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MECHANICAL ANALYSIS OF FIBERGLASS-REINFORCED POLYESTER COMPOSITES ARTIFICIALLY AND NATURALLY AGED

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Abstract. *Fiberglass-reinforced polyester matrix composites are used in the Brazilian electricity sector. These composite materials can manufacture poles and crossarms for electricity distribution networks installed in a hard-to-reach locations. For its application in electrical networks, poles and crosses must be sized and manufactured according to specific standards. The Brazilian standard for this application is ABNT NBR 16989. Although available technical Standards consider the aging test performance in a weathering chamber on the material, there is no consensus in the technical community about the relationship between the aging test results degradation and durability of the structure. The present study aims to establish a relationship between natural aging and aging in a weathering chamber of composite samples of polyester reinforced with fiberglass. This relationship provides information on the structure life span after installation. This work was done in four stages to establish this relationship: tensile strength tests were made in three kinds of samples: non-aged samples, naturally aged samples and artificially aged samples. After that a analysis of data was made to establish a correlation between the two types of aging.*

Keywords: *polymer composite material; fiberglass reinforced polyester; weathering chamber; artificially aging; mechanical properties.*

1. INTRODUCTION

The use of composite materials has become increasingly common in several areas of industry, due to their superior mechanical properties compared to conventional materials. Among the most used composites, FRP (Glass Fiber Reinforced Polyester) stands out, which is composed of a polyester resin matrix and reinforced with glass fibers. According to K. Mayandi *et al*., 2020, about 90% of the composite materials market uses fiberglass in structures. This is because glass fiber is the most economically advantageous among synthetic fibers, as it has good mechanical characteristics and a lower price than others in the category. The Brazilian electricity sector uses widely fiberglass-reinforced polyester poles and crossarms for electricity distribution networks installed in a hard-to-reach locations, due to the low weight and excellent mechanical resistance of these products.

However, it is important to evaluate the behavior of these materials over time, especially in relation to aging. Aging can be natural, caused by environmental factors such as exposure to sunlight, humidity and temperature variations, or artificial, carried out in weathering chambers. Feng and Guo, 2016, developed a theoretical model that allows evaluating and validating such properties taking considering variations in the temperature. However, his study is applied to composites with epoxy matrix and does not cover other types of weathering actions, such as UV rays and humidity.

Zu et al, 2022, investigated the effects of deionized water, sea water and solutions with various concentrations on the physical and mechanical properties of FRP samples. Got to the conclusion that alkaline solutions had a more severe effect on GFRP than deionized water, seawater and acidic solutions. Also was found that the experimental values and the predictions of the Arrhenius model were in good agreement with each other.

Mohammed et al, 2021, presented in their study the results of comparison between mechanical properties of composite samples without aging and samples exposed for four months under bad weather in Malaysia. Tensile test results showed an average loss of 15% of the mechanical properties of the composite after the exposure period.

In this sense, this study analyzed the influence of natural and artificial aging on the mechanical properties of FRP composites. Tensile tests were carried out in order to compare naturally and artificial aged samples.

2. METHODOLOGY

2.1 Materials

The naturally aged samples analyzed in this experiment were taken from poles thar were produced through filament winding process using fiberglass and polyester resin. The most uniform parts of the product were chosen, however, as each pole was intended for a different application, the thickness of the poles were different from each other. Therefore, after cutting the samples, they were sanded until they were all between 3.5 and 4mm thick.

The non aged and artificially aged were made in laboratory, simulating the filament winding process. The same raw material, angle and fiber fraction were used. They were also subjected to a 2h post-curing process at 80°C, as is done in the pole production process.

The fraction of fiberglass by mass is 70%. However, it is possible for this fraction to vary in the order of 5% more or less, due to process deviations.

The fiberglass used to manufacture the samples is E-glass direct roving, with a surface layer (sizing) of silane compatible with unsaturated polyester resin. The technical data presented by the manufacturer can be analyzed in table 1:

Table 1 – Fiberglass Technical Data

Linear Density (g/km)	Density (g/cm³)	Maximum load in the longitudinal direction (GPa)	Modulus of Elasticity longitudinal direction (GPa)
2200	2.5 – 2.7	2741	81.232

The resin is a non-accelerated unsaturated polyester resin, whose physical and mechanical characteristics are listed in tables 2 and 3.

