DURABILITY ASSESSMENT OF ECO-INNOVATIVE PANELS BASED ON ACCELERATED AGEING TESTS

Joana Maia[1*]
Andrea R. Souza[1]
André Vidal[1]
Pedro F. Pereira[1]
Rita C. Veloso[1,2]
João Ventura[1]
Roberta Moschetti[3]
Lars Gullbrekken[3]
Catarina Campos[4]
Nuno Cristelo[4]
Helena Corvacho[1]
Maria Lurdes Lopes[5]
Nuno M.M. Ramos[1]

[1] CONSTRUCT-LFC, Faculty of Engineering of the University of Porto|Portugal
[2] IFIMUP, Faculty of Sciences of the University of Porto|Portugal
[3] SINTEF Community, 7465 Trondheim |Norway
[4] Centro de Química - Vila Real, Universidade de Trás-os-Montes e Alto Douro|Portugal
[5] CONSTRUCT-GEO, Faculty of Engineering of the University of Porto|Portugal
Corresponding author: joanamaia@fe.up.pt

Keywords

Industrial waste; Façades; Sustainability; Durability.

Abstract

One of the challenges of climate change in the building sector is related to the durability of materials, i.e., the resistance to degradation due to weathering over time. Also, the application of new products and systems in building façades can contribute to a reduction of the building service life when a knowledge gap is stated. As such, the durability assessment during product development is a relevant aspect. The durability of building components can be assessed through long-term natural exposure or accelerated climate ageing in the laboratory. This article assesses the durability through accelerated ageing tests performed on different configurations of sandwich panels with a new waste-based alkali-activated core material for application in building façades. This work benefits from relevant experimental data of an ongoing research project, which is crucial for reliable results. The tests were performed in a climate simulator apparatus, according to the Nordtest method NT Build 495. The samples were tested for one month, corresponding to about one year of natural outdoor climate exposure. The results from the test performed in the climate simulator include information on the visual assessment of changes occurring during the analysed period, as well as the scale of such changes and the time of occurrence. Therefore, the first set of tests included a qualitative analysis considering that a change in the performance properties corresponds to a change in their appearance during the test. This includes, for instance, signs of degradation, such as cracks, loss of gloss, or delamination. The second batch of tests quantitatively analyses the most relevant properties, such as solar reflectance, colour, emissivity and liquid water permeability. The whole durability assessment procedure allowed to examine how accelerated ageing affects these new eco-innovative panels and contributed to increasing the knowledge of adequate testing methodologies.

1. INTRODUCTION

The durability of building materials and components has gained more significant interest in recent times, particularly in light of the looming challenges posed by climate change. The ability of materials to resist degradation resulting from long-term weathering can be evaluated through exposure to natural outdoor climates over an extended period or through appropriate accelerated climate ageing techniques carried out within a laboratory setting. Various apparatuses can be employed in laboratories to subject test samples to diverse climate exposures, using different ageing methods and standards [1].

Structural insulated panels (SIP) are made up of two oriented strand boards (OSB) boards, i.e., wood-based, surrounding the core insulation (usually EPS). Concerning their durability, the biggest problem is exposure to humidity, although a waterproof treatment is applied. Despite that, to study these degradation processes on SIP, the SIPA – Structural Insulated Panel Association carried out a durability assessment on SIP when exposed to distinct moisture conditions. The average results showed no significant loss of mechanical strength compared to the control sample [2].

Nanoparticles significantly affect the thermal behaviour of façades by reducing the surface temperature. Also, they allow the improvement of the characteristics of materials such as cement, increase the durability of composite materials, allow weight reduction, and confer antimicrobial, anti-corrosive, and self-cleaning properties to façades [3,4].

The production of building materials, in particular mortars, and the consequent management of their construction and demolition waste (RCD), has become an important issue worldwide due to the significant volume of waste generated annually by this industry, with a substantial contribution to carbon dioxide emissions into the atmosphere [5]. As such, there has been a growing concern to create new applications for this waste and waste from other industries in developing alkali-activated mixtures (i.e., without incorporating Portland cement). Its reuse alters the status of "waste", thus creating a "sub-product", generating a fundamental step towards waste management and control success and a direct contribution to the circular economy in the construction industry.

