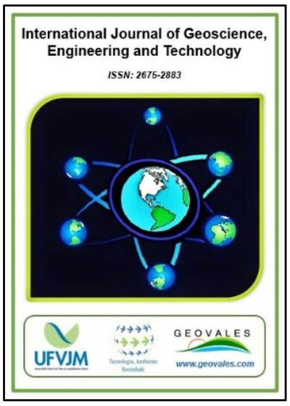
International Journal of Geoscience, Engineering and Technology
ISSN: 2675-2883
https://doi.org/10.70597/ijget.v9i1.534
Volume 9 – Nº 1 – Year: 2024 – pp.21-38



Received:
April 18, 2024

Accepted:
April 27, 2024

Published:
April 30, 2024

Experimental Investigation of Resin Produced with PET Applied to the Surface of Wooden Fence Posts

Nérisson Caldeira dos Santos[1], Dumar Esteves Jardim[1], Eduardo Lourenço Pinto[1], Éverton Wilker de Abreu Almeida[1], Flávio Alchar Barbosa [1] Cristiano Agenor Oliveira de Araújo[2]

[1] Federal University of Jequitinhonha and Mucuri Valleys, Teófilo Otoni, Brazil.
[2] Federal Rural University of Rio de Janeiro, Seropédica-RJ, Brazil

Email address
nerisson.caldeira@ufvjm.edu.br (Nérisson C. dos Santos)
dumar.jardim@ufvjm.edu.br (Dumar E. Jardim)
eduardo.lourenco@ufvjm.edu.br (Eduardo L. Pinto) – Corresponding Author
everton.wilker@ufvjm.edu.br (Éverton W. de A. Almeida)
fabarbosa@gmail.com (Flávio A. Barbosa)
cristiano@ufrrj.br (Cristiano A.O. de Araújo)

Abstract

Polyethylene terephthalate (PET) stands out as a recyclable material of great importance, its versatility makes it a valuable resource in industry, ensuring the conservation of natural resources and the minimization of waste when disposed of correctly. The search for an alternative method to increase the useful life of wood used as fence posts is necessary given the current use of toxic materials, such as the use of Copper-Chromium-Arsenic (CCA), a material harmful to humans and the environment. In this sense, this work presents the development of a polymeric resin, obtained through the depolymerization process, from PET discarded with a glycerin solution. The resin resulting from depolymerization, once applied to the surface of eucalyptus (*Eucalyptus Cloeziana)*, in proportions of 4:1 (PET: Glycerin), presented a texture similar to a varnish and, after drying, proved to be efficient in protecting of wood. The field tests carried out revealed that, even though the resin applied to some test bodies had peeled off, the wood absorbed a much smaller amount of water when compared to wood not coated with resin, regardless of whether the wood was treated or not previously with CCA.

Keywords: Copper-Chromium-Arsenic (CCA); Glycerin; Plastic, Polyethylene Terephthalate (PET); Polymeric Resin.

1. Introduction

Wood is the oldest construction material used, due to its great availability in nature and its relative ease of handling. Because its strength and weight ratio is one of its positive points, wood is widely used in the manufacture of various products, as well as fence posts.

Fence posts are prefabricated pieces made of wood that can also be called stakes or palanques (Galvão *et al.*, 2004). Its use is related to the support of fences and divisions of land and environments. These items are used in residential, industrial and rural constructions and in sports constructions, as well as in football stadiums, used to separate the field from the stands. In addition to their purpose focused on wooden fences, fence posts also have the function of providing security to the place in which they are being used. This is why different materials can be found and variations between models. On the other hand, fence posts have negative aspects, including biological degradation by fungi, poor durability and low resistance to moisture (Pfeil, 2003).

To reduce wood degradation, treatments are currently carried out with toxic materials, such as Copper-Chromium-Arsenic (CCA) (Ferrarini, 2015). CCA is an extremely dangerous compound applied to wood, which industries use to increase its resistance. The use of this material has impacts on different areas of your production process. The application of CCA exposes the operator to health risks and also soil pollution through direct contact (Chiaramonte, et. al., 2017). Due to the toxicity of CCA, its replacement with a non-toxic and sustainable alternative becomes interesting.

In this sense, this work proposes the insertion of a plastic coating on wood using PET 1, in order to avoid rapid degradation, but without using toxic substances. PET 1 is the PET commonly used in bottles of non-alcoholic beverages, water, vegetable oils, and other packaging such as sauces, butter, mayonnaise, among others. The plastic coating is part of the family of polymers, which are formed by macromolecules characterized by the multiple repetition of one or more simple chemical units, the monomers, being joined together by chemical reactions called polymerization reactions (Cirino; Lino and Teixeira, 2017, p.12).

PET 1 is one of the most resistant polymers, both in relation to physical impact and chemical impact. This plastic can be molded through a heating process or depolymerization through chemical recycling (Simon, 2011).

2. Objectives

2.1. General Objectives

Study the behavior and possibility of using PET 1, to create a resin that can be applied to Eucalyptus Cloeziana surfaces, aiming to obtain greater durability of the wood.

2.2. Specifics Objectives

Determine the resistance of the wood through the compression test parallel to the fibers without protection and with Copper-Chromium-Arsenic (CCA) protection;

Carry out preliminary tests for the experimental determination of wood moisture without protection and with Copper-Chromium-Arsenic protection;

Carry out bibliographical research on Polyethylene Terephthalate and propose methodologies for creating a resin capable of protecting the surface of wood samples.

3. Literature Review

The PET 1 polymer is used on a large scale to manufacture disposable bottles, due to its lightness and practicality, however, this material has become a major creator of volumes due to its disposal without proper recycling.

According to IUPAC (International Union of Pure and Applied Chemistry), PET is structured in aliphatic and aromatic part. Figure (1) show the structure of the polymer.

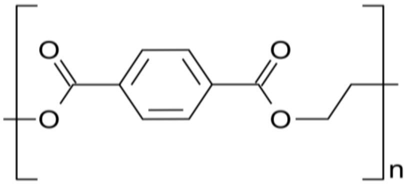


Figure 1 – Chemical structure of the pet. (Gomes, 2017).

For the Brazilian Association of the PET Industry, around 550 tons are produced per year in Brazil, where 71% are used in the manufacture of packaging and, of this amount, 32% are used for the manufacture of bottles (ABIPET, 2016). However, excessive consumption and inadequate disposal cause serious environmental problems. Even though PET has been recycled, a large amount of this material, after its useful life, ends up being discarded and starts polluting landfills, rivers and oceans.

3.1. Polymer Synthesis

The synthesis can be done through polycondensation steps, first occurring direct esterification using acid, or transesterification if the process starts from dimethyl terephthalate. The second stage is where polycondensation actually occurs, producing grade 30 polymer. As for bottles, this polymer reaches grade 150, going through the last stage of solid state polymerization (Oliveira, 2006). Figure (2) shows the methods for obtaining PET.

3.2. Polymer Recycling

According to Romão, Spinacé and Paoli (2009), plastics are the most produced material in the world. Due to this massive production, its main application in Brazil is in the packaging industry, representing 71% of the total.