Table 2 – Physical Characteristics of the Resin

Brookfield Viscosity, spindle #2 / 30 rpm (cP)	Solid content (%)	Gel Time (min)	Exothermic Peak Range (min)	Exothermic Peak (°C)
500	55	11 - 15	17	200

Table 3 – Mechanical Characteristics of the Resin

Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Elongation (%)	Barcol Hardness
60	3200	4.5	35

For resin curing, 0.42% by mass of cobalt octoate and 3% by mass of methyl ethyl ketone peroxide curing initiator were used.

Figure 1. Filament winding pole production.

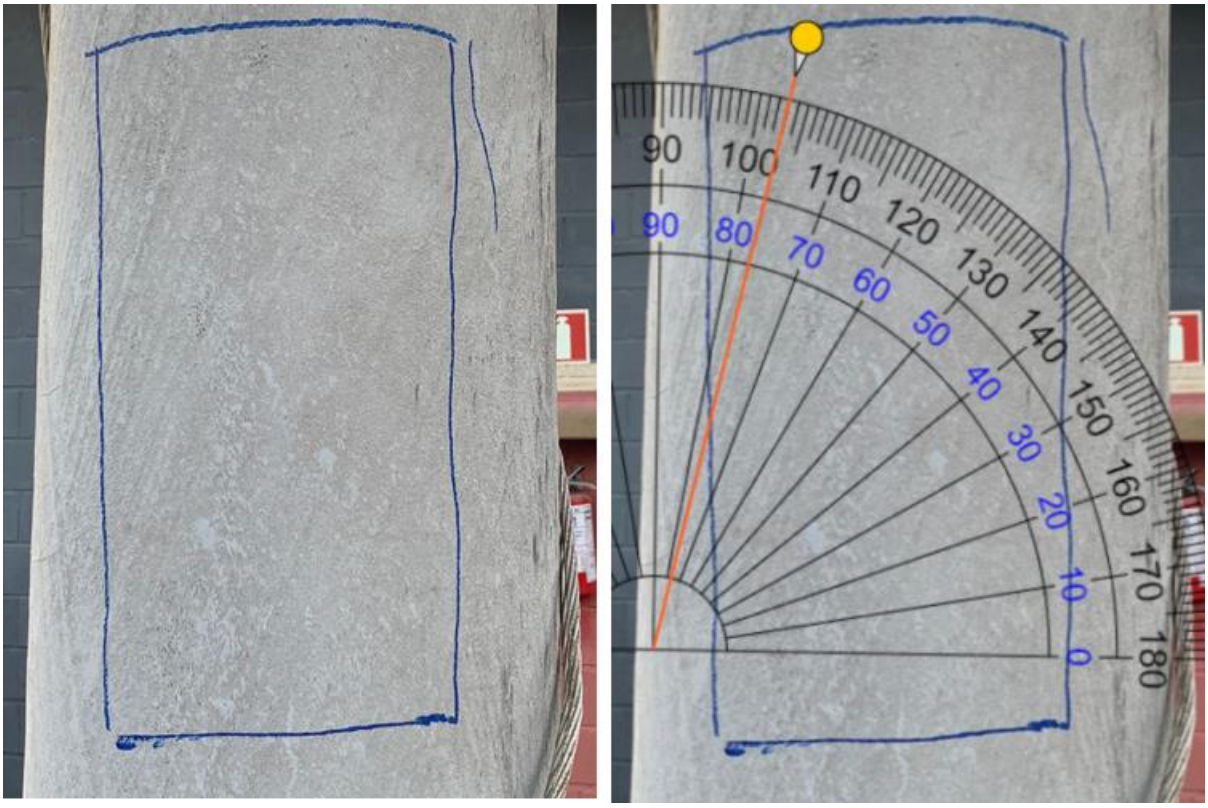


Figure 2. Area demarcation for sample removal from installed pole.

