CERAMIC SANDWICH CONTRIBUTIONS TO INDUSTRIALISED CONSTRUCTION

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ABSTRACT

The development in ceramic sandwich since its presentation at Qualicer 2022 has taken place following several lines where we believed we had to improve and adapt to the needs, chiefly, of the ceramic and the industrialised construction sector.

The intention is to work with thin ceramic thicknesses, which means consuming fewer natural resources, helping to emit less **CO_2** in raw materials extraction and transformation, in the manufacturing process, and in the firing stage. It also mitigates emissions during transport of the finished goods, as they are much lighter.

Moreover, a further improvement in the ceramic sandwich has been achieved by the incorporation in 2023 of a new structural PET (polyethylene terephthalate) core made from 80% recycled and recyclable material.

This PET core is an **eco-friendly** material, enabling materials that we normally use just once in their life cycle to be re-used and which now can be incorporated into the world of construction, industrialised construction, decoration and architectural elements. All of that enables us in turn to improve the carbon footprint in those sectors, thus contributing to a reduction of plastic waste in the environment and fostering the circular economy by giving **recycled materials** a second life.

In regard to industrialised construction, the proposal is for self-supporting ceramic sandwiches for bathroom and kitchen floors, eliminating concrete flooring and improving the carbon footprint in manufacturing and transport, lightening the finished elements and improving handling in manufacturing facilities and on site. They are water-repellent raised access floors.

For industrialised construction, we also propose coverings using the ceramic sandwich, in which thin porcelain slabs (between 3 and 6 mm thick) provide rigidity and thermal and acoustic properties, enabling ceramic sandwich installation with a dry construction system, eliminating the need for buttering and floating.

At present, we are developing a project for coverings in industrialised bathrooms and kitchens in which we aim to eliminate the use of plasterboard panels to reduce assembly times, replacing traditional glues with single-component adhesives or mechanical anchors, thus making installation faster and providing a much more sustainable procedure. All of this is to reduce the detriment suffered by the lack of skilled labour in the building industry.

1. INTRODUCTION

Industrialised construction is a growing trend in the building industry, driven by a need for faster, more efficient, sustainable construction and as a way of offsetting the lack of skilled labour. In this context, the ceramic sandwich has emerged as a promising option, enabling ceramics to be incorporated into new products in the trend towards industrialisation.

The product is made up of advanced materials, consisting of a ceramic outer layer and a structural PET (polyethylene terephthalate) core made of recycled, recyclable and thermally and acoustically insulating material. Other skins can be added *ad hoc* to the PET core to improve qualities as a function of a project's technical demands.

2. QUALITIES

2.1. SUSTAINABILITY

The new recycled core we use in the ceramic sandwich helps reduce reliance on conventional building materials and diminish the amount of plastic