Considering a lack of durability assessment on these innovative systems, this article aims to show the results from an accelerated climatic ageing test (Nordtest method NT Build 495:2000) performed on different configurations of sandwich panels characterised by waste-based core materials and dark finishing coatings incorporating nanoparticles. This test was performed in SINTEF facilities on the ambitus of Circular2B – Circular Construction in Energy-efficient Modular Buildings, funded by the EEA grants. The project focuses on developing new waste-based materials, such as the sandwich panel core for SIP construction, by replacing the original insulation slab with an equivalent, incorporating residues, such as plastics, construction and demolition waste, and slag [6]. Also, the outer protection was given by applying an acrylic painting doped with nanoparticles [7].

2. MATERIALS AND METHODS

2.1. ECO-INNOVATIVE FAÇADE PANELS

Three different panel configurations were produced to assess the durability, as shown in Figure 1. These panels, developed under EEA Grants Circular2B project, have a new core material incorporating industrial wastes to replace the EPS slab. The same project also addressed the influence of nanoparticle inclusion in exterior coatings, which resulted in selecting a specific formulation/concentration.

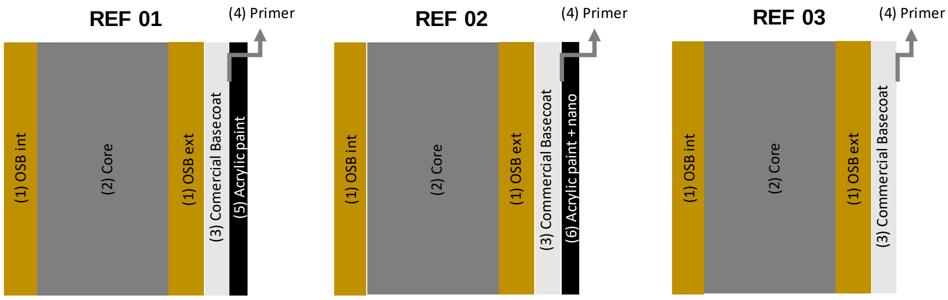

Figure 1. Schematic representation of the panel configurations.

The main characteristics of each layer are: (1) OSB board, 12 mm, 630 kg/m^3; (2) 15 cm thickness of a porous alkaline cement made of fly ash (90 % w/w), polyurethane (% 5 w/w), timber (% 5 w/w) and aluminium powder (< 0.1% w/w), alkali-activated with sodium hydroxide (NaOH, 3M) and sodium silicate (ratio of NaOH/silicate was 0.3), S/L=0.6 to obtain desirable workability; (3) 3/4 mm of a reinforced commercial mortar with mixed binders and specific aggregates and additives; (4) Universal aqueous primer; (5) Acrylic water-based paint (PBk7 index) and (6) with SiO_2 60-70 nm nanoparticles.

Three specimens of each configuration with 40 cm × 40 cm × 15 cm were produced. The core panel was assembled to the OSB boards using polyurethane glue.

2.2. ACCELERATED AGEING TEST

SINTEF Research Centre owns a climate simulator apparatus to perform ageing tests according to the Nordtest method NT Build 495:2000 [8]. This test was developed by SINTEF about 50 years ago. The method description was developed and later approved as the Nordtest method after many years of experience, including comparisons with natural climatic ageing of façade materials [9,10]. The specimens were subjected to accelerated ageing for one month, corresponding to about one year of natural outdoor climate exposure.

SINTEF's climate simulator is a non-commercial accelerated climate ageing apparatus in which test samples are subjected by rotation to four different climate zones. The first zone is an ultraviolet (UV) and infrared (IR) irradiation chamber, where UV radiation is applied using fluorescent UV tubes with a relative spectral distribution in the UV band close to that of global solar irradiance. The black panel's temperature reaches a designated value (normally 63 °C) within 45 minutes of UV light and heat radiation exposure. The black panel temperature may be chosen as 35±5 °C, 50±5 °C, or 75 ±5 °C, based on ISO 4892 [5]. The temperature is controlled using infrared halogen lamps and the UV intensity can vary at different levels depending on the choice of the UV tubes. For instance, for one specific set of UV tubes, the UVA and UVB intensities are averaged to 15 W/m^2 and 1.5 W/m^2, respectively. The second zone is a water spray zone, where the specimens are wetted with a spray of demineralised water. The suggested strain is 15 $dm^3/m^2/h$, but several spraying conditions may be used. Furthermore, to allow water to drip off the examined samples, the spraying is terminated 10 min before the rotation into the third zone. The third zone is a freezing zone, where an air temperature of -20±5 °C is suggested, but it is also possible to use other air temperatures if registered and reported. The fourth and last zone is the ambient laboratory thawing zone, where the specimens are thawed at the laboratory climate of 23±5 °C and 50% ± 10% relative humidity. The exposure time is 1 hour in each climate zone in the given sequence. The samples were prepared by sealing all the lateral faces with epoxy resin-based material, which means the front surface will be exposed to the climate simulator. The specimens were positioned in one of the four test faces in the mid-section of the climate simulator.