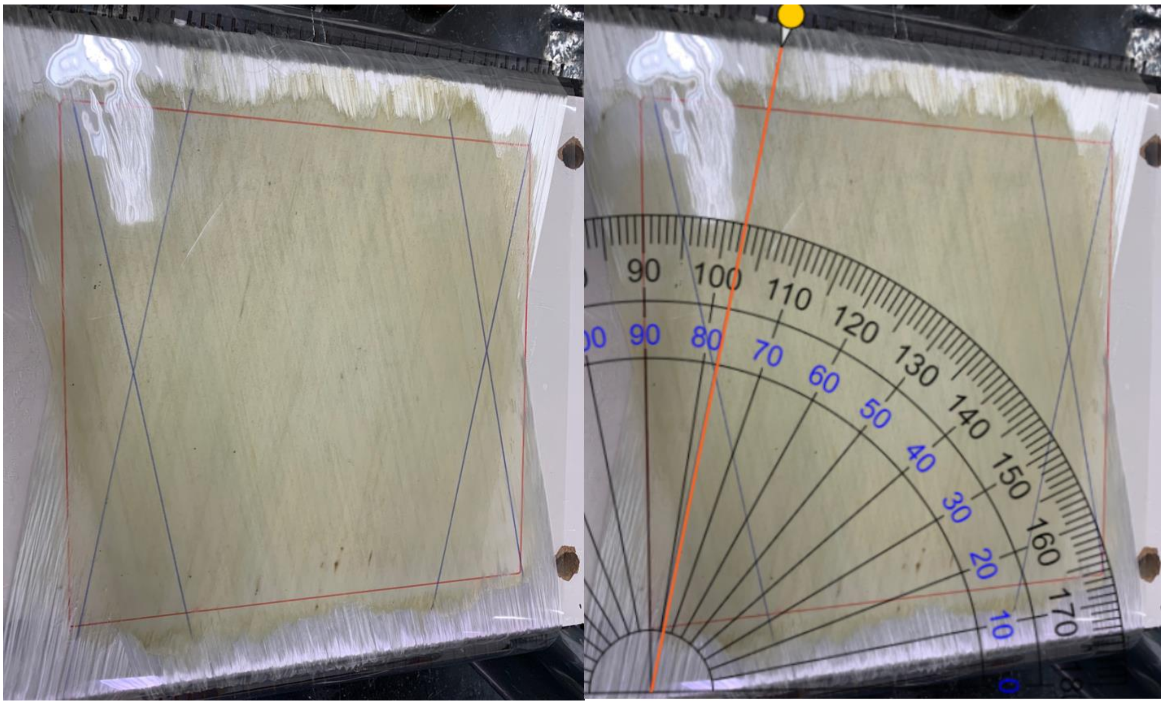


Figure 3. Laboratory production of samples.

2.2 Aging tests

The naturally aged samples were taken from poles, all installed within a radius of 2 km in the southern region of Brazil.

The artificially aged samples were subjected to accelerated aging cycles according to ASTM G155 - Operating Xenon Arc Light Apparatus for Exposure of NonMetallic Materials during 4,000h. The used equipment was a QLAB accelerated weathering chamber. The aging cicle are described in table 4:

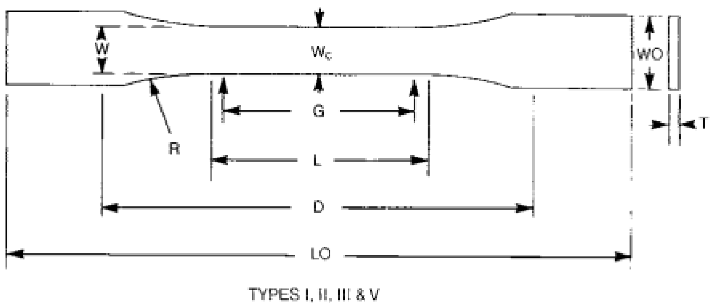
Table 4 – Aging cicle

Cicle	Lamp	Typical Irradiance (W/(m².nm))	Approximate Wavelenght (nm)	Exposure Cycle
1	UVA-340	0.89	340	8 h UV at 60 (±3) °C Black Panel Temperature; 4 h Condensation at 50 (±3) °C Black Panel Temperature

2.3 Mechanical tests

The unaged and aged samples were tested in tensile.