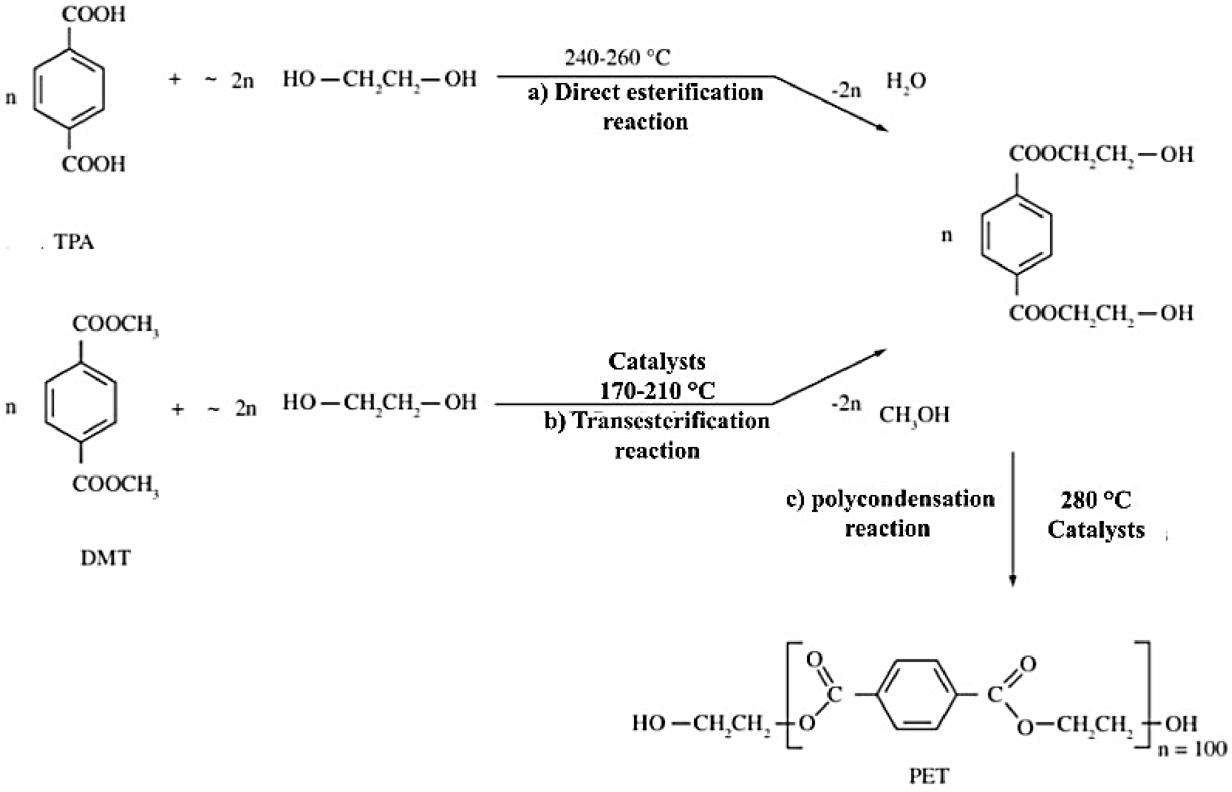


Figure 2 – Methods for obtaining PET (Adapted from Romão, Spinacé e Poali, 2005).

In the food industry, the use of plastics reaches 32%. However, large production also results in inadequate disposal of plastics, leading to environmental problems.

Packaging and disposal of materials produced with PET, polypropylene (PP), polystyrene (PS) and other polymers have difficulties returning to the recycling production chain, due to their low market value, which varies between R$1.00 to R$ $1.07/kg (Rezende et al., 2018).

The low interaction of polymers with the environment makes them difficult to degrade in the environment after being discarded without any treatment. Based on this problem, recycling becomes the most attractive solution from an environmental perspective, and this process can occur in primary forms with direct reuse of the product; in secondary form, transforming waste through mechanical action into a material to be processed later; tertiary where the raw material is reprocessed, obtaining mixtures reused in refineries; and finally, quaternary recycling through energy recovery after thermal treatment of plastic (Franchetti and Marconato, 2003).

The chemical recycling of PET reduces it to monomers in its total depolymerization, and, in partial form, transforms it into oligomers and other compounds. In this process, amide, glycerin, methanol and water can be used to break down the polymer. In conjunction with these processes, acidic, basic or neutral catalysts can be used, where the process is most notable when it occurs in an alkaline environment (Di Souza, Torres and Ruvolo Filho, 2008).

In the chemical recycling part of the material it is common to use degradation using glycerol, undergoing partial depolymerization, as in the case of this work. The addition of methanol, ethylene glycol, diethylene glycol, propylene glycol is used to produce terephthalate or its acid, among other similar compounds (Kao; Cheng; Wan, 1997). This entire process is dependent on temperature, concentration and processing time.

3.3. Glycerin

Glycerin or glycerol is an environmentally friendly material, being a renewable compound, giving its products a sustainable character. Its use in industry is currently largely in the manufacture of pharmaceuticals and cosmetics (Mota, Silva and Gonçalves, 2009), where chemical recycling is another use.

Glycerin has the appearance of a colorless, sweet, odorless and viscous liquid, resulting from transesterification in the biodiesel production process, with a melting point of 18.2 °C and a boiling point after 290º C.

Glycerin was chosen as an alternative for depolymerization of PET 1 as its boiling temperature is 300º C, which makes the reaction favorable since the melting point of PET 1 is 260º C.

The thermal cracking process of glycerin must be avoided as it occurs at its boiling point. This process has been the subject of study by the academic community. However, due to the presence of hydroxyls and the factors responsible for this reaction, knowledge of the mechanisms that control cracking is extremely challenging (Riatto *et al.*, 2015).

The glycerin molecule forms hydrogen bonds, with cyclic groups in the internal hydroxyl bonds, providing the basis for several reaction mechanisms. This geometry provides great possibilities for applying the product (Gomes, 2017). In Figure (3), the possible reactions of PET 1 and Glycerol in the presence of heat in a certain time interval are demonstrated.

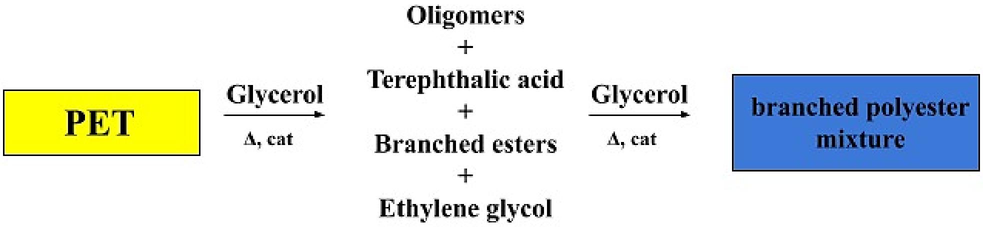


Figure 3 – Steps for using glycerol in the reaction with PET 1 (Adapted from Gomes, 2017).

3.4. Eucalyptus (*Eucalyptus Cloeziana*)

This work focuses on the treatment of wood, in order to coat it to increase its useful life. Wood is a material from trees that can be classified into two main categories: softwood and hardwood. Hardwoods are recognized for their strength and quality, while softwoods are distinguished by cellular characteristics that impact their strength (Pfeil, 2003).

Wood is subject to degradation from various sources, including biological agents and the action of fire. The vulnerability of wood is a characteristic dependent on its own species, environmental conditions, rehumidification cycles due to contact with the soil, with fresh or salt water. Due to this fragility, chemical treatment is applied which can increase resistance to biological attacks and the action of fire (Pfeil, 2003).

The heartwood of Eucalyptus Cloeziana wood has a cellular arrangement in different directions, which, according to the cut made in the trunk, makes it possible to observe the growth rings. Wood's supporting cells are the fibers that define its properties according to their orientation (Simon, 2011). Regarding its chemical composition, wood has 50% carbon, 44% oxygen and 6% hydrogen, it also contains nitrogen and minerals (Simon, 2011).

This Eucalyptus is one of the main woods used for the production of fence posts, but due to its low resistance to biodegradation, it must undergo preservative treatment (Lima *et al.*, 2019). The fence posts are generally made from the trunk of the tree, but as they are partially buried in the ground, their degradation becomes faster. (Galvão *et al.*, 2004).

The material to be treated in this work are fence posts made of Eucalyptus Cloeziana, widely used to manufacture parts for fences and for the construction of residential roofs. This type of tree is abundant in the north of Minas Gerais and found in several plantations in the region. To be analyzed, fresh and treated (with CCA) eucalyptus fence posts were chosen.

3.5. Copper-Chromium-Arsenic (CCA) protection

Copper-Chromium-Arsenic (CCA) is a water-soluble preservative widely used in the preservation of wood, seeking to reduce its biological degradation. However, this treatment presents dangers due to the material being classified as toxic (class I). The application of CCA to wood can be carried out industrially, following technical standards to provide greater safety, high production and quality (Silva, 2006).

