LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL

PROJECT "CIRCULARBUILD" – STUDY OF THE DURABILITY OF THE PANEL CLADDING PLATE

REPORT 89/**2023 – DE/NCE**

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PROJECT "CIRCULARBUILD" – STUDY OF THE DURABILITY OF THE PANEL CLADDING PLATE

Project CircularBuild - Development and Validation of the Concept of Circularity Applied to Modular Prefabricated Construction

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R&D STRUCTURES

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Title

PROJECT "CIRCULARBUILD" – STUDY OF THE DURABILITY OF THE PANEL CLADDING PLATE

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STUDY OF THE DURABILITY OF THE PANEL CLADDING PLATE

Abstract

The project CircularBuild - “Development and Validation of the Concept of Circularity Applied to Modular Prefabricated Construction” aims to investigate solutions based on alternative materials for the panels of the prefabricated modular system, in a perspective of circularity, allowing total reuse of the waste generated, without compromising the building performance, namely in terms of energy efficiency. The promoter was CONCEXEC – Arquitectura, Lda (Portugal), and Laboratório Nacional de Engenharia Civil, I.P. (LNEC; Portugal) was one of the partners. The LNEC’s Prevention of Biodeterioration Unit (LNEC/UPB) team was responsible for the evaluation of the biological susceptibility of the panel cladding within the task T3.1: Study of the durability of the panel cladding plate. The laboratory evaluation of the biological durability of the materials was conducted on the bio-based material chosen within this project: AGEPAN® DWD PROTECT (16 mm thickness). Some tests were selected to evaluate the durability of this material: 1) swelling in thickness after immersion in water, and the resistance of the board against 2) moulds and 3) decay fungi, including 4) soft rot, and 5) the resistance against subterranean termites as a model for insect deterioration. Parallel tests after leaching of the board samples were also conducted to assess the importance of water on the biological deterioration mechanisms. The AGEPAN® DWD PROTECT resistance against moisture penetration was confirmed through the results of the swelling in thickness test performed. Under the test conditions, the samples of AGEPAN® DWD PROTECT were considered susceptible to mould growth, and highly susceptible to decay fungi, particularly to brown rots and soft rot. The material was also highly susceptible to subterranean termites, which were able to cross the material and to feed on it. The results obtained demonstrate a weak resistance of the tested plate to biological degradation under high moisture situations. The material tested, according to the results obtained in this report, should therefore always be protected from moisture when applied.

Keywords: Biological durability / AGEPAN® DWD PROTECT / Decay fungi / Subterranean termites / Moulds

ESTUDO DA DURABILIDADE DA PLACA DE REVESTIMENTO DO PAINEL

Resumo

O projeto CircularBuild - “Desenvolvimento e Validação do Conceito de Circularidade Aplicado à Construção Pré-fabricada Modular” tinha como objetivo investigar soluções baseadas em materiais alternativos para os painéis do sistema modular pré-fabricado, numa perspetiva de circularidade, permitindo a total reutilização dos resíduos gerados, sem comprometer o desempenho do edifício, nomeadamente em termos de eficiência energética. A entidade promotora foi a CONCEXEC – Arquitectura, Lda (Portugal), e o Laboratório Nacional de Engenharia Civil, I.P. (LNEC; Portugal) foi um dos parceiros. A equipa da Unidade de Prevenção da Biodeterioração do LNEC (LNEC/UPB) foi

