PERFORMANCE COMPARISON BETWEEN PRESERVATIVE PRODUCTS CONCERNING TERMITES ATTACK ON PINE TIMBER

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ABSTRACT – CLT (Cross Laminated Timber) is a pre-fabricated engineered wood panel, generally made from conifer woods, mainly pine and spruce. Due to the low natural resistance of this species to deteriorating organisms attack, the Brazilian standard ABNT NBR 7190:1 (2022) orients the treatment of structural elements before being used. This study aimed to evaluate the resistance of woods from Pine and Spruce species, with different preservative treatments and retentions, against wood termite (*Cryptotermes brevis*) attack. Different species of Pine and Spruce (*Pinus abies*, *Pinus sylvestris*, *Pinus elliottii* e *Pinus taeda*) were evaluated, as well as different preservatives such as Impralit KDS-B, CCA (Chromated Copper Arsenate), CCB (Copper Borate Chromated), MCA-C (Micronized Copper Azol type C) and HQC 791 (fire retardant for wood), usually used in Brazil, the United States and Europe. The results demonstrated that the fire retardant induced greater resistance to attack by xylophagous organisms, with total insect mortality and no surface deterioration after 45 days of testing. The CCA preservative also demonstrated efficiency in wood treatment with high resistance to termite attack, high mortality and only superficial wear of the specimen. It was concluded, therefore, that preservative treatments are recommended to guarantee the durability of the constructive system so that the so-called engineered wood elements can be used as structural systems.

Keywords:Wood preservation; Mass timber; *Cryptotermes brevis*.

COMPARATIVO DO DESEMPENHO ENTRE PRODUTOS PRESERVATIVOS EM RELAÇÃO AO ATAQUE DE XILÓFAGOS EM MADEIRA PINUS

*RESUMO – CLT (Cross Laminated Timber) é um painel de madeira engenheirado pré-fabricado, geralmente feito de madeiras de coníferas, principalmente pinus e abeto. Devido à baixa resistência natural desta espécie ao ataque de organismos deteriorantes, a norma brasileira ABNT NBR 7190:1 (2022) orienta o tratamento de elementos estruturais antes de serem utilizados. Este trabalho teve como objetivo avaliar a resistência de madeiras das espécies Pinus e Spruce, com diferentes tratamentos conservantes e retenções, ao ataque do cupim xilófago (***Cryptotermes brevis***). Diferentes espécies de pinus e abeto (***Pinus abies***,* ***Pinus sylvestris***, ***Pinus elliottii*** *e* ***Pinus taeda****) foram avaliadas, bem como diferentes conservantes como Impralit KDS-B, CCA (Chromated Copper Arsenate), CCB (Copper Borate Chromated), MCA- C (Azol de Cobre Micronizado tipo C) e HQC 791 (retardante de fogo para madeira), normalmente utilizados no Brasil, Estados Unidos e Europa. Os resultados demonstraram que o retardante de fogo induziu maior resistência ao ataque de organismos xilófagos, com mortalidade total dos insetos e sem deterioração da superfície após 45 dias de teste. O conservante CCA também demonstrou eficiência no tratamento da madeira com alta resistência ao ataque de cupins com alta mortalidade e desgaste apenas superficial do corpo de prova. Concluiu-se, portanto, que para garantir a durabilidade do sistema construtivo são recomendados tratamentos preservativos para que os chamados elementos de madeira engenheirada possam ser utilizados como sistemas estruturais.*

Palavras-Chave: Preservação de madeira; Madeira "engenheirada"; ***Cryptotermes brevis***.

1. INTRODUCTION

In Brazil, the utilization of engineered wood, commonly referred to as "engineered wood", in civil construction is experiencing growth. More and more qualified companies are showing interest in this market segment. Among the various types of engineered wood, Glulam (Glued Laminated Timber) and CLT (Cross Laminated Timber) stand out.