2.3. DURABILITY ASSESSMENT TESTS

The durability of the different sandwich panels was assessed by considering two approaches: a qualitative and quantitative analysis. The qualitative analysis consists of observing the changes occurring during the analysed period, the scale of such changes and the time of occurrence. This includes, for instance, signs of degradation, such as cracks, loss of gloss, or delamination. Quantitative analysis refers to performing different tests before and after the ageing cycles of the following properties: solar reflectance, colour, emissivity and liquid water permeability. The optical properties, such as reflectance and colour, were measured using a modular spectrophotometer according to ASTM E903 [10]. The CIE L*a*b colour coordinates, according to the Commission Internationale de l'Eclairage (CIE) [11], were determined using a 10º observed angle and D65 illuminant. Emissivity measurements were performed with an emissometer (Model AE1, Emittance Measurements) using a Port Adapter Model AE-ADP, following ASTM C1371 − 04a [12]. The L-shape Karsten tube method measured the liquid water permeability according to [13]. All tests comprised three measurements in each specimen.

3. RESULTS

3.1. QUALITATIVE ANALYSIS

Observing Figure 2, the effect of the acrylic paint absence in Ref 03 is evident since the surface presented several microcracks in contrast with Ref 01 and Ref 02, where few cracks were observed. Also, all the configurations exhibited stains, more prominent in the black coatings due to the water action, especially in REF 01. In addition, some of the samples in all configurations showed delamination of the front surface sealant, which could boost the degradation process.

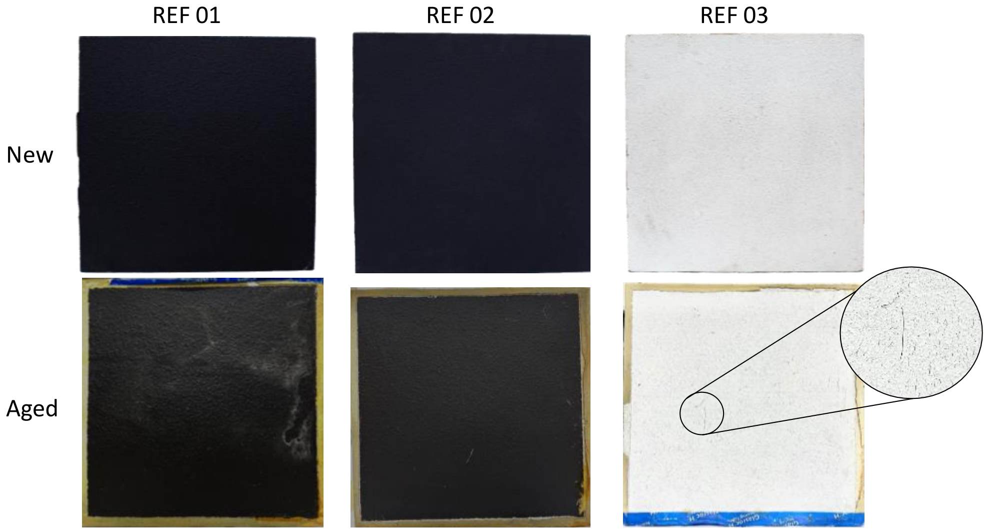

Figure 2. Visual aspect of the panels before and after ageing.

3.2. QUANTITATIVE ANALYSIS

Figure 3 presents the average values and the standard deviation of emissivity and total reflectance of the three configurations before and after the accelerated ageing exposure.

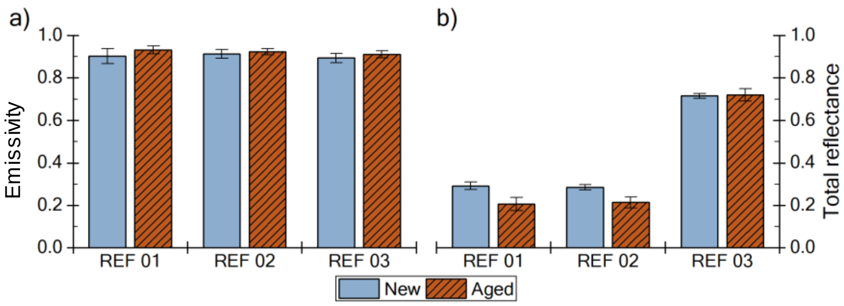

Figure 3. Initial and aged optical evaluation. a) Emissivity; b) Total reflectance.