responsável pela avaliação da suscetibilidade biológica do painel de revestimento no âmbito da tarefa T3.1: Estudo da durabilidade da placa de revestimento do painel. A avaliação laboratorial da durabilidade biológica dos materiais foi realizada utilizando o material de base biológica escolhido no âmbito deste projeto: AGEPAN® DWD PROTECT (com 16 mm de espessura). Alguns testes foram efetuados para avaliar a durabilidade deste material: 1) inchamento em espessura após imersão em água, a resistência da placa contra 2) bolores e 3) fungos de podridão, incluindo 4) podridão mole, e 5) a resistência contra térmitas subterrâneas como modelo de deterioração por insetos. Testes paralelos após a lixiviação das amostras do material em questão também foram efetuados para avaliar a importância da água nos mecanismos de deterioração biológica. A resistência do AGEPAN® DWD PROTECT relativamente à penetração de água foi positivamente confirmada através dos resultados do teste de inchamento em espessura realizado. Nas condições dos testes, as amostras de AGEPAN® DWD PROTECT foram consideradas suscetíveis ao crescimento de fungos, e altamente suscetíveis a fungos de podridão, particularmente a fungos de podridão castanha e de podridão mole. O material também demonstrou ser altamente suscetível a térmitas subterrâneas, que conseguiram atravessar o material e alimentar-se dele. Os resultados obtidos demonstram uma fraca resistência da placa testada à degradação biológica em situações de exposição a elevada humidade. O material testado, de acordo com os resultados obtidos neste relatório, deve, portanto, ser protegido da humidade quando aplicado.

Palavras-chave: Durabilidade biológica / AGEPAN® DWD PROTECT / Fungos de podridão / Térmitas subterrâneas / Bolores

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1 | Introduction

The project CircularBuild - “Development and Validation of the Concept of Circularity Applied to Modular Prefabricated Construction” aims to investigate solutions based on alternative materials for the panels of the prefabricated modular system of CONCEXEC - Arquitetura, Lda., in a perspective of circularity, allowing total reuse of the waste generated, without compromising the building performance, namely in terms of energy efficiency, consequently contributing to the new paradigm of "Zero Carbon Buildings". This project is funded by the program: European Economic Area (EEA) Financial Mechanism 2014-2021, Environment Programme (EEA grants). The promoter was CONCEXEC – Arquitectura, Lda (Portugal), and the partners were: Cluster Habitat Sustentável (Portugal), Laboratório Nacional de Engenharia Civil, I.P. (LNEC; Portugal), and RISE Fire Research (Norway).

CONCEXEC has developed a constructive technology with the following characteristics: Modular prefabrication; Industrialized, sustainable and evolutive; With almost zero energy needs; According to Circular Economy (with the optimization of the waste produced, and with the reuse and reintegration of waste as raw material); Environmentally friendly, with clean and safe performance; Optimization of production costs/time and labor (green jobs).

The objectives of this project were:

- To investigate alternative materials for the constructive system described above;
- Foster the complete circularity of the system;
- Completely reuse the waste generated by the "deconstruction" of buildings, as a raw material for new panels and new constructions;
- Maintain the energy efficiency performance of the buildings.

The plan of activities of the project CircularBuild was distributed over 24 months, starting on 10-01-2020 and ending on 30-09-2022 (meanwhile, a time extension until 30-03-2023 was authorized). The tasks were defined as: Activity A1: Study and Definition of Functional Requirements for Alternative Materials; Activity A2: Adaptation of the Production Process and Industrial Validation; Activity A3: Functional Validation Tests – Laboratory scope; Activity A4: Construction “CircularBuild”; Activity A5: Promotion and Dissemination of Results and Activity A6: Project Management.

The LNEC’s Prevention of Biodeterioration Unit (LNEC/UPB) team was responsible for the evaluation of the biological susceptibility of the panel cladding within task T3.1: Study of the durability of the panel cladding plate. The laboratory evaluation of the biological durability of the materials was conducted on the bio-based material chosen within this project: AGEPAN® DWD PROTECT (16 mm thickness).

Considering the importance of water in the durability of the materials, a number of tests were selected to evaluate the durability of the chosen material, namely: 1) swelling in thickness after immersion in water, and the resistance of the board against 2) moulds and 3) decay fungi, including 4) soft rot, and 5) the resistance against subterranean termites as a model for insect deterioration. Parallel tests after

leaching of the tested samples were also conducted to further assess the importance of water on the biological deterioration mechanisms.