CLT panels are prefabricated and generally consist of multiple layers of sawn timber that are glued orthogonally on top of each other. Developed in Europe during the 1990s, these panels can be employed in slabs and walls, either with or without a structural function (Brandner et al., 2016; Oliveira, 2018).

Typically, for the production of CLT, wood from the Pinus genus is used. However, this wood has low natural resistance to deterioration agents. This issue is exacerbated by the fact that Brazil is a tropical country with favorable conditions for the proliferation of biodeteriorating organisms (Oliveira et al., 2018).

The inherent resistance of wood to biodeterioration is a critical factor that must be considered in civil and architectural projects. According to ABNT NBR 7190:1 (2022), prior to designing a timber structure, the conditions of the site must be assessed to determine the necessity for specific preservative treatments that enhance wood's resistance to organisms such as fungi, xylophagous insects, and marine borers.

Among the various groups of organisms capable of damaging wood, the drywood termite *Cryptotermes brevis* (of the Kalotermitidae family) is particularly noteworthy. These insects can thrive in low humidity conditions, around 10 to 12%, and are commonly found in domestic settings. They can attack furniture, books, wooden structures, chipboard, and plywood (Lepage et al., 2017; Maistrello, 2018). Due to the significant economic impact of damage caused by these termites, most studies on biodeterioration of wood focus on them (Fontenele et al., 2020; Gonçalves et al., 2013; Ribeiro et al., 2014; Terezo et al., 2017). Additionally, the Kalotermitidae family comprises more than 53 different termite species (Gonçalves and Oliveira, 2006).

Given that the majority of CLT panels in Brazil are made from pine wood, NBR 7190:1 (2022) stipulates that the lamellae must undergo treatment with preservative products to ensure durability and protection against biological factors, as per ABNT NBR 16143 (2013).

For wood treatment, Chromated Copper Arsenate (CCA) is the most widely used preservative worldwide (Ferrarini et al., 2016). Applied under pressure in an autoclave, CCA treatment is both effective and economically viable compared to other natural, thermal, and chemical treatments (Kima and Park, 2020). However, due to its high toxicity, CCA has been banned in many countries over the last decade. In Brazil, there are no records of restrictions or prohibitions on CCA usage, and this preservative accounts for roughly 80% of the treated wood volume in the country. Chromated Copper Borate (CCB) has emerged as an alternative to CCA, with boron replacing arsenic. CCB is also applied under pressure in an autoclave (Ferro et al., 2016; Moreschi, 2011).

In countries like the United States, where CCA usage is heavily restricted, Micronized Copper Azole Type C (MCA-C) is commonly employed for wood treatment. This treatment is also applied under pressure in an autoclave and offers benefits such as strong protection against deterioration organisms and a reduced presence of heavy metals (Lankone et al., 2019). In Europe, Impralit KDS-B is used as wood preservative. It is applied under pressure and is based on copper salts and betaine polymer.

Given the increasing usage of engineered wood components in Brazilian civil construction, often produced from reforested coniferous wood, and the need for preservative treatment to enhance its resistance to biodeterioration, this study aims to evaluate the resistance of pine species with various preservative treatments and retentions against attacks by drywood termites.

2. MATERIALS AND METHODS

Tests of resistance to dry wood termite attack were conducted at the Laboratory of Technology and Performance of Constructive Systems (LTDC) at São Paulo State Technological Research Institute (IPT).