According to Revista Madeira (2007), wood preservation is any set of procedures that aim to provide greater resistance to wood and protect it against biological degradation. The most used is Copper-Chrome-Arsenic, which uses an autoclave, high pressure steam and temperature to cure the material. At the end of this autoclave process, Ferrarini et al. (2012) specify that the drying process occurs, leaving the wood for two weeks to occurs chemical reactions between the applied material and the wood.

Due to the toxicity of the applied material, some European countries, such as Sweden and Denmark, have already banned the use of CCA treatment on wood (Revista Madeira, 2007).

3.6. Other wood treatments

With a global trend in the search for biodegradable materials, which do not pollute and come from biomass, studies on polyurethanes manufactured from castor oil have become a trend, expanding the search for alternative forms of preservative compounds (Dias, 2023).

Godoy (2007) tested another resin created based on castor oil and obtained good performance results. Dry form characteristics and mechanical properties, such as strength, have been improved.

Another alternative method of providing resistance to wood is the application of a thermoplastic composite resin. This resin provides considerable thermal stability to cellulose.

The work of Correa *et al*. (2003), studied the reactivity of polypropylene modified with maleic anhydride, showing significant gains in relation to the hardness of the materials for unmodified samples.

4. Materials and methods

4.1. Materials

The complete process analysis was conducted qualitatively and divided into three stages.

The 1st Stage refers to the investigation of the physical parameters of moisture and resistance of the wood. The moisture content of the wood was evaluated through the use of the oven and the resistance of the wood through compression tests applied to the test bodies. Both methods were performed in accordance with the ABNT NBR 7190-3:2022 standard. The press used was the Martins & Campelo Press (capacity 150 kN), magnetic bases (Digimess brand) and displacement transducers (LVDTs).

The 2nd Stage refers to the investigation of protection methods using the PET 1 melting procedure and the PET 1 Depolymerization. The objective was to find alternative methods for creating a protective layer on the wooden pieces (test bodies) in order to provide a greater resistance of the material to bad weather. In this experimental step, a Fisatom drying oven with a maximum temperature of 300°C, a glass Becker, and a Lucadema fume hood were used.

The 3rd Stage verified the efficiency of the protection methods, through field testing of the covered test bodies. The test bodies were buried, similar to wooden fence posts, which are subjected to field climatic conditions. Therefore, periodic moisture control was necessary.

Initially, the objective was to check if the wood complied with the NBR 7190-3 compression and moisture standards. The main point was to find a method to apply PET 1 to wood, with the aim of transforming the final product into a viscous liquid. This would allow for easier transfer of the product from the beaker to the test bodies.

The materials used in this work included bottles of Polyethylene Terephthalate 1 (PET 1), from the consumption of various drinks, P.A. glycerin, with a content equal to or greater than 99.5%, and Eucalyptus Cloeziana fence posts. Wood was used to generate test bodies measuring 15x5x5cm for compression tests and measuring 5x3x2cm for moisture and coating tests. Among the equipment, we highlight dial indicators, a universal mechanical testing machine, an analog drying oven, a muffle furnace, a teflon non-stick mat, welded metal sheets in the shape of a rectangular box, a round ceramic crucible for high temperatures, stainless steel metal tweezers, 100 and 250ml graduated beaker, glass rod, metal spatula and the Bioscale balance (FA2204B) with an accuracy of 0.0001g.

All stages of this work took place at the Institute of Science, Engineering and Technology (ICET), Campus Mucuri – Teófilo Otoni-MG.

Twenty pieces of fence posts were used as shown in Figure (4), measuring 10 to 12 cm in diameter and approximately 1 meter high. These woods were taken to the carpentry shop and worked to obtain the test bodies. It was observed that these samples contained treated and untreated wood for test bodies.

For the compression test, moisture test, heating and depolymerization, the following were used: universal testing machine, analog sterilization and drying oven model SSA 110L (working temperature 50 to 250°C), digital muffle furnace, heating blanket with magnetic stirring and 250 ml graduated beaker.

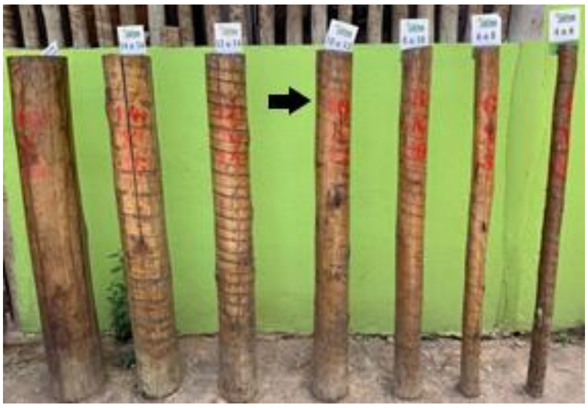


Figure 4 – Amostras de mourões (Autor, 2023).

4.2. Methodology

4.2.1 Moisture Testing

Within the scope of this work, the wood moisture test is important for understanding the moisture content value that wood presents. This understanding is fundamental for adjusting the mechanical properties of strength and hardness in accordance with the NBR 7190-3 standard.

The 5x3x2cm test bodies were placed in the heating oven in accordance with standard NBR 7190-3, with the temperature adjusted to 103°C (±2°C). The model SSA 110L heating oven, with temperature control from 50°C to 250°C, can be seen in Figure (5).

Figure 5 – Analogic heating oven.

As stipulated by the ABNT standard, each measurement of the test bodies is carried out with a minimum interval of 6 hours, and the measurements are subsequently collected. The test bodies then return to the oven to continue the drying process.

For the moisture tests, the dimensions and initial masses of the test bodies were obtained. Table (1) presents the dimensions of the seventeen prepared test bodies. The test bodies numbered 1 to 10 correspond to untreated wood samples, while those numbered 10 to 17 represent wood treated with CCA.

Table 1- Measurements of the test bodies.

TB	Width (mm)	Length (mm)	Height (mm)
1	20,86	31,26	51,18
2	21,15	31,6	52,55
3	21,07	31,91	52,33
4	21,06	31,51	50,62
5	21,14	31,53	63,03
6	20,88	31,25	52,87
7	20,88	31,86	50,8
8	20,91	31,27	51,68
9	21,13	31,51	50,75
10	20,93	31,68	51,59
11	21,04	31,72	51,54
12	20,92	31,44	50,92
13	20,94	31,54	50,96
14	27,16	31,82	51,14
15	20,84	31,36	53,44
16	21,14	31,54	52,56
17	21,12	31,12	53,22

* TB – Test Bodies

4.2.2. Compression Test

The compression of the wood is carried out in accordance with the NBR 7190-3 standard, which makes possible to understand the maximum compression achieved by the test bodies and comprehend the value of its resistance.

The wooden test bodies used must correspond to the dimensions described in the wood experimental testing ABNT standard, with test bodies measuring 15x5x5cm to evaluate compressive resistance. The compression test was a test parallel to the fibers to obtain the maximum compression value supported by that amount of wood.

In Figure (6), it can be seen how the test bodies is prepared for testing parallel to the fibers, exemplifying the compression time applied to the test bodies with magnetic bases (Digimess) and displacement transducers (LVDT's).

In Figure (8) it is possible to observe the assembly of the wood compression test procedure, with the apparatus fixed to the base of the wood.

4.2.3. PET 1 Melting

The objective was to propose a method for using PET 1 with wood coating, which was simple and easy to apply and did not require large costs. The bottles used were PET 1 and were collected with the help of members and consumers outside the project. Bottles without pigmentation were chosen, separated and treated, removing seal, labels and lid. They were cleaned with soap and water, left to dry for a minimum of 24 hours and cut into small pieces to facilitate contact with the glycerin.

For melting PET 1 and applying it to wood, three alternatives were tested. In the first option, PET 1 was cut into small pieces and inserted into the crucible, taken to the muffle furnace at a temperature of 270°C to be melted and deposited on the wood. In the second option, the muffle furnace temperature was 270 °C, where PET 1 was placed in an iron mold that was introduced into the heating oven, and then the wooden test bodies was added. The third and final alternative also used a muffle furnace (270 °C), where PET 1 was inserted onto a teflon sheet that was taken for heating. Subsequently, the sheet containing the melted PET 1 and impregnated with the test body was removed.