The initial emissivity (Figure 3a) ranges between 0.89 and 0.91, increasing to 0.91-093 after ageing (orange bar), which is non-significant. Also, the values align with coatings and renders commonly applied in façades. The total reflectance (Figure 3b) reveals the finishing layer's aesthetic, where dark colours present total reflectance lower than 0.4 and white/light colours higher than 0.7 [14]. The ageing effect on REF 03 is also insignificant, while on dark colours, REF 01 and REF 02, the reflectance reduces by more than 25%. The degradation stimulated by the accelerated process (NORDTEST) preconises the natural degradation. In these terms, the founded results are similar to those found by [15], where the emissivity values are unaffected by climatic agents, i.g. temperature, humidity, or ice.

Aesthetical properties, like colour, can be related to coatings' reflectance and thermal performance. Table 1 details the colour CIELab coordinates and the total colour difference for the samples after accelerated ageing.

Table 1. Colour coordinates and total colour difference.

SAMPLE	CONDITION	L	a	b	COLOUR DIFFERENCE
REF 01	New	47.95 ± 1.056	0.73 ± 0.560	1.26 ± 0.987	-
	Aged	46.94 ± 1.753	0.72 ± 1.405	3.35 ± 1.241	2
REF 02	New	44.08 ± 1.983	2.71 ± 0.940	1.13 ± 1.650	-
	Aged	45.97 ± 1.647	1.66 ± 1.565	3.82 ± 1.132	3
REF 03	New	86.88 ± 0.286	-0.65 ± 0.250	0.42 ± 0.360	-
	Aged	88.48 ± 1.034	-0.83 ± 0.558	1.89 ± 0.686	2

The lightness of nanoparticle samples is lower than the reference coating, respectively REF 02 and REF 01. This effect was also observed in Ramos*, et al.* [16] and Cozza*, et al.* [17]. The total colour difference indicates the colour perception imposed by the degradation, which, in this study, does not produce a significant modification to be perceptible for the human eye (higher than 3) [17]. The opposite effect is highlighted on lightness (L) since it was expected that the dark sample (REF 01 and REF 02) would become lighter and the white one (REF 03) darker (lower lightness). However, the observed increase is little.

Regarding liquid water permeability, measured through the Karsten tube method, all the configurations did not absorb water under low pressure (volume of absorbed water = 0 ml). The ageing process did not affect the coatings when the acrylic paint was applied (REF 01 and REF 02) since no water was absorbed too. However, REF 03 registered a total volume of 0.07 ml at the end of the test (60 minutes). This was expected regarding the characteristics of the universal primer and the microcracks observed in REF 03.

4. CONCLUSIONS

The durability of sandwich panels with a new waste-based alkali-activated core material for application in building façades was assessed in the present work through accelerated ageing tests. The novelty in using highly porous alkali-activated cement as core sandwich panel insulation highlighted the need to test several properties, where durability is a crucial aspect regarding the service life of façades. Also, substituting insulation boards, such as EPS, with a waste-based core panel may reduce the amount of plastic in building construction, leading to a new construction paradigm. The selected accelerated ageing process – Nordtest method NT Build 495 – is widely used in Norway, which evidence the experience and reliability of the results. Generally, the ageing cycles promoted overall degradation in the surface of the different configurations. Through the qualitative analysis, it was possible to confirm the importance of the finishing layer, such as the acrylic paint, since it protects the façade from water penetration by reducing cracking, for example. From the quantitative analysis, the solar reflectance of the dark coatings presented a significant reduction, which was not observed with the white primer, as expected. Also, the ageing procedures did not significantly affect the colour. The inclusion of nanoparticles did not demonstrate an apparent effect on the durability in terms of quantitative evaluation, despite the low amount of stains. The new waste-based panels are intended to be a sustainable alternative to traditional sandwich panels for SIP construction. The preliminary results showed their potential and highlighted the importance of continuing the research and testing of such eco-innovative building solutions, taking into account the system as a whole, which means the new core material and the outer layers.