Wood specimens from pine and spruce species (*Pinus abies*, *Pinus sylvestris*, *Pinus taeda*, and *Pinus elliottii*) from Austria and Brazil were subjected to testing. During the tests, the contracting company

Table 1 – Experimental conditions of the study.
Tabela 1 *– Condições experimentais do estudo.*

Wood Species	Condition	Preservative	Retention
Austrian Spruce (*Picea abies*)	Untreated	-	-
Austrian KLH Pine (*Pinus sylvestris*)	Untreated	-	-
Austrian KLH Pine *Pinus sylvestris*)	Autoclave	Impralit KDS-B	5 kg/m^3
Austrian KLH Pine (*Pinus sylvestris*)	Autoclave	Impralit KDS-B	10 kg/m^3
Brazilian Pine *(Pinus taeda/elliottii*)	Autoclave	CCA	4 kg/m^3
Brazilian Pine (*(Pinus taeda/elliottii*)	Autoclave	CCA	6,5 kg/m^3
Brazilian Pine (*(Pinus taeda/elliottii*)	Autoclave	MCA-C	1 kg/m^3
Brazilian Pine (*(Pinus taeda/elliottii*)	Autoclave	MCA-C	2,4 kg/m^3
Brazilian Pine (*(Pinus taeda/elliottii*)	Autoclave	CCB	4 kg/m^3
Brazilian Pine (*(Pinus taeda/elliottii*)	Autoclave	CCB	6,5 kg/m^3
Brazilian Pine (*(Pinus taeda/elliottii*)	Superficial	HQC 791	1 coat (300ml/m^2/coat)
Control - Brazilian Pine (*(Pinus taeda/elliottii*)	Untreated	Untreated	-

(Amata/Urbem) was importing structural elements of engineered wood from the Austrian manufacturer KLH. Technological Research Institute (IPT) was requested to include lamellas of the same species used in the imported structural elements for analysis.

The specimens underwent different treatment conditions (autoclave and surface treatments) using various types of preservatives (Impralit KDS-B, CCA, CCB, MCA-C, and HQC 791, a fire retardant for wood), along with different retentions. Untreated specimens were also tested, resulting in a total of 12 experimental conditions (Table 1).

When retentions were not defined by standards, they were determined in collaboration with the technical managers of Technological Research Institute (IPT). This was done in consultation with the supplier and producer of engineered wood structural elements, following the guidelines of ABNT 16143:2013 – Preservation of Wood and technical information provided by the preservative product manufacturers. A control group, untreated with preservatives, was also maintained.

The specimen dimensions were 2.3 cm x 0.6 cm x 7.0 cm, following Technological Research Institute (IPT) technical guidelines.

The treatments of Brazilian Pine specimens with CCA, CCB, and MCA-C were conducted in an IPT-owned pilot autoclave. An initial vacuum of 610 mmHg (81.33 kPa) was applied for 30 minutes, and the retention was calculated based on the amount of preservative solution absorbed by the specimen. Application of the HQC 791 product was done through brushing, following manufacturer's recommendations.

The tests followed the procedures outlined in the document “Standard Method of IPT – Publication IPT No. 1157 – Part D/D2, 1980”, procedure IPT 2230 – “Resistance to attack by dry wood termites”, revision 5. Specimens were paired and joined using adhesive tape, and a glass glove was fixed in the center of each specimen to delimit the area to be attacked by the termites. Each glove contained 40 dry wood termites of the *Cryptotermes brevis* species (Kalotermitidae family), including 39 workers and one soldier.

The specimens were exposed to termites on their surface or normal face for 45 days, with periodic observations conducted within a climatic chamber.

At the end of the tests, the wear caused by termites was assessed (Table 2). Grades ranging from 0 to 4 were assigned by Technological Research Institute (IPT), based on specified criteria. Grade 0 indicated no wear, grade 4 represented significant wear on the control group specimens, and grades 1 to 3 indicated various levels of wear in between (as in Figure 1).

To determine the degree of wear's aggressiveness, factors such as the percentage of dead termites and number of holes in the specimens were evaluated, following IPT's established methodology.