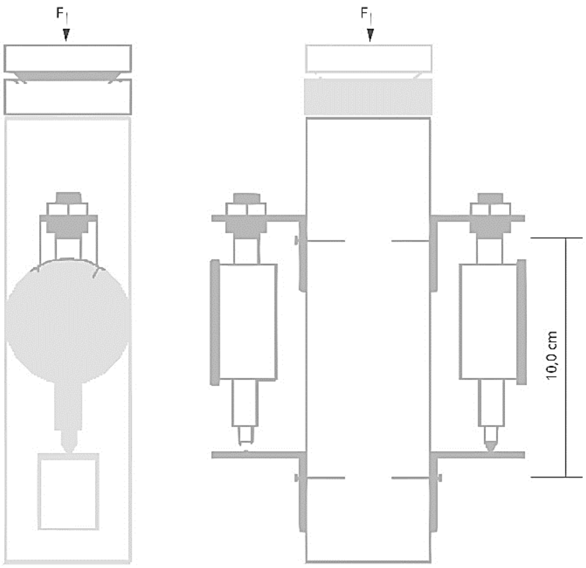


Figure 6 – Arrangement of the compression test parallel to the fibers with two comparators (adapted from ABNT NBR 7190-3, 2022).

In Figure (7) we can see the compression loading diagram for the test bodies.

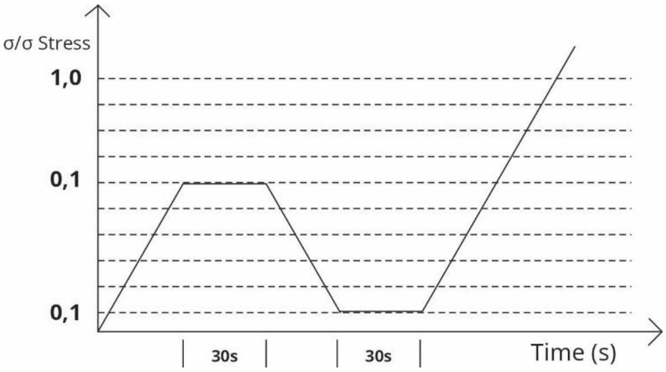


Figure 7 – Diagram for determining wood hardness (adapted from ABNT NBR 7190-3, 2022).

Figure 8 – Wood compression test assembly.

Figure (9) below highlights the muffle furnace used in the melting stage, which has a temperature range of 50 to 1200°C with an accuracy of 7°C.


Figure 9 – Zezimaq microprocessed muffle furnace.

4.2.4. Development of polymeric resin with PET 1

The polymeric resin was developed through the depolymerization of PET 1 by glycerolysis, according to Araújo et al. (2019). The aim was to improve the uniform application of the material on the wooden test bodies, and variations in the glycerin and PET 1 masses were used, establishing proportions between the materials. It was possible to evaluate the behavior of the material with different amounts of glycerin after drying.

Table (4) shows the proportions of PET 1 and glycerin used in the depolymerization process.

Figure (10) shows the fume hood and the heating blankets used.

Table 4 – PET 1 and glycerin proportion test.

Test	PET 1 (g)	Glycerin (g)	PET 1: Glycerin ratio	Temperature (°C)	Time (min)
1	40.05	121.00	0.33:1	280	150
2	40.18	10.09	3.9:1	301	27
3	40.11	20.23	1.98:1	300	29
4	40.05	10.14	3.94:1	300	21
5	40.17	10.09	3.98:1	300	20
6	40.05	5.08	7.8:1	300	17
7	40.05	10.14	3.9:1	300	19
8	40.03	10.23	3.9:1	303	19
9	48.00	73.70	0.65:1	305	60
10	48.00	20.58	2.3:1	300	27

4.2.5. Field test of covered test bodies.

In the field test of the bodies covered with the polymeric material, three test bodies measuring 15x5x5cm and six test bodies measuring 5x3x2cm untreated (without CCA) were evaluated and covered with resin.

Three test bodies with dimensions of 15x5x5cm and five others with dimensions of 5x3x2cm, treated with CCA and not covered with resin, were also evaluated. All bodies were made from Eucalyptus Cloeziana wood and buried. The bodies were buried in a pit approximately 40 cm deep, as illustrated in Figure (11).


Figure 10 – Fume hood and heating blankets.

Figure 11 – Cova para madeira.

The smaller test bodies were positioned with a minimum distance between them before being buried. The bodies were wetted every two days using a volume of water of 1 liter.

The test bodies identified as G1 to G3 and P1 to P6 were produced from untreated wood and covered with resin obtained from the combination of PET 1 + glycerin. On the other hand, the test bodies identified as G4 to G6 and T1 to T6 were made of wood treated with CCA.

5. Results and Discussion

5.1. Moisture Test

Figure (12) shows the results of the moisture values obtained in four tests for each test bodies. Remembering that the bodies numbered 1 to 10 correspond to untreated wood samples, while those numbered 11 to 17 represent wood treated with CCA.

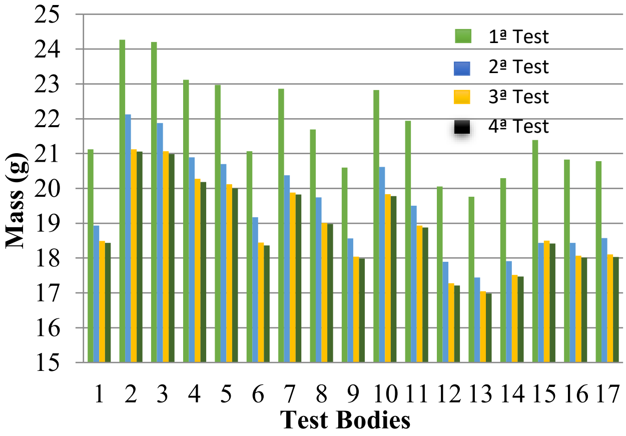


Figure 12 – Moisture test.

From these tests, it was possible to calculate moisture variations in accordance with the ABNT NBR 7190-3:2022 norms, where it is expected to achieve variations equal to or less than 0.5% for the mass to be considered dry, according to the norms ABNT. Equation 1 shows the formula for calculating moisture content:

$$U(\%) = \left(\frac{Mi - Ms}{Ms}\right) * 100 \qquad (1)$$

where:
Mi – initial mass of test bodies (g).
Ms – final mass of test bodies (g).

Moisture content plays a crucial role in the strength of wood. The values of moisture content variations of the seventeen test bodies are represented in Figure (13).

From the obtained data, it can be seen that the variation dry mass of wood was obtained with a value less than or equal to 0.5%, and from that moment on, the samples can be evaluated using compression tests.

5.2. Compression Tests

In accordance with the NBR 7190-3 norms, compression tests were carried out with the aim of investigating and interpreting the magnitude of the maximum compressive strength value achieved by the test bodies. Experimental tests were carried out on four samples of untreated wood and five samples of wood treated with CCA.

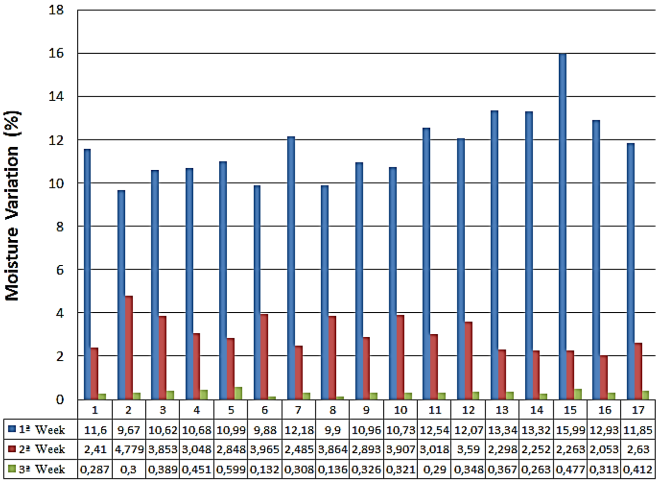


Figure 13 – Variation in moisture content (%) for test bodies with untreated (1 to 10) and treated (11 to 17) wood.