The tensile tests followed the ASTM D638 - Standard Test Method for Tensile Properties of Plastics standard, with bone-shaped test samples. The samples dimensions are according to Type I of the standard, total length 165mm, length of narrow section 57mm and width of narrow section 13mm. Thickness was between 3,5 and 4mm.



Dimensions (see drawings)	7 (0.28) or under
	Type I
W—Width of narrow section[E,F]	13 (0.50)
L—Length of narrow section	57 (2.25)
WO—Width overall, min[G]	19 (0.75)
WO—Width overall, min[G]	...
LO—Length overall, min[H]	165 (6.5)
G—Gage length[I]	50 (2.00)
G—Gage length[I]	...
D—Distance between grips	115 (4.5)
R—Radius of fillet	76 (3.00)
RO—Outer radius (Type IV)	...

Figure 4. Test Specimens according ASTM D 638.

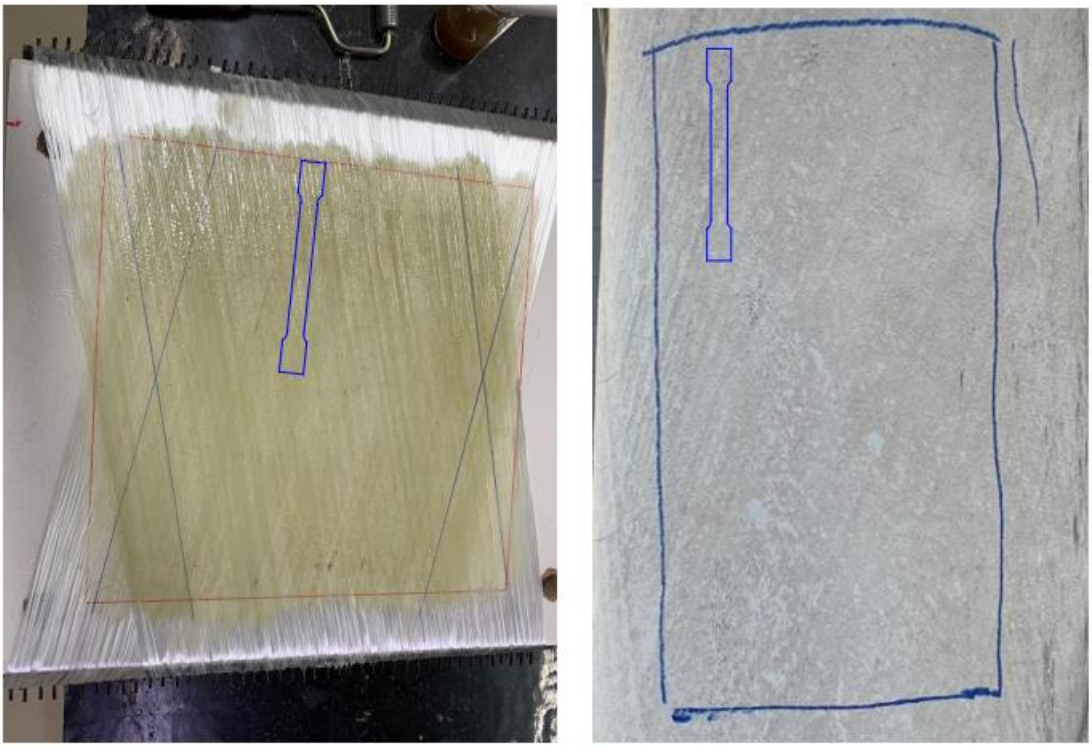


Figure 5. Demonstration of demarcation for sample collection.

The used equipament was a INSTRON universal testing machine, model 4467. The load cells had capacity for 100,000 kgf. The speed of testing was 5 ± 25% mm/min, according the table 1 of the standard.