This report focuses on the results obtained from all the tests performed at LNEC/UPB regarding the evaluation of the biological durability of the bio-based material studied within this project and gives guidance on the adequate application of the material.

2 | Materials and methods

2.1 Swelling in thickness

According to its technical sheet (Anon,2018), the AGEPAN® DWD PROTECT offers resistance against moisture penetration due to an improved surface. This was confirmed by testing in laboratory according to EN317 (1993), using ten replicate samples of AGEPAN® DWD PROTECT boards, with the dimensions of 50 x 50 x 16 mm. Figure 2.1 illustrates the immersion step of the method applied.

Figure 2.1 – Swelling in thickness test. Samples under immersion

2.2 Resistance to moulds

The susceptibility to mould growth of the AGEPAN® DWD PROTECT boards was evaluated by exposure to a saturated environment (near 100 % relative humidity) for four weeks in a culturing chamber (T = 22ºC ± 1ºC and 70 % ± 5 % relative humidity). Nine replicates (40 x 40 x 16 mm) were tested. Three maritime pine (*Pinus pinaster* Ait.) samples (30 x 10 x 10 mm) were included as controls.

All specimens and controls were visually rated for mould growth at the end of the test, using the scale defined in ASTM D5590-17 (2017): 0 = no growth; 1 = less than 10 % of sample surface affected; 2 = 10 % to 30 %; 3 = 30 % to 60 %; 4 = > 60 %. The specimens and controls were carefully removed from the test flasks and the final percentage of contaminated surface was evaluated using a stereo microscope Olympus B061.

2.3 Resistance to wood decay fungi

The susceptibility to decay fungi was evaluated according to an adaptation of EN113-3 (2023) using smaller samples (miniblocks – figure 2.2). Eight replicates of AGEPAN® DWD PROTECT (30 x 10 x 16 mm), and of maritime pine and beech (*Fagus sylvatica* L.) (30 x 10 x 10 mm), were exposed (with and

without an aging procedure according to EN84 (2020)) for eight weeks to pure cultures of each of the three fungi, *Coriolus versicolor* (L.) Quél. (white rot), *Rhodonia placenta* (Fr.) Niemelä, K.H. Larss. & Schigel (brown rot) and *Gloeophyllum trabeum* (Pers.) Murrill. (brown rot). Maritime pine and beech were used as controls for brown rots and white rots, respectively.

At the end of the exposure time the final moisture content of the samples and the mass loss due to the fungi were evaluated. The initial moisture content was 8 % for the panel (n=10), 13 % for maritime pine (n=3), and 11 % for beech (n=3).

Figure 2.2 – Durability against wood rotting fungi (miniblocks): example with exposure to *C. versicolor*

2.4 Resistance to soft rot fungi

To test the resistance of the AGEPAN® DWD PROTECT panel against soft rot fungi, an adapted method based on EN113-2 (2020) (with and without an aging procedure according to EN84 (2020)), thirty mini stakes (100 x 10 x 16 mm) were placed half dipped in an unsterile soil of known water absorption capacity (53.25 %) (Figure 2.3). Fifteen of those stakes were submitted to a leaching procedure prior to the test. Controls of maritime pine (100 x 10 x 5 mm) were also introduced in the vessels. The test ran for 24 weeks, and stakes were collected and evaluated after 12 (n=5) and 24 (n=10) weeks of exposure. Mass loss (in % of initial dry mass), final moisture content (%), and level of attack were used to evaluate the resistance of the panel in comparison to maritime pine.