Table (2) presents the results of the compression test carried out on untreated wood bodies, showing the maximum compression force supported by them. It was possible to observe that the Eucalyptus Cloeziana test bodies showed ruptures before the value predicted by the ABNT NBR 9480 norms. The value predicted by the standard indicates that the bodies should resist up to 52 MPa of tension, however, the bodies test samples CP_01NT, CP_02NT, CP_03NT and

CP_07NT, showed failures of 27.63 MPa, 25.5 MPa, 22.68 MPa and 26.27 MPa, respectively.

In Figure (14) it is possible to observe the behavior of test body 1 in the face of compression, identified as CP_01NT (untreated test body 1).

Table 2 – Stress supported (MPa) by untreated wood.

Test Body	Dimensions (mm)			Weight (g)	Supported Stress (MPa)	Supported Force (Kgf)
1- (CP_01NT)	51.98	58.68	152.70	255.3	27.63	7568
2- (CP_02NT)	51.90	51.70	151.12	255.20	25.50	6978
3- (CP_03NT)	51.98	52.04	152.22	257.9	22.68	6256
7- (CP_07NT)	51.22	51.06	152.24	248.3	26.27	7006

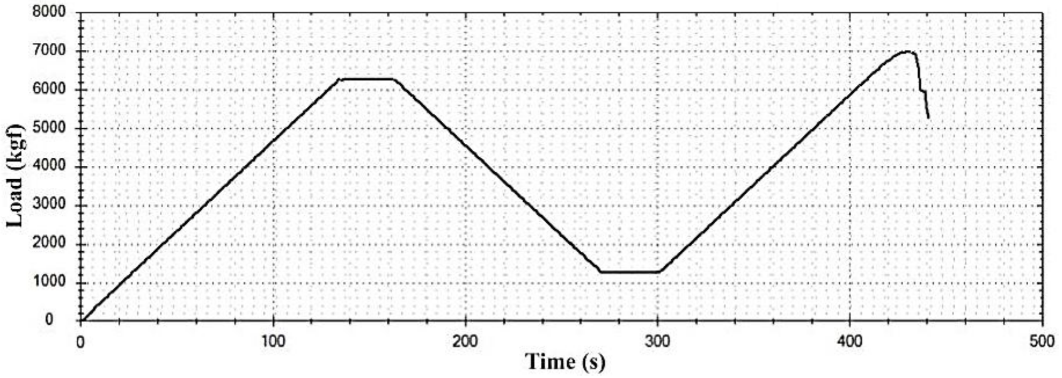


Figure 14 – Graph of compression performed on test body 1 with untreated wood (CP_01NT).

Table (3) presents the results of compression tests carried out on treated wood bodies, showing the maximum compression force supported by them. Once again, it was possible to observe that the test bodies showed ruptures before the value predicted by the ABNT NBR 9480 norms.

Table 3 – Table containing tension supported by treated wood.

Test Body	Dimensions (mm)			Weight (g)	Supported Stress (MPa)	Supported Force (Kgf)
4- (CP_04T)	51.66	51.60	152.12	248.5	22.77	6389
5- (CP_05T)	51.70	51.68	152.18	243.4	22.88	6233
6- (CP_06T)	51.08	51.06	152.22	240.4	22.38	5953

In Figure (15), it is possible to observe the behavior of the compression body, identified as CP_04T. From these tests, it was concluded that none of the samples complied with the established norms. A possible reason for the lack of satisfactory results may be related to the maturation time of the wood.

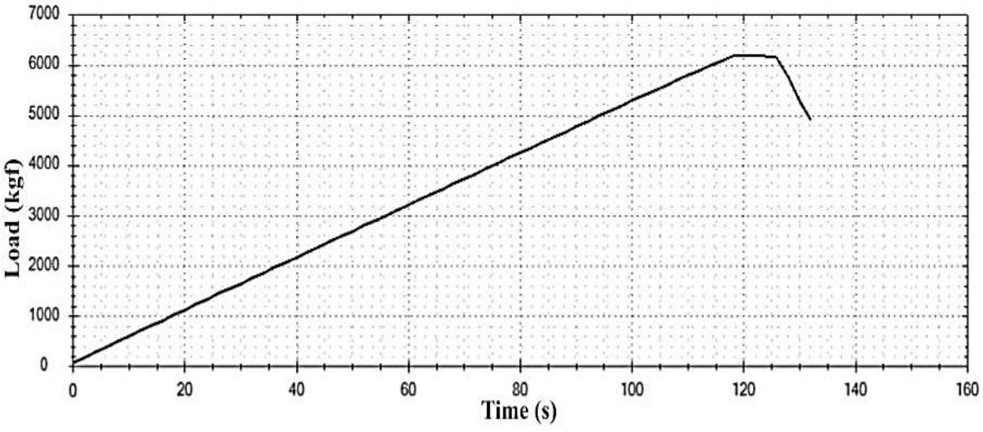


Figure 15 – Compression of the CP 04T test body.

Figure (16) shows the result of a test body that shows the failure (breakage) that occurred after the stress test.

Figure 16 - Test body failure after test.

5.3. PET 1 Melting Tests

The first test was carried out by melting PET 1 in the muffle furnace at a temperature of approximately 270º C. This experiment found that the material obtained did not have the necessary malleability to cover the desired wooden test body. The procedure aimed to cover the wood with a thin layer of PET 1, but unfortunately it was not possible to mold the PET 1 to the test bodie due to the lack of temperature control. The rapid solidification of the material was noted as illustrated in Figure (17).

Figure 17 - Test body after molding with melted PET.

The second test involved heating PET 1 in a metal mold. After the material reached a temperature of 270º C in the muffle, it was removed and the test bodies was introduced into the mold. The material remained trapped in the metal mold, making it impossible to assess the adhesion of the heated PET 1 product to the wood.

The third test was conducted by heating the cut PET 1 (small pieces) directly on a Teflon sheet, resulting in the formation of a wrap on the test bodies. However, this test also cooled quickly, making it difficult to apply it uniformly on the test bodies, as in the first case. When the material cools quickly, it becomes difficult to spread the melted plastic, which prevents the test bodies cover.

The complexity identified in this experiment arises from the fact that, the material resulting from the burning of PET 1, is in a state with high viscosity, making it difficult to apply to the test bodies.

These challenges point to the need for improvements in the method, aiming to ensure success in obtaining the desired coating on the wood surface.

5.4. Development of polymeric resin with PET 1

Given the difficulties presented with the melting of PET 1 in the muffle, it was necessary to look for an alternative for coating the test bodies. A polymeric resin was developed for coating test bodies. The coating was obtained through the partial depolymerization product of PET 1 with glycerin, as described in the literature, previously mentioned. It is noted that the addition of glycerin results in a liquid material, significantly facilitating handling and application, as evidenced in Figure (18).

Figure 18 – Plastic resin obtained by heating glycerin with PET 1.

It was observed that in the process of heating PET 1 with glycerin, the maximum temperature of 300°C cannot be exceeded, otherwise the glycerin suffers thermal cracking, making it unsuitable for coating, as shown in Figure (19).

Figure 19 - Heating test glycerin with PET 1.

After analyzing Figure (19), it is evident that the observed failure, characterized by spongy, solid and sticky material, can be attributed to exposure to a temperature above 300 degrees Celsius.

Variations in the PET 1/Glycerin proportions were fundamental to find the ideal proportion to obtain the polymeric resin. After 24 hours of exposure to the environment, significant moisture absorption was noted, leading to sticky resin with malleability in the wood.

The analysis indicated that reducing the amount of glycerin gave greater consistency to the material, keeping it rigid. This effect was evident in the proportion of four parts of PET 1 to one part of glycerin. The most successful test involved the addition of 40g of shredded PET 1 and 10g of glycerin, representing 20% of the total content of the heating process, as detailed in Table (5). This finding highlights the critical importance of adjusting the ratio of glycerin to achieve the desired resin properties when applied to wood.

Table 5 – Mixture proportion of PET 1 with glycerin.