Figure 6. INSTRON universal testing machine, model 4467.

3. RESULTS

3.1 Visual Inspection

The samples were compared visually as it shows the figures 1 and 2.

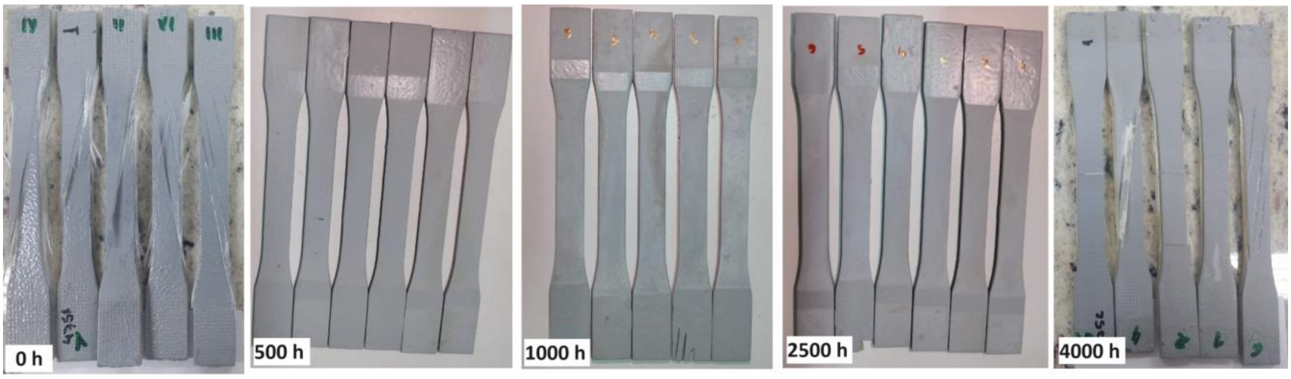


Figure 7. Artificially aged samples.

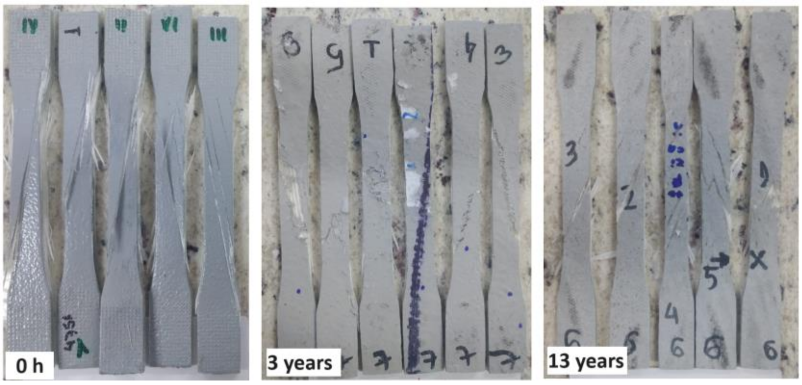


Figure 8. Natural aged samples.

It is possible to see that the samples lost bright, but not color in a significant value.

3.2 Tensile Test

The obtained results are shown in table 5.

Table 5. Result obtained in tensile tests.

Sample	Maximum Stress (MPa)						
Aging time	**0**	**500 h**	**1,000 h**	**2,500 h**	**4,000 h**	**3 years**	**13 years**
1	479	400,51	425,31	311,69	354	273,42	323,05
2	466	417,33	497,69	351,47	398	316,97	166,89
5	456	399,09	505,27	507,49	379	366,39	311,97
4	487	370,17	466,08	332,86	352	296,91	292,81
5	465	365,54	511,58	446,94	400	293,92	254,23
Avarage	**470,60**	**390,53**	**481,19**	**390,09**	**376,60**	**309,52**	**295,52**
Standard deviation	**12,30**	**21,97**	**35,80**	**83,56**	**23,06**	**35,34**	**63,20**
Coefficient of variation	**2,61%**	**5,62%**	**7,44%**	**21,42%**	**6,12%**	**11,42%**	**21,39%**

Sample 2 of the 13 years aged pole was dismissed. It presented many variations in thickness, caused when sanding the test piece for the test.