Table 2 – Evaluation of wood degradation.
Tabela 2 *– Avaliação da degradação da madeira.*

Grade	Evaluation
0	No wear
1	Superficial or incipient wear
2	Moderate wear
3	Accentuated wear
4	Deep wear (similar to control group)

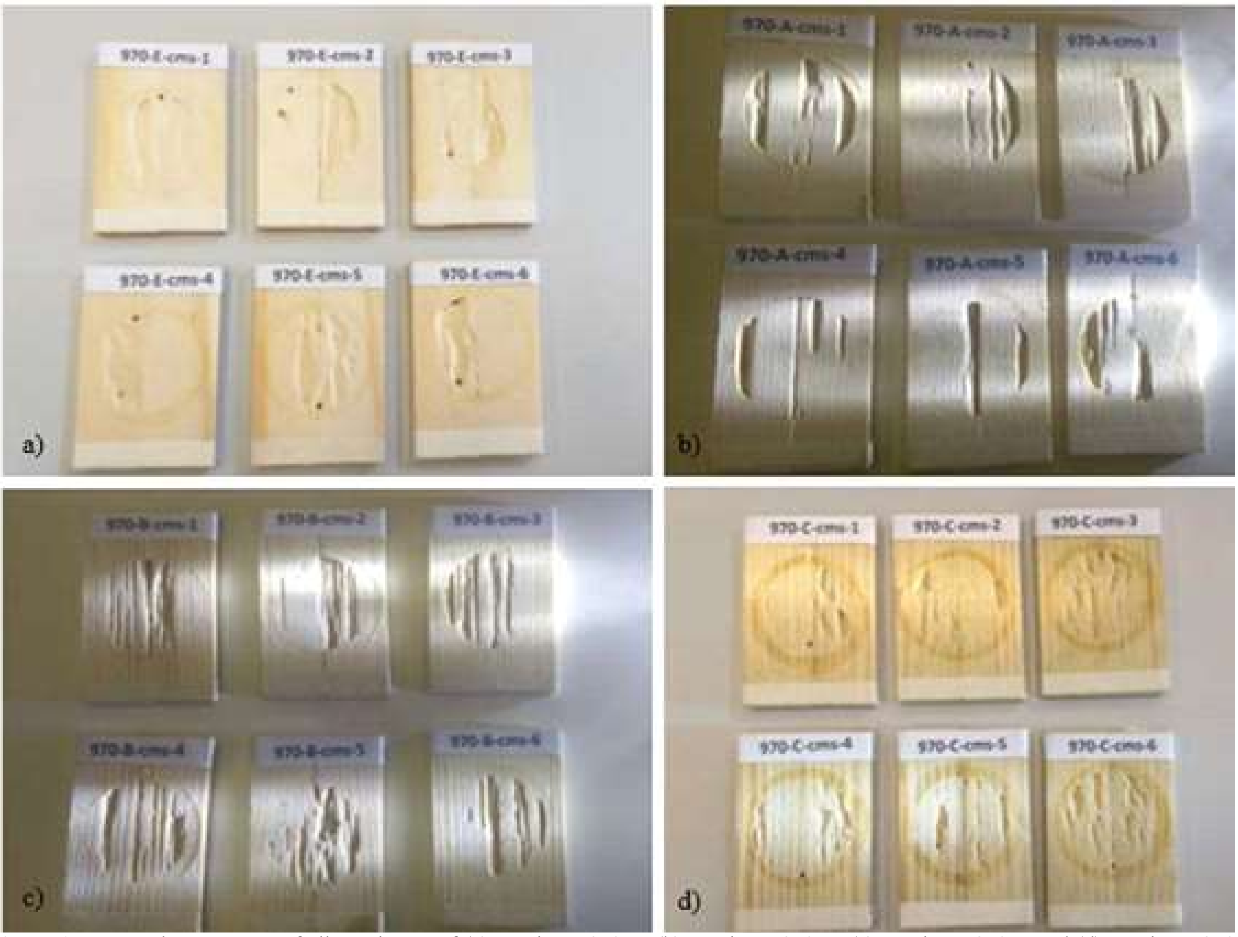

Figure 1 – General appearance of all specimens of (a) specimen 970 E; (b) specimen 970 A; (c) specimen 970 B and (d) specimen 970 C - after exposure to dry wood termite attack, for a period of 45 days: detail of wear caused by termites. Source: Technological Research Institute (IPT) test report Nº. 1 136 740-203.