Test	PET Mass (g)	Glycerin Mass (g)	PET: Glycerin Rate	Max. Temperatura (°C)	Time (min)
1	40.07	10.12	4:1	302	17
2	40.05	10.14	4:1	300	18
3	40.07	10.74	4:1	301	16
4	40.03	10.12	4:1	307	23

The resin obtained in this process was considered suitable for application to the test bodies, as it was fluid enough to completely cover the bodies. The result is clearly presented in Figure (20).

In Test 4, as detailed in the table, it was found that a total of 50.14g of material (PET + Glycerin) were used. This amount made it possible to coat six test bodies designated P1 to P6, each measuring 5x3x2cm. When considering the surface area of each bodies, the material consumption for the applied resin could be obtained by calculating the material consumption per area.

$$\text{Consumption} = 50{,}14\ \text{g}/\ 15{,}0\text{cm}^2 = 3{,}34\ \text{g/cm}^2$$

Figure 20 - Test body after melting PET 1.

5.5 Field Test of Covered Test Bodies

The larger test bodies were partially buried, while the smaller were completely buried, as shown in Figure (21). This approach allowed observing the behavior of the material in an environment similar to that used in the installation of fence posts.

Figure 21 – Buried test bodies.

Table (6) presents the masses of the wooden test bodies with and without resin application, before the burial process. Remembering that the bodies identified as G1 to G3 and P1 to P6 were produced from untreated wood and covered with resin (PET 1 + glycerin), and the bodies identified as G4 to G6 and T1 to T6 were produced from CCA treated wood.

The buried test bodies were removed from the site every seven days to measure their masses, in addition to observing the condition of the wood and the applied resin. As recorded in Table (7), there was an increase in mass over time.

Every seven days, the test specimens were removed to weigh the masses, in order to calculate absorbed moisture. They were then buried and subsequently removed every seven days for reweighing. The conclusions arising from these data are presented in Figure (22).

Test Bodies Mass Value		
Test Bodies	Mass without Resin (g)	Mass with Resin (g)
G1	255.50	307.00
G2	247.10	280.40
G3	249.60	283.70
G4	239.20	-
G5	252.90	-
G6	249.20	-
P1	23.72	27.17
P2	24.22	29.55
P3	22.79	28.86
P4	23.82	28.90
P5	21.60	26.58
P6	22.67	28.78
T1	14.60	-
T2	18.39	-
T3	19.51	-
T4	19.51	-
T5	22.48	-

Table 6 – Mass values of the test bodies with and without resin.

According to Figure (22), it was possible to observe that the untreated wood test bodies, coated with the resin: P1, P2, P3, P4, P5 and P6, presented a much lower percentage of moisture absorption than the treated wood bodies, uncoated T1, T2, T3, T4 and T5.

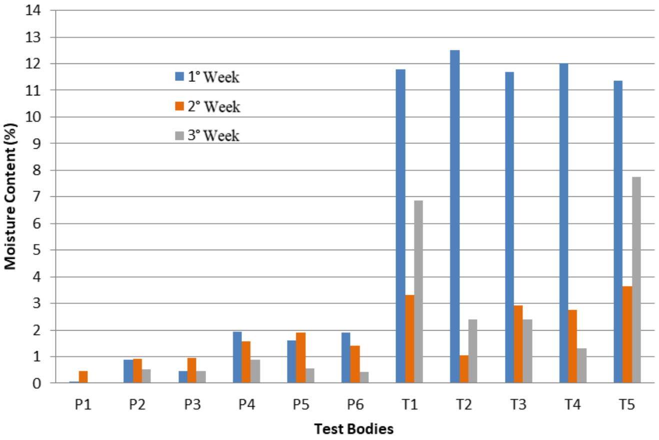


Figure 22- Moisture content of buried test bodies measured on 7, 14 and 21 days.

The treated wood test bodies G1 to G3 were coated with the resin and presented a moisture absorption rate not very different from treated wood G4 to G6, as shown in the graph in Figure (23). This can be attributed to the fact that they are partially buried.

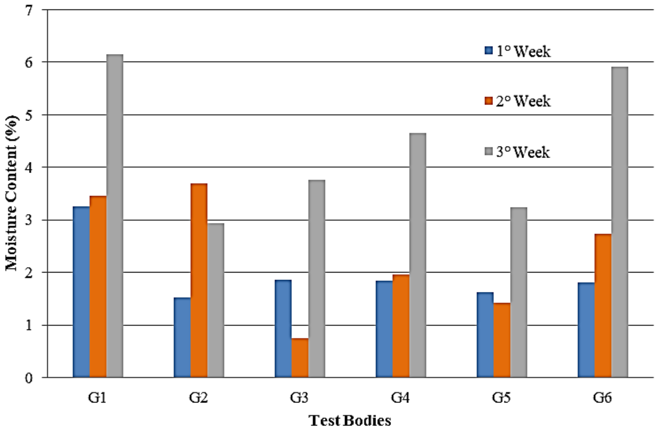


Figure 23 – Moisture content of buried test bodies.

Partial exposure to the sun, resulting from the partial burial of the 15x5x5cm test bodies, resulted in wear of the resin in bodies G1 to G3 during the third week. The wear of the resin is evident in the images before and after the test. Test bodies G1 and G3 showed visible loss of resin. In Figure (24) on the right, the sample of wood with resin is shown, buried for a period of 15 days longer than the one on the left.

In Figure (25) we also have comparisons before and after being buried, for test body G3.

The 5x3x2cm test bodies did not show deterioration of the resin. In Figure (26), it is possible to observe that the loss of color of the material is due to moisture absorption.

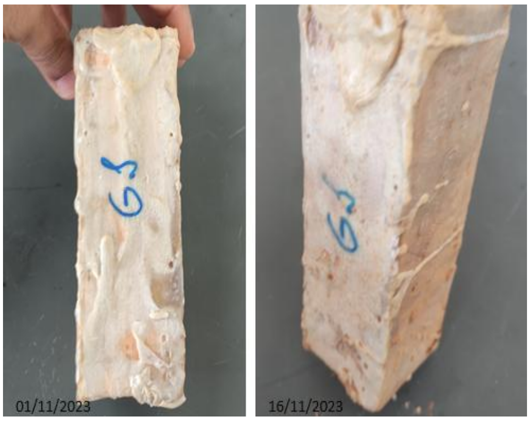


Figure 24- Test body G1 before (left) and after (right) being partially buried (5x5x15cm).

Figure 25- Test body G3 before (left) and after (right) being partially buried (5x5x15cm).

Figure 26 – Test body P5 before (left) and after (right) being completely buried (2x3x5cm).

In Figures (27) and (28), the percentage variations in the moisture of the test bodies will be presented. The analysis of the Figure (27) (test bodies 15x5x5 cm) allows us to observe that the average moisture absorbed by the resin coated test bodies (G1 to G3) was lower compared to the bodies without resin treatment, made of wood treated with CCA (G4 to G6). Figure (28) (test bodies 5x3x2cm) shows that the difference in the moisture content of the coated and uncoated test bodies is clear, where we conclude that the depolymerization method is an alternative for covering wood.

Mass Values of the Test Bodies			
Test Bodies	Mass (g) (7 Days)	Mass (g) (14 Days)	Mass (g) (21 Days)
G1	307.20	308.60	308.50
G2	282.90	285.50	287.00
G3	285.00	287.70	289.00
G4	243.80	247.60	249.80
G5	254.40	259.20	260.60
G6	253.90	257.50	256.40
P1	28.05	29.02	30.81
P2	30.00	31.11	32.02
P3	29.39	29.61	30.73
P4	29.42	30.01	31.40
P5	27.01	27.40	28.28
P6	29.30	30.10	31.88
T1	21.81	22.53	24.08
T2	21.95	22.18	22.71
T3	25.10	25.84	26.46
T4	20.59	21.16	21.44
T5	16.26	16.85	18.16

Table 7 – Mass values of the test bodies every seven days, for 3 weeks.