The level of attack was adapted in accordance with the standard NP EN252 (1992), which defines the following ratings: 0 – no attack (no change perceptible); 1 – slight attack (perceptible changes, but very limited in their intensity and distribution, changes in colour and very superficial degradation, commonly softening of the specimen to an apparent depth of less than 1 mm); 2 – moderate attack (clear changes to a moderate extent, including the softening of the specimen to a depth of approximately 2 to 3 mm over all or part of the test specimen from the ground level zone and below); 3 – severe attack (severe changes as a marked decay in the specimen to a depth of 3 to 5 mm over a wide surface, including the ground level zone or below, or by softening of the specimen to a greater depth over a more limited area); 4 – failure (impact failure of the stake). The initial moisture content was 8 % (n=10) for the panel and 13 % for maritime pine (n=3).

Figure 2.3 – Resistance to soft rot fungi: Example of test adapted from EN113-2 (2020), with 24 weeks of exposure

2.5 Resistance to subterranean termites

The susceptibility to subterranean termites (*Reticulitermes grassei* Clément) was evaluated according to an adaptation of EN117 (2012) using smaller samples (miniblocks – figure 2.4). Ten replicates of AGEPAN® DWD PROTECT, with the dimensions of 30 x 10 x 16 mm, were exposed (with and without an aging procedure according to EN84 (2020)) to groups of 150 termite workers, for four weeks (Figure 2.4). Maritime pine was used as control (n=6), with the dimensions of 30 x 10 x 10 mm.

The ability of the termites to cross the material was further evaluated using EN118 (2013) (Figure 2.4) with eight weeks of exposure. This was evaluated using ten replicates of AGEPAN® DWD PROTECT, with the dimensions of 50 x 50 x 16 mm. Three replicates of maritime pine (60 x 40 x 10 mm) were also tested as control. Groups of 250 termite workers were established on glass tubes and placed in contact with the test samples (Figure 2.4)

After both tests, termite survival (%) was registered, as well as the degree of attack by termites of the samples, according with the visual examination classification proposed in EN117 (2012) and EN118 (2013): 0 – no attack, 1 – attempted attack, 2, slight attack, 3 – average attack, and 4 – strong attack.

Figure 2.4 – Durability against subterranean termites: Examples of the exposure conditions of the test adapted from EN117 (2012; left) and of the test according to EN118 (2013; right)

3 | Results and Discussion

3.1 Swelling in thickness

The following table 3.1 presents the results of swelling (%) and mass variation (%) obtained after immersion of the samples in water for 24 hours.

Table 3.1 – Swelling (%) and mass variation (%) after immersion in water for 24 hours

Sample	Swelling (24h) (%)	Mass variation (%)
1	6.81	22.32
2	6.86	22.74
3	7.02	21.32
4	6.96	21.56
5	6.91	22.76
6	6.81	22.27
7	6.78	22.28
8	7.10	22.34
9	6.99	23.22
10	7.09	23.16
Average	**6.93**	**22.40**
Standard Deviation	**0.12**	**0.62**

According to the Declaration of Performance of the product (Koerner, 2017) the expected maximum percentage of swelling should be 8.50 %. The average percentage of swelling in thickness obtained in this test was below that value (6.93 % ± 0.12 %) thus confirming the improved surface performance of AGEPAN® DWD PROTECT samples.

3.2 Resistance to moulds

The average grading for mould growth at the end of the test was 1.44 ± 0.53 for AGEPAN® DWD PROTECT samples, and 3.67 ± 0.58 for maritime pine samples. Figure 3.1 shows samples tested at the end of the exposure time.

Figure 3.1 – Aspect of AGEPAN® DWD PROTECT samples (n=9; at left) and maritime pine (n=3, at right) at the end of the test of resistance to moulds

Under the test conditions described the samples of AGEPAN® DWD PROTECT can be considered as moderately susceptible to mould growth.

3.3 Resistance to wood decay fungi

The average results of the decay test, including the final moisture content (%) and mass loss (%) of the samples after exposure to the different fungal species, are presented in table 3.2.