Figura 1 *– Aparência geral de todos os corpos de prova de (a) corpo de prova 970 E; (b) corpo de prova 970 A; (c) corpo de prova 970 B e (d) corpo de prova 970 C - após exposição ao ataque de cupins de madeira seca, por um período de 45 dias: detalhe do desgaste causado por cupins. Fonte: Relatório do IPT nº 1 136 740-203.*

The results of specimen wear due to dry wood termite attacks and the mortality rate were statistically analyzed at a 95% confidence level using non-parametric methods: Kruskal-Wallis to investigate statistical differences between specimens and Mann-Whitney for pairwise comparisons between tested specimens.

The Kruskal-Wallis test is a non-parametric analysis used to compare three or more independent specimens, assessing differences between at least two of them by transforming numerical values into ranks. Group comparison involves the use of average ranks.

The Mann-Whitney test is employed for comparing two unpaired groups, determining whether they belong to the same population. This analysis involves comparing group values and evaluating the degree of separation between them.

3. RESULTS

Table 3 below presents the calculated average preservative retentions in the wood after specimen treatment in the autoclave, alongside the targeted retentions.

It is evident from Table 3 that the obtained retentions (calculated average retention) were similar to the intended retentions, indicating the effectiveness of the preservative treatment. This outcome holds

Table 3 – Preservative retention in wood.
Tabela 3 *– Retenção do preservativo na madeira.*

Preservative treatment	Aimed Retention (kg/m³)	Calculated Average Retention (kg/m³)	Standard deviation	Number of specimens
CCA	4	4,03	0,1522	17
CCA	6,5	6,54	0,1365	13
CCB	4	4,18	0,0929	12
CCB	6,5	6,44	0,1669	13
MCAC	1	1,09	0,1204	21
MCAC	2,4	2,48	0,1290	14

significance, as inefficient treatment can heighten wood's susceptibility to dry wood termites.

For the CCA and CCB preservatives employed in pressure treatments, the recommended retentions are 4 kg/m^3 for wood not in contact with the ground and 6.4 kg/m^3 for wood in ground contact, assuming 100% permeable wood portion (ABNT NBR 16143, 2013). As for MCA-C retention, the aforementioned standard suggests 0.8 to 2.4 kg/m^3, contingent on the installation location (greater or lesser ground contact).

It's important to note that specimens treated with Impralit KDS-B were purchased pre-treated; consequently, their retentions couldn't be measured.

Results encompassing wear, the number of holes in specimens, termite mortality rate, and test duration following exposure to dry wood termite attack are provided in Table 4.

Table 4 underscores that the trial extended for 45 days across all tested treatment conditions. Except for the HQC 791 superficially treated specimen—displaying no wear—specimens suffered various degrees of damage, ranging from level 1 (superficial wear only) to level 4 (deep wear). Notably, HQC 791 application resulted in complete termite mortality (100%). Proper superficial product application, ensuring comprehensive surface coverage, coupled with a high concentration of 300 ml/m^2 and wood's good permeability, conferred enhanced resistance to termite attack. For other treatments, mortality rates ranged from 26.7% to 90.4%, with distinct preservative retentions within wood exerting no significant impact on these results.