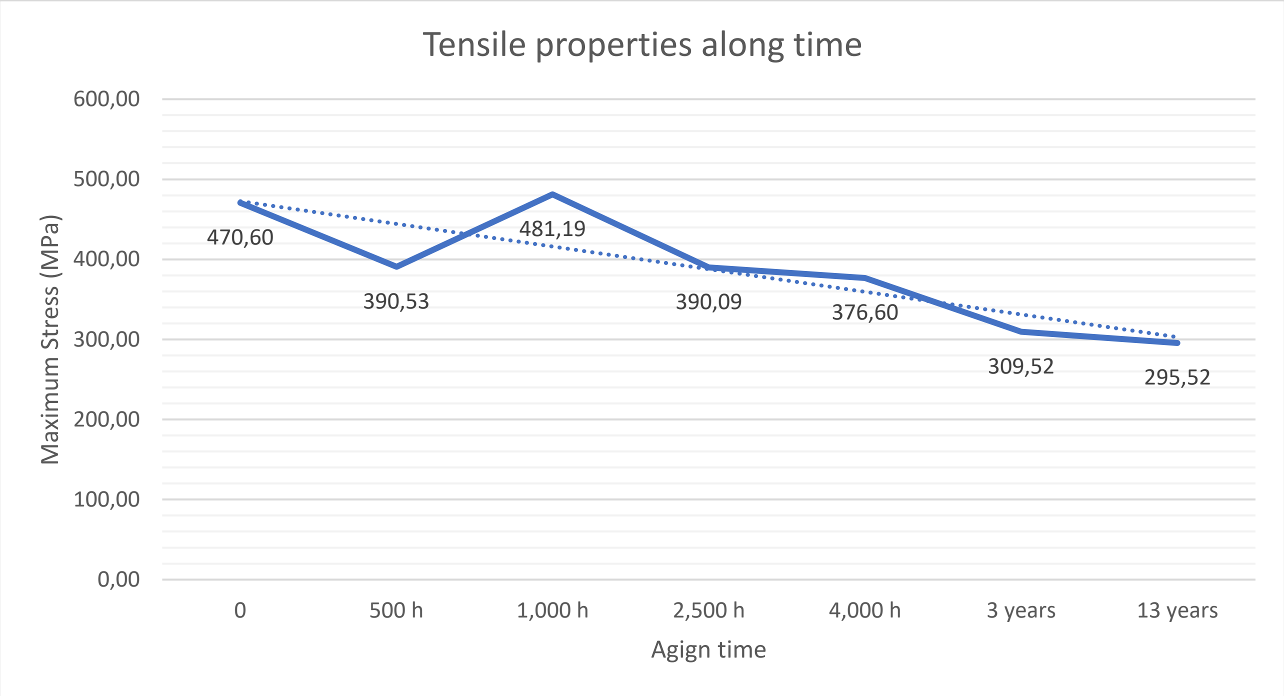


Figure 9. Tensile Test Results Comparison Chart on Unaged and Aged Samples

4. DISCUSSION OF RESULTS

The relationship between the loss of mechanical property and aging time could not be determined. There was an increase in mechanical properties after 1,000, which did not converge with the results found.

Possible factors that may have influenced the variability of sample results:

1) variation in the fiber/resin proportion of the compound;
2) voids between layers;
3) Difference in the curing process of samples;
4) Molecular rearrangement

Although it is not possible to determine a clear relationship between the loss of mechanical properties and aging, it is possible to observe that the tendency is for the material to lose mechanical properties over the exposure time. It is also possible to notice that the artificial aging generates mechanical losses significantly faster than natural aging. This can be seen in table 6

Table 6. Loss of tensile resistance along time

	Loss of tensile resistance	Accumulated loss	Loss / h
500 h	-17%	-17%	-0,034%
1,000 h	23%	6%	0,006%
2,500 h	-19%	-13%	-0,005%
4,000 h	-3%	-16%	-0,004%
3 yeasrs (26,298h)	-18%	-34%	-0,001%
13 years (113,958h)	-5%	-39%	0,000%

Considering another scenario, where the 1000h test is disregarded, the result is very coherent.