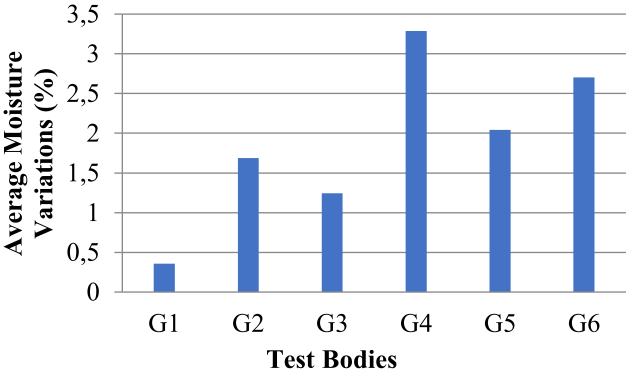


Figure 27 - Average moisture variation of the body test (15x5x5cm) with untreated wood and resin (G1 to G3), and wood treated with CCA without resin (G4 to G6).

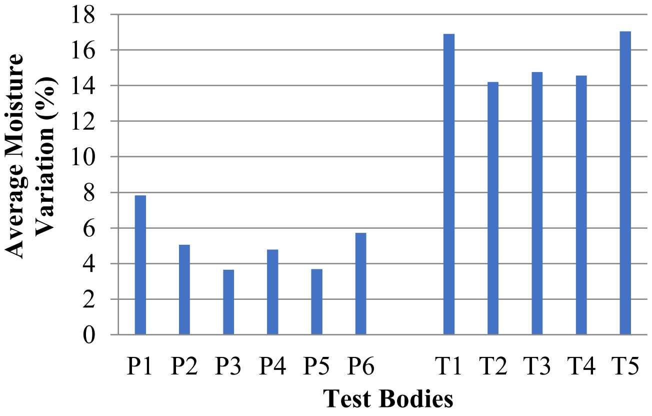


Figure 28 - Average moisture variation of the body test with resin (P1 to P6) and wood treated with CCA without resin (T1 to T5).

6. Conclusions

The moisture tests revealed that the test bodies, both treated and untreated, showed similar behavior in relation to water absorption, suggesting that the CCA treatment does not prevent the wood from absorbing a considerable amount of water.

The compression tests carried out on the treated and untreated Eucalyptus Cloeziana wood teste bodies indicated that the maximum compression loads did not vary significantly. A possible reason for the lack of results in accordance with the current norms may be related to the maturation time of the wood.

Research to achieve a product that could protect wood against water absorption was carried out through the depolymerization of PET 1 with Glycerin, using heating. The results showed that the resin was able to cover the wood satisfactorily, reducing the moisture absorption of the organic material and increasing its resistance against water.

The average moisture absorbed by the resin-coated test bodies was lower compared to the CCA-treated wood bodies. There was a clear difference in the moisture content of the coated and uncoated test bodies, which made it clear that the depolymerization method was an alternative for protecting the wood.

Therefore, the possibility of replacing conventional wood treatment methods that use substances harmful to humans and the environment, such as CCA, is evident. The resin from the depolymerization process through the recycling of PET 1 has been shown to be capable of covering wood, preventing its rapid degradation, and also opens up a new alternative for recycling PET 1. However, it is important to highlight that the deterioration of resin applied after the field test, reinforces the continuity of this work.

References

ABIPET – Associação Brasileira da Indústria do PET. *10º Censo da Reciclagem de PET no Brasil.* Brasília, 2016.

ABIPLAST – Associação Brasileira Da Indústria Do Plástico, 2022. *Perfil 2021*. [online] Available at: <https://www.abiplast.org.br/publicacoes/perfil-2021/> [Accessed 18 April 2023].

ABIPLAST – Associação Brasileira Da Indústria Do Plástico, A.B. da I. de P., 2019. *Reciclabilidade de Materiais Plásticos Pós-Consumo*. [online] Available at: <https://www.abiplast.org.br/wp-content/uploads/2019/03/cartilha_reciclabilidade_abiplast_web.pdf> [Accessed 18 March 2023].

ABNT – Associação Brasileira De Normas Técnicas, 2009. *NBR 9480: Peças roliças preservadas de eucalipto para construções rurais – Requisitos.* Rio de Janeiro, Brasil.

ABNT – Associação Brasileira De Normas Técnicas, 2022a. *NBR 7190-1: Projeto de estruturas de madeira - Parte 1: Critérios de dimensionamento*. Rio de Janeiro.

ABNT – Associação Brasileira De Normas Técnicas, 2022b. *NBR 7190-2: Projeto de estruturas de madeira - Parte 2: Métodos de ensaio para classificação visual e mecânica de peças estruturais de madeira*. Rio de Janeiro.

ABNT – Associação Brasileira De Normas Técnicas, 2022c. *NBR 7190-3: Projeto de estruturas de madeira - Parte 3: Métodos de ensaio para corpos de prova isentos de defeitos para madeiras de florestas nativas*. Rio de Janeiro.

ABNT – Associação Brasileira De Normas Técnicas, 2022d. *NBR 7190-4: Projeto de estruturas de madeira - Parte 4: Métodos de ensaio para caracterização peças estruturais*. Rio de Janeiro.

Almeida, I.S., Costa, I.D., Ribeiro, M.M., Heinrich, M., Moreira, Q., Araujo, P.J. and Leite, M.S., 2013. *Reciclagem de garrafas PET para fabricação de telhas*. Caderno de Graduação-Ciências Exatas e Tecnológicas, 1(3), pp.83-90. Disponível em: <https://periodicos.grupotiradentes.com/cadernoexatas/article/view/897/569> [Accessed 2 december 2023].

Ambrosi, T.V., 2009. *Logística reversa de embalagens de isopor.* Porto Alegre.

Araújo, D.P.R., Melo, B.N., ARAÚJO, L.V., Gomes, R.V. and Araújo, R.C.S., 2019. Avaliação da Despolimerização do Politereftalato de Etileno (PET) e a Preparação de Novos Poliois. In:

Blucher Chemical Engineering Proceedings. São Paulo: Editora Blucher.

Carmo, E.S.D., 2018. *Reciclagem Química do Pet: Obtenção da Resina Alquídica.* Available at:<https://dspace.bc.uepb.edu.br/jspui/handle/123456789/17748#:~:text=A%20resina%20PET%20pode%20ser,utilizada%20em%20tintas%20e%20vernizes> [Accessed 18 March 2023].

Chiaramonte, R., Garbin, M., Calheiro, D. and Brehm, F. A., 2017. Levantamento De Estudos Sobre O Arseniato De Cobre Cromatado – CCA. *IFSUL, Ifsul-Seminário De Inovação E Tecnologia*. Disponível em: <https://www.researchgate.net/profile/Marilise-Garbin-2/publication/320992232_LEVANTAMENTO_DE_ESTUDOS_SOBRE_O_ARSENIATO_DE_COBRE_CROMATADO-CCA/links/5a0623d8a6fdcc65eab188a6/LEVANTAMENTO-DE-ESTUDOS-SOBRE-O-ARSENIATO-DE-COBRE-CROMATADO-CCA.pdf> [Acessed 1 agosto 2022].

Choi, S., Ruddick, J.N. and Morris, P., 2004. *Chemical redistribution in CCA-treated decking.* Forest products journal, 54(3), pp. 33-37.

Cirino, C., Lino, D. And Teixeira, M., 2017. *A Indústria De Transformados Plásticos.* [online] São Paulo: Sindicato dos Químicos de São Paulo. Available at: <https://quimicosp.org.br/wp-content/uploads/2017/10/livro-a-indu-stria-de-transformados-pla-sticos.pdf> [Accessed 12 November 2022].

Correa, C.A., Fonseca, C.N., Neves, S., Razzino, C.A. and Hage Jr, E., 2003. *Compósitos termoplásticos com madeira*. Polímeros,13(3), pp.154-165. https://doi.org/10.1590/S0104-14282003000300005

Costa, P.M., Costa, M.M. and Freitas, L., 2017. Créditos de Logística Reversa para Gestão de Resíduos Sólidos Urbanos: Estudo de caso da BVRIO no Brasil. In: Basen, G.R., Jacobi, P.R., Freitas, L., 2017. *Política Nacional de Resíduos Sólidos: Implementação e Monitoramento de Resíduos Urbanos*. IEE USP: OPNRS.