Acknowledgements

This work was financially supported by project Circular 2B – 37 CALL#2 – Circular Construction in Energy-Efficient Modular Buildings, financed under the Environment, Climate Change and Low Carbon Economy Programme, and within the scope of the European Economic Area Financial Mechanism – EEA Grants 2014-2021 and by Base Funding—UIDB/04708/2020 of the CONSTRUCT—Instituto de I&D em Estruturas e Construções—funded by national funds through the FCT/MCTES (PIDDAC). R. C. Veloso and A. Souza would like to acknowledge the support of FCT—Fundação para a Ciência e Tecnologia for the funding the doctoral grant SFRH/BD/148785/2019 and DFA/BD/8418/2020, respectively.

References

[1] Jelle, B. P., 2012. "Accelerated climate ageing of building materials, components and structures in the laboratory", Journal of Materials Science 47, 6475-6496.
[2] SIPA. *Durability of SIPs Exposed to Moisture*; 2012.
[3] Papadaki, D.; Kiriakidis, G.; Tsoutsos, T. 2018. "Chapter 11 - Applications of nanotechnology in construction industry", In Fundamentals of Nanoparticles, Elsevier,
[4] Veloso, R. C.; Souza, A.; Maia, J.; Ramos, N. M. M.; Ventura, J., 2021. "Nanomaterials with high solar reflectance as an emerging path towards energy-efficient envelope systems: a review", Journal of Materials Science 56, 19791-19839.
[5] Secco, M. P.; Bruschi, G. J.; Vieira, C. S.; Cristelo, N., 2022. "Geomechanical Behaviour of Recycled Construction and Demolition Waste Submitted to Accelerated Wear", 14, 6719.
[6] Maia, J.; Ramos, N. M. M.; Veloso, R. C.; Ventura, J.; Pereira, P. F.; Campos, C.; Corvacho, H.; Lopes, M. L.; Cristelo, N. O potencial dos resíduos industriais no desenvolvimento de novas argamassas para aplicação em fachadas. In Proceedings of the Construção 2022, Guimarães, Portugal, 5, 6 e 7 dezembro 2022, 2022.
[7] Veloso, R. C.; Dias, C.; Praça, R.; Maia, J.; Ramos, N. M. M.; Ventura, J. Study of near-infrared reflective performance of metal oxide nanomaterials for building's external walls coatings. In Proceedings of the ANM 2022 – 19th series of Advance Nanomaterials Conference, Aveiro, Portugal, 27-29 July 2022, 2022.
[8] Nordtest, 2000. "NT BUILD 495. Building materials and components in the vertical position: Exposure to accelerated climatic strains". Nordtest Method.
[9] Kvande, T.; Bakken, N.; Bergheim, E.; Thue, J. V., 2018. "Durability of ETICS with Rendering in Norway—Experimental and Field Investigations", 8, 93.
[10] Asphaug, S. K.; Time, B.; Kvande, T., 2021. "Moisture Accumulation in Building Façades Exposed to Accelerated Artificial Climatic Ageing—A Complementary Analysis to NT Build 495", 11, 568.

[11] ISO 11664-4, 2019. ”Colorimetry - Part 4 - CIE 1976 L*a*b* Colour space”. European Committee for Standardization.
[12] ASTM, 2010. ”Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers”. ASTM International.
[13] RILEM, 2015. ”Measurement of Water Absorption Under Low Pressure RILEM Test Method - Test No. 11.4”.
[14] Levinson, R.; Berdahl, P.; Akbari, H., 2005. ”Solar spectral optical properties of pigments - Part II: Survey of common colorants”, Sol. Energ. Mat. Sol. C. 89, 351-389.
[15] Santamouris, M.; Synnefa, A.; Kolokotsa, D.; Dimitriou, V.; Apostolakis, K., 2008. ”Passive cooling of the built environment - use of innovative reflective materials to fight heat islands and decrease cooling needs”, Int. J. Low-Carbon Tec. 3, 71-82.
[16] Ramos, N. M. M.; Souza, A. R.; Maia, J.; Almeida, R. M. S. F., 2020. ”Colour degradation of facade coatings - the effect of nanopigments incorporation”, Proceedings of the 12th Nordic Symposium on Building Physics (Nsb 2020) 2020,
[17] Cozza, E. S.; Alloisio, M.; Comite, A.; Di Tanna, G.; Vicini, S., 2015. ”NIR-reflecting properties of new paints for energy-efficient buildings”, Sol. Energy 116, 108-116.