Table 3.2 – Average results of fungal decay test including final moisture content (%) and mass loss (%)

Fungal species	Samples	Final moisture content (%)	Mass loss (%)
Coriolus versicolor	Control (beech)	53.84 ± 18.62	21.16 ± 13.97
	AGEPAN® DWD PROTECT	44.51 ± 3.88	8.88 ± 1.28
	AGEPAN® + Leaching	33.71 ± 3.93	2.77 ± 0.55
Rhodonia placenta	Control (maritime pine)	51.45 ± 11.28	17.22 ± 11.32
	AGEPAN® DWD PROTECT	83.45 ± 19.52	31.60 ± 6.02
	AGEPAN® + Leaching	49.21 ± 13.60	15.02 ± 11.21
Gloeophyllum trabeum	Control (maritime pine)	51.25 ± 19.85	8.25 ± 3.94
	AGEPAN® DWD PROTECT	62.06 ± 6.76	29.03 ± 3.43
	AGEPAN® + Leaching	51.41 ± 6.54	15.39 ± 7.59

Under the conditions of the test, although the results showed variability, which might be linked to the differences in the final moisture content, the samples of AGEPAN® DWD PROTECT demonstrated high susceptibility to decay fungi, particularly to brown rots.

3.4 Resistance to soft rot fungi

The results of the durability of AGEPAN® DWD PROTECT samples to soft rot fungi are presented in table 3.3, showing the average mass loss (%) of the samples at both exposure times: 12 weeks and 24 weeks. At the end of the exposure periods most samples had very high moisture contents between 100 and 150 %, and a clear change in its dimensions (Figures 3.2 and 3.3).

Table 3.3 – Average mass loss (%) results of the soft rot test

Samples	Time of exposure	
	12 weeks (n=5)	24 weeks (n=10)
Control (maritime pine)	0	5.47 ± 2.59
AGEPAN® DWD PROTECT	5.33 ± 0.20	10.41 ± 1.22
AGEPAN® + Leaching	6.98 ± 0.69	11.41 ± 1.46

Figure 3.2 – Aspect of the samples of AGEPAN® DWD PROTECT (first row), AGEPAN® DWD PROTECT submitted to leaching (second row), and maritime pine (third row), at the end of the soft rot test of 12 weeks of exposure time

Figure 3.3 – Aspect of the samples of AGEPAN® DWD PROTECT (first row), AGEPAN® DWD PROTECT submitted to leaching (second row), and maritime pine (third row), at the end of the soft rot test of 24 weeks of exposure time

The results obtained in this test demonstrate a weak resistance to soft rot of the tested panel under high moisture situations.

3.5 Resistance to subterranean termites

The susceptibility of AGEPAN® DWD PROTECT to subterranean termites was evaluated through an adaptation of EN117 (2012) using miniblocks (Figure 3.4). In the end of this test, moisture content (%) and mass loss (%) of the AGEPAN® DWD and maritime pine controls were calculated, as well as the average survival of the termites (%) and the grade of termite attack (0 to 4 scale) (Table 3.4). The ability of the termites to cross the material was further evaluated using EN118 (2013; Figures 3.5 and 3.6). The average survival of the termites (%) and the grade of termite attack (0 to 4 scale) are presented on table 3.5.

Figure 3.4 – Durability against subterranean termites: Aspect of the tested specimens - AGEPAN® DWD PROTECT samples in the first column, AGEPAN® DWD PROTECT samples submitted to leaching in the second column, and maritime pine in the third column (left image), and example of one sample of AGEPAN® DWD PROTECT submitted to leaching (right image) after the test adapted from EN117 (2012) showing extensive tunneling by the termites

Figure 3.5 – Durability against subterranean termites: Aspect of the end of the test adapted from EN118 (2013) with an AGEPAN® DWD PROTECT sample, and the termites installed in the sample