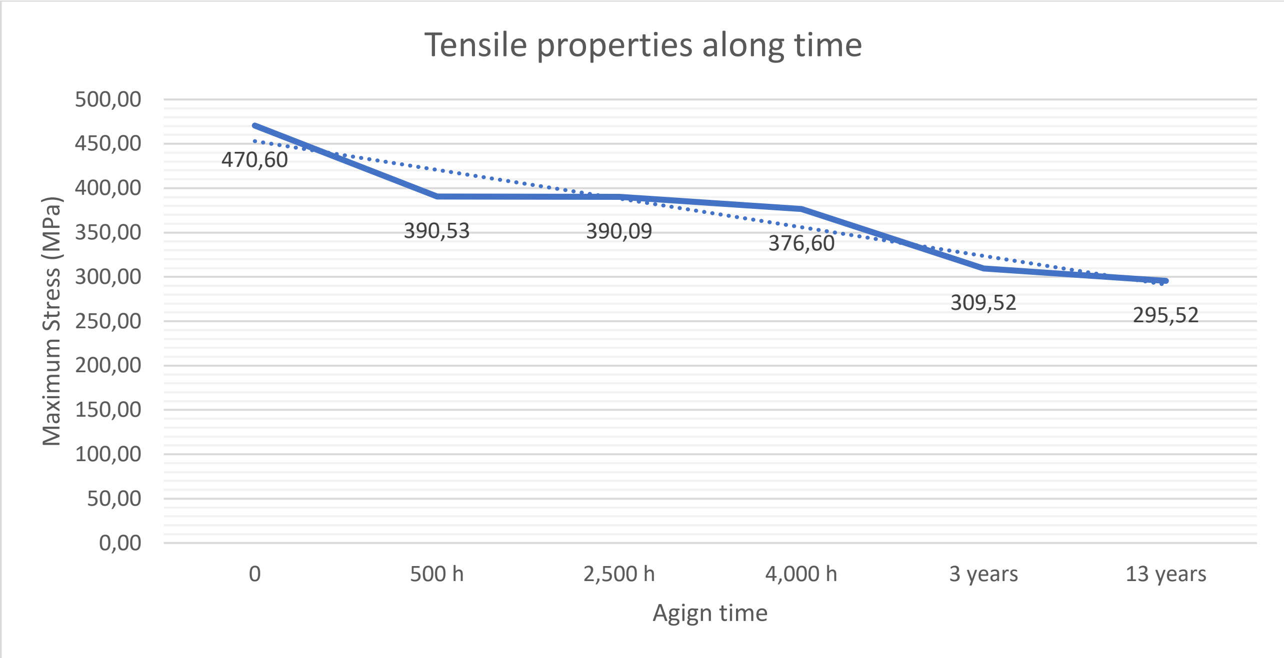


Figure 10. Tensile Test Results Comparison Chart on Unaged and Aged Samples

The severity of artificial aging becomes even more evident in this scenario, as shown in table 7 and figure 11.

Table 7. Loss of tensile resistance along time

	Loss of tensile resistance	Accumulated loss	Loss / h
500 h	-17%	-17%	-0,034%
2,500 h	-19%	-36%	-0,008%
4,000 h	-3%	-39%	-0,001%
3 yeasrs (26,298h)	-18%	-57%	-0,001%
13 years (113,958h)	-5%	-62%	0,000%

