of a surface from discrete data is a particular challenge that requires the use of multiple matrix systems or even numerical methods. For the need to generate continuous surfaces from discrete data, the Kriging surface or commercial software (for example MATLAB) is used. To provide a view of this surface, **Fig. 11** shows the graphic result obtained through the tool "Curve Fitting" in MATLAB for the discrete dataset.

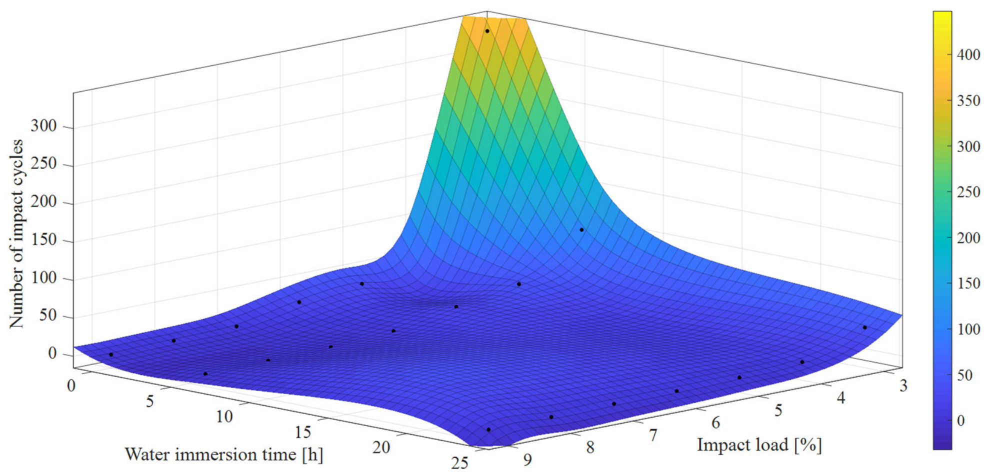

Fig. 11. Continuous surface generated in MATLAB.

4. Conclusion

Analyzing the experimental results, it can be affirmed that the increase in load and the longer immersion time in water decrease the resistance of the multifilament to the impact cycles. Here, it is not the hydrolysis mechanism that stands out, but the plasticizing effect of moisture in the polyamide fiber.

When dealing with this plasticization on multifilaments, it appears that both for static loads and for dynamic loads there is a decrease in resistance. However, if you observe the impact results when compared to the rupture results under dry and immersed conditions, it is noticeable that the decrease in strength is much greater for dynamic loads. That is, although plasticization reduces the strength for static cases, this decrease is less intense when compared to the decrease for dynamic impact loads. This provides an indication that in conditions of high humidity, care must be taken with dynamic loads, such as impact, fatigue, and abrasion, as these are likely to limit the system.

Regarding the parameterizations carried out for the amounts of impact cycles until the rupture was reached, in general, it appears that the best model is the power model, with satisfactory determination coefficients (R^2), above 95%. Therefore, it is stated that for polyamide subjected to impact loads and immersion conditions, the best model in general is the power model.

In the rupture tests on dry and wet polyamides, it should be noted that in the constant loss of strength as the immersion time in water increases, there is also an increase in the elongation at break. This is the result of plasticization, which, as it modifies the chemical structure of the material, changes mechanical properties, such as this loss of stiffness, which must be limited by a saturation condition.

Force-time graphs provide conclusions about energy dissipation in multifilaments. Gravitational potential energy generates an impulse, the specimen dissipates this energy partly in plastic deformation (stretching) and partly in elastic form (rebounds), as more cycles are applied, the multifilament gains stiffness, and each peak of force becomes greater than the above because the free fall height is added to the plastic deformation plots, until the specimen reaches failure. That is, the smallest impulse (area below the main peak of the force versus time graph) corresponds to the maximum stiffness of the multifilament and the maximum peak force captured by the load cell, this usually occurs in the rupture cycle.

Regarding the application of impact cycles, the gain in stiffness that occurs as the fibers are elongated, which theoretically increases the tensile strength, may be of interest. Creating oriented lenses in impact cycles in a controlled manner could improve the tensile mechanical performance of the material.

This work is a contribution to the understanding of dynamic loading in polyamide. The material has been studied for mooring systems, especially for floating wind turbines, and other applications in shallow water. As these uses are subject to possible dynamic loads, it is important to study impact loads and conditions of plasticizing effect associated with polyamide. In addition, the fact that it is an experimental study with a synthetic material of non-linear behavior makes it difficult to build the results, some graphs in specific showed anomalous behavior, but nothing that disfigured the general behavior of the experiments.

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