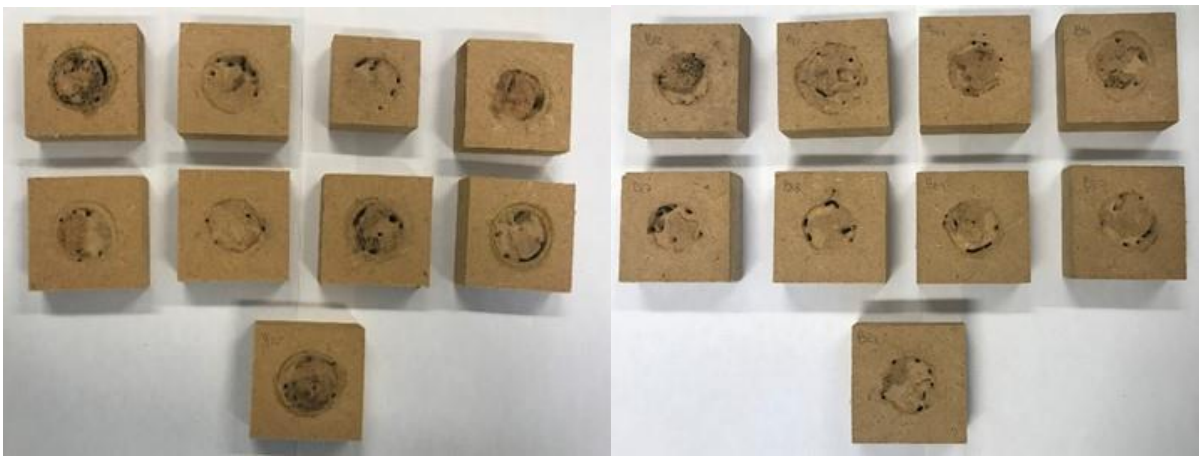

Figure 3.6 – Durability against subterranean termites: Aspect of the AGEPAN® DWD PROTECT samples (left image), and of the AGEPAN® DWD PROTECT samples submitted to leaching (right image) after the test adapted from EN118 (2013)

Table 3.4 – Average results of subterranean termite resistance test adapted from EN117 (2012), including final moisture content (%), mass loss (%), survival rate (%) and attack degree (scale: 0 to 4)

Samples	Final moisture content (%)	Mass loss (%)	Termite survival rate (%)	Attack degree
Control (maritime pine)	35.05 ± 8.71	5.00 ± 2.61	76.55 ± 6.41	4.00 ± 0.00
AGEPAN® DWD PROTECT	33.49 ± 2.13	3.21 ± 1.51	76.33 ± 9.38	4.00 ± 0.00
AGEPAN® + Leaching	32.34 ± 1.82	5.73 ± 1.74	60.20 ± 15.20	4.00 ± 0.00

Table 3.5 – Average results of subterranean termite resistance test adapted from EN118 (2013), including survival rate (%), and attack degree (scale: 0 to 4)

Samples	Termite survival rate (%)	Attack degree
Control (maritime pine)	57.20 ± 4.51	4.00 ± 0.00
AGEPAN® DWD PROTECT	55.05 ± 9.53	4.00 ± 0.00
AGEPAN® + Leaching	65.65 ± 5.12	4.00 ± 0.00

The results obtained for the controls allowed the validation of the tests conducted.

In both tests the susceptibility of the material to subterranean termites was very high, with average survival of the termites after the test above 50 % and grade of attack always reaching the highest level described in the standards (Tables 3.4 and 3.5).

In the conditions of these tests, it was demonstrated that, not only the termites are able to cross the material, but they also can feed on it and survive.

4 | Conclusions

Considering the characteristics of the durability against biological agents and the ability to absorb water of the samples of AGEPAN® DWD PROTECT in the different tests performed at LNEC/UPB, applications in permanent contact with a source of humidification (use class 4, EN335 (2013)) should be avoided, and applications in which occasional contact with a source of humidification is expected (use class 3, EN335 (2013)) should be carefully considered.

The material tested, according to the results obtained in this report, should therefore be protected from moisture when applied.

Lisbon, LNEC, March 2023

APPROVED

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