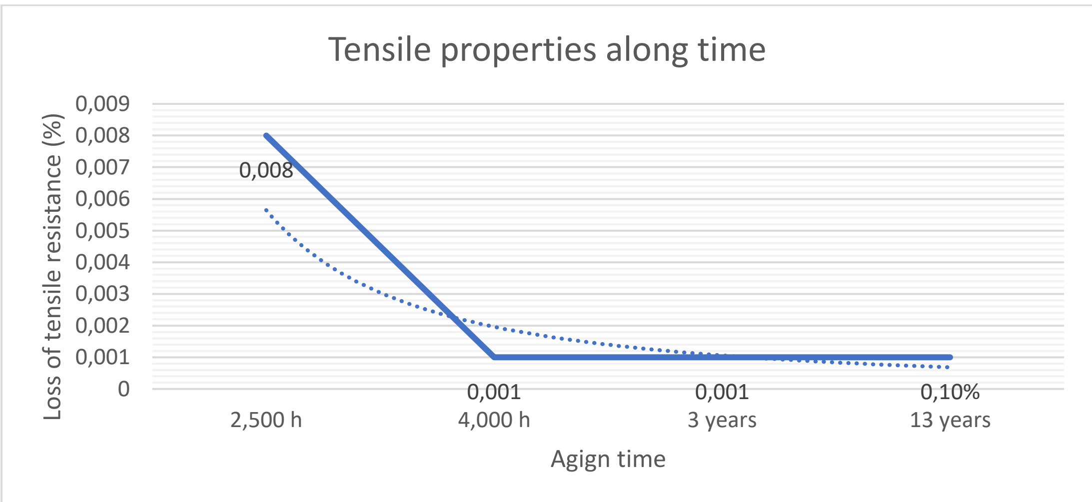


Figure 11. Loss of tensile resistance along time

Analyzing artificial aging and natural aging separately, it is possible to conclude that the results curve was very consistent between the two. Both present a severe loss of initial resistance:

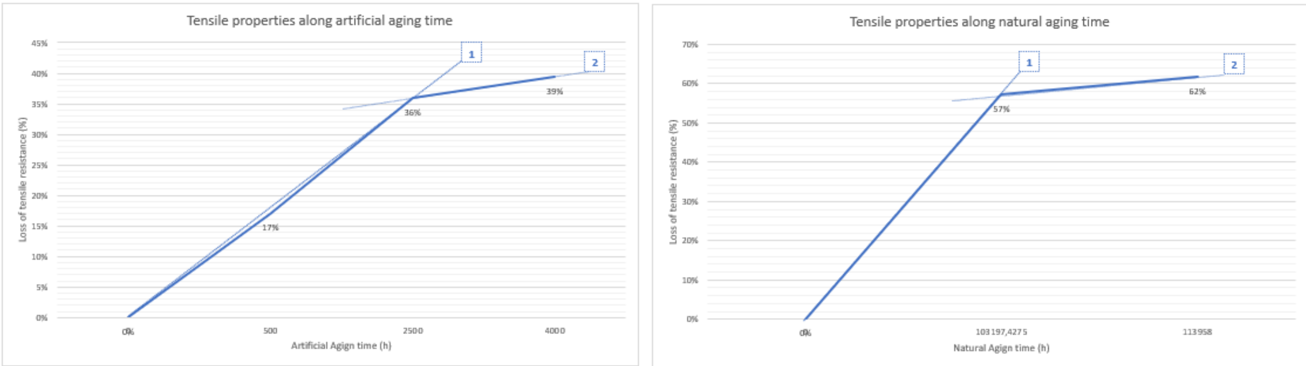


Figure 12. Comparison between artificial and natural aging

Finally, through linear interpolation, the correlation between years of natural aging and hours of artificial aging is found.

Table 8. Correlation between years of natural aging and hours of artificial aging

Curve	Natural aging time (years)	Artificial aging time (h)
1	0	0
1	0,22	500
1	1,11	2500
1	1,77	4000
2	3	6785
2	13	7492

5. CONCLUSIONS

It was possible to conclude that accelerated aging affected the mechanical properties of the samples.

Furthermore, it is possible to state that after the initial 4,000h of aging, the tendency towards loss of tensile resistance decreases greatly, remaining almost stable statistically speaking.

It is still necessary to investigate the cause of the increase in mechanical properties after 1,000h of aging. Several possible reasons were listed, the most likely of which is a molecular rearrangement of the compound at this time.

In future work, it would be interesting to collect more data from posts with different installation times, in order to improve the correlation between results.

6. REFERENCES

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7. RESPONSIBILITY NOTICE

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