Observing Table 4, concerning termite-induced wear, untreated Austrian KLH Pine and Austrian Fir, along with Pine specimens treated with Impralit KDS-B (5 kg/m^3 retention), exhibited no statistically significant difference from the untreated Brazilian Pine control group, displaying substantial wear. In terms of termite mortality in these conditions, the Austrian

Table 4 – Results of dry wood termite resistance test.
Tabela 4 *–Resultados do teste de resitência ao ataque de cupins da madeira seca.*

Wood Species	Condition	Wear (*)	Mortality (%) (**)	Holes (average)	Duration (days)
Austrian Spruce(*Picea abies*)	Untreated	4 [a]	32,1 [1,2,6]	0	45
Austrian KLH Pine(*Pinus sylvestris*)	Untreated	4 [a]	29,2 [2,6]	0	45
Austrian KLH Pine(*Pinus sylvestris*)	Impralit KDS-B 5kg/m³	4 [a]	37,9 [1,3]	0	45
Austrian KLH Pine(*Pinus sylvestris*)	Impralit KDS-B10 kg/m³	2 [c]	35,4 [1,2,4]	0,67	45
Brazilian Pine(*Pinus taeda/elliottii*)	CCA 4,0 kg/m³	1 [b]	90,4 [5]	0	45
Brazilian Pine (*Pinus taeda/elliottii*)	CCA 6,5 kg/m³	1 [b]	88,8 [5]	0	45
Brazilian Pine (*Pinus taeda/elliottii*)	MCA-C 1,0 kg/m³	2 [c]	26,7 [6]	0	45
Brazilian Pine (*Pinus taeda/elliottii*)	MCA-C 2,4 kg/m³	2 [c]	29,6 [2,6]	0,2	45
Brazilian Pine (*Pinus taeda/elliottii*)	CCB 4 kg/m³	2 [c]	44,2 [1,7]	0	45
Brazilian Pine (*Pinus taeda/elliottii*)	CCB 6,5 kg/m³	2 [c]	44,2 [3,4,7]	0	45
Brazilian Pine (*Pinus taeda/elliottii*)	Superficial HQC 791 300ml/m²	0	100	0	45
Brazilian Pine – control (*Pinus taeda/elliottii*)	Untreated	4 [a]	31,7 [1,2,6,7]	0,17	45

(*) - Kruskal-Wallis ($p=2,009 \times 10^{-10}$); Mann-Whitney - means followed by the same letter do not differ statistically.
(**) - Kruskal-Wallis ($p= 9,34 \times 10^{-8}$); Mann-Whitney - means followed by the same number do not differ statistically.
(*) - Kruskal-Wallis ($p=2,009 \times 10^{-10}$); Mann-Whitney - médias seguidas pela mesma letra não diferem estatisticamente.
(**) - Kruskal-Wallis ($p= 9,34 \times 10^{-8}$); Mann-Whitney - médias seguidas pelo mesmo número não diferem estatisticamente.

KLH Pine specimen diverged statistically from those treated with Impralit KDS-B (37.9%) and the control (31.7%). However, its mortality was comparable to untreated Austrian Fir (32.1%). The differentiation in the untreated specimen's outcome could relate to the slightly lower apparent density of the *Pinus sylvestris* species in comparison to others.

Brazilian Pine treated with CCB (retentions of 4 and 6.5 kg/m^3) and MCA-C (retentions of 1.0 and 2.4 kg/m^3) exhibited moderate wear (level 2), with no statistical difference between them. Yet, the CCB preservative showcased heightened resistance against termite attack, averaging a 44.2% mortality rate, while MCA-C's average mortality was 28.15%.

Conversely, Brazilian Pine treated with CCA, at both 4 and 6.5 kg/m^3 retentions, experienced only superficial wear (level 1), demonstrating no significant difference between them. In contrast to other treated specimens, they exhibited greater resistance compared to CCB and Impralit KDS-B treatments. CCA treatment demonstrated efficacy relative to the others, with an average termite mortality rate of 89%, affirming the preservative's efficiency.

4. DISCUSSION

Terezo et al. (2017) examined the resistance of untreated and CCA-treated Paricá wood (Schizolobium amazonicum) against drywood termite attack. Their findings demonstrated that the preservative treatment resulted in a termite mortality rate of 75% and an absence of holes. This underscores the necessity of treating the species when it's intended for structural use. A similar outcome is observed in this study, where results indicate that preservative treatment is essential for all conifer species under investigation.