Dias, F.M., 2005. *Aplicação de adesivo poliuretano à base de mamona na fabricação de painéis de madeira compensada e aglomerada.* Doctoral Thesis. Universidade de São Paulo.

Di Souza, L., Torres, M.C.M. and Ruvolo Filho, A.C., 2008. *Despolimerização do Poli (Tereftalato de Etileno) - PET: Efeitos de Tensoativos e Excesso de Solução Alcalina*. Polímeros: Ciência e Tecnologia, 18(4), pp. 334-341. https://doi.org/10.1590/S0104-14282008000400013

Ferrarini, S.F., Miranda, L.G., Maia, S.M. And Pires, M., 2015. *Madeira tratada com arseniato de cobre cromatado (cca): opções de destino para os resíduos gerados e perspectivas no desenvolvimento de metodologias para a remoção dos elementos tóxicos.* Periódico Tchê Química, 12(23).

Ferrarini, S.F., Santos, H.S.D., Miranda, L.G., Azevedo, C., Pires, M.J. and Maia, S.M., 2012. *Classificação de resíduos de madeira tratada com preservativos à base de arseniato de cobre cromatado e de boro/flúor*. Química Nova, 35(9), pp. 1767-1771. https://doi.org/10.1590/S0100-40422012000900012

Franchetti, S.M.M. and Marconato, J.C. eds., 2003. *A Importância das Propriedades Físicas dos Polímeros na Reciclagem*. Química Nova na Escola (QNEsc). (18), pp. 42-45. Available at: <http://qnesc.sbq.org.br/online/qnesc18/A09.PDF> [Acessed 6 junho 2022].

Galvão, A.P.M., Magalhães, W.L.E. e Mattos, P.P., 2004. *Processos Práticos para preservar a Madeira*. [online] Colombo: Embrapa Florestas. Disponível em: <https://www.infoteca.cnptia.embrapa.br/bitstream/doc/310319/1/doc96.pdf> [Acessed 2 december 2023].

Godoy, J., 2007. *Estudo de um novo compósito madeira-resina poliuretana para o desenvolvimento de um isolador híbrido*. Dissertation. Escola de Engenharia de São Carlos. Universidade de São Paulo. https://doi.org/10.11606/D.18.2007.tde-04042008-150701

Gomes, D.R.V., 2017. Avaliação da despolimerização do politereftalato de etileno (PET) por glicerólise. Monography. Universidade Federal do Espírito Santo. Available at:

<https://quimica.saomateus.ufes.br/sites/quimica.saomateus.ufes.br/files/field/anexo/avaliacao_da_despolimerizacao_do_politereftalato_de_etileno_pet_por_glicerolise_rodrigo_da_vitoria.pdf> [Acessed 26 julho 2022].

Gorni, A.A., 2003. *Introdução aos plásticos*. Revista plástico industrial, 10(09).

Gotaquimica, 2023. *Tudo sobre Glicerina*. [online] GOTAQUIMICA. Disponível em: <https://gotaquimica.com.br/tudo-sobre-glicerina> [Acessed 2 december 2023].

Kao, C.Y., Cheng, W.H. and Wan, B.Z., 1997. Investigation of catalytic glycolysis of polyethylene terephthalate by differential scanning calorimetry. Thermochimica acta, 292(1-2), pp.95-104. https://doi.org/10.1016/s0040-6031(97)00060-9

Lima, P.A.F., Demarchi, J., Silva, M.F. da, Moraes, M.D.A. de, Caldas, D.J. e Sette Júnior, C.R., 2019. *Qualidade da madeira de eucalipto para aplicação como mourão tratado*. Revista de Ciências Agrárias, 42(2), pp. 509-519. https://doi.org/10.19084/RCA.17179

Maciel, J.P., Bueno, A.B. e Moraes, C.A., 2023. *Non-recyclable polymeric materials in Waste Sorting Units in Porto Alegre/RS and metropolitan region*.

Matos, R.C., Oliveira, H., Fonseca, H.M.A.C., Moaris, S., Sharma, B., Santos, C. e Pereira, M.L., 2020. *Comparative Cr, As and CCA induced Cytostaticity in mice kidney: A contribution to assess CCA toxicity.* Environmental Toxicology and Pharmacology, 73. https://doi.org/10.1016/j.etap.2019.103297

Melo, J.W., 2004. *Produção e caracterização de pó de PET – poli(tereftalato de etileno) obtido a partir de garrafas pós-consumo*. Dissertation. Universidade Federal de Ouro Preto. Disponível em: <http://www.repositorio.ufop.br/handle/123456789/2761> [Accessed 12 November 2022].

Mendes, A.D.S. and Alves, M.D.S., 1988. *A degradação da madeira e sua preservação*. IBDF. Departamento de Pesquisa. Laboratório de Produtos Florestais.

Modro, N.L.R., Modro, N.R., Modro, N.R. e Oliveira, A.P.N., 2009. *Avaliação de concreto de cimento Portland contendo resíduos de PET*. Matéria (Rio de Janeiro), 14(1), pp. 725-736. https://doi.org/10.1590/s1517-70762009000100007

Mota, C.J.A., Silva, C.X.A. da and Gonçalves, V.L.C., 2009. *Gliceroquímica: novos produtos e processos a partir da glicerina de produção de biodiesel*. Quimica nova, 32(3), pp. 639-648. https://doi.org/10.1590/s0100-40422009000300008

Oliveira, J.A., 2006. *Oligomerização e Policondensação em Estado Fundido do Poli(tereftalato de etileno) - Estudo Experimental e de Modelagem da Curva de Distribuição de Pesos Moleculares*. COPPE/UFRJ, Rio de Janeiro, RJ, Brasil.

REMADE (ed.), 2007. *Tecnologia amplia possibilidades de usos*. Revista da Madeira, (109). Available at: <https://www.remade.com.br/br/revistadamadeira_materia.php?num=1187&subject=Preservantes&title=Tecnologia> [Accessed 29 April 2024].

Rezende, G.M., Cardoso, V.L., Pereira, K.C., Silveira, F. and Almeida., A., 2018. *ANUÁRIO DA RECICLAGEM 2017-2018*. [online] Available at: <https://cempre.org.br/wp-content/uploads/2020/11/2-Anu%C3%A1rio-da-Reciclagem.pdf> [Accessed 12 November 2022].

Riatto, V.B., Victor, M.M., Cunha, S., Magalhães, A.C., Cruz, F.T. and Carriço, C.S., 2015. *Craqueamento Térmico da Glicerina: Uma proposta de Experimento para Química Orgânica*. Química Nova, 38(5), pp. 727-731. https://doi.org/10.5935/0100-4042.20150052

Romão, W., Spinacé, M.A.S. e Paoli, M.-A.D., 2009. Poli(tereftalato de etileno), PET: uma revisão sobre os processos de síntese, mecanismos de degradação e sua reciclagem. *Polímeros*, [online] 19(2), pp. 121-132. https://doi.org/10.1590/s0104-14282009000200009

Silva, J.D.C, 2007. *Preservantes*. Revista Madeira.

Silva, J.D.C., 2006. Madeira preservada - *Os impactos ambientais. Revista da Madeira. Viçosa: UFV*, (100). Disponível em: <https://www.remade.com.br/br/revistadamadeira_materia.php?num=985&subject>. [Accessed 12 February 2024].

Silva, J.D.C., 2006. *Madeira preservada: os impactos ambientais*. Revista da Madeira, 100(1).

Simon, S., 2011. *Compósitos Madeira-Plástico*. [online] Universidade Federal do Pampa. Disponível em: <https://repositorio.unipampa.edu.br/handle/riu/4387.>. [Acessed 26 july 2022].

SINDIPLAST – Sindicato da Indústria de Material Plástico, 2022. *Os plásticos*. [online] SINDIPLAST. Disponível em: <http://www.sindiplast.org.br/os-plasticos/> [Acessed 26 july 2022].

Pfeil, W.P.M., 2003. *Estruturas de madeira.* 6 ed. LTC. Disponível em: <https://www.academia.edu/13223956/167631220_LIVRO_Estruturas_de_Madeira_Walter_Pfeil> [Acessed 1 August 2022].