Ferro et al. (2016) assessed the resistance of Oriented Strand Board (OSB) panels treated with CCA, CCB, and left untreated, against drywood termite attack. The authors determined that the CCA preservative exhibited superior efficiency compared to others, evidenced by a higher termite mortality rate. This aligns with the results seen in the current study.

From Table 4, only the following specimens: control Brazilian Pine (*Pinus taeda* and *Pinus elliottii*), Austrian KLH Pine (*Pinus sylvestris*) with Impralit KDS-B retention of 10 kg/m^3, and Brazilian Pine (*Pinus taeda* and *Pinus elliot*) treated with MCA-C retention of 2.4 kg/m^3, displayed insect-made holes in the dry wood after the 45-day test period.

Images detailing the appearance of the specimens are provided below.

With the exception of the control group (without treatment), this outcome suggests that the fixation of the preservative within the wood may have occurred unevenly and ineffectively, from the surface toward the interior.

Oliveira et al. (2018) emphasized the significance of implementing a quality control process for pressure-treated lamellae used in CLT production, particularly given the more conducive rotting conditions in Brazil. In their study, the authors observed that CCB-treated wood utilized by a Brazilian CLT manufacturer exhibited inadequate retention and penetration in a majority of tested specimens. Inefficient treatment might have occurred in specimens treated with Impralit KDS-B at 10 kg/m^3 and MCA-C at 2.4 kg/m^3 retention. While these specimens theoretically possess higher preservative component retention, they display holes, underscoring treatment inefficiency when compared to the same preservative at a lower retention level.

5. CONCLUSION

As anticipated, untreated specimens exhibited the highest level of wear (grade 4), akin to the control group.

The conducted tests illustrate that among the examined products, CCA treatment is the most efficient, yielding superficial or incipient wear (grade 1). CCB, MCAC, and Impralit KDS-B products with a retention of 2 (10 kg/m^3) produced results within the same range, displaying moderate wear (grade 2). Notably, the limited protective efficacy of Impralit KDS-B with a retention of 1 (5 kg/m^3) is apparent, presenting a wear degree akin to untreated specimens.

Given that Impralit KDS-B has not yet been approved by ANVISA or listed in NBR 16143 (2013) – Wood Preservation, this article will, for practical purposes, confine the comparison to MCAC and CCB products—both accessible in the Brazilian market.

The MCAC product (comprising tebuconazole, propiconazole, and micronized copper) has been deemed a more sustainable alternative to traditional products like CCA (chromated copper arsenate) and

CCB (chromated copper borate), attributed to its lower prevalence of heavy metals (chromium and arsenic). The results from these tests affirm that MCAC indeed presents itself as a technical alternative for wood preservation against termite attack relative to CCB. However, among the three products, CCA continues to manifest greater protective efficacy.

The influence of retention on the wear degree is also highlighted. In most cases, raising the retention of the impregnated product doesn't correspondingly enhance the wear degree of the specimen, with the exception of Impralit KDS-B, as noted earlier.

For CCA, CCB, and MCAC, based on the results elucidated in this article, escalating the retention of the impregnated product cannot be deemed an effective strategy to heighten wood protection against termite attack.

Additionally, the performance of the HQC791 product, when applied to the surface, deserves special mention. NBR 16143 (2013) – Preservation of Wood advocates for impregnation treatment in an autoclave for wood structural elements with low inherent durability, such as pine. Nonetheless, the aforementioned product can be recommended as a strategy to augment protection against termite attacks, applied superficially to parts that have already undergone autoclave impregnation, particularly in regions where termite presence or their aggressive potential raises concerns.

AUTHOR CONTRIBUTIONS

AB structured the article and the theoretical framework. FO provided guidance for the research of which this article is a part. FI and MV defined the scope of the trial and oversaw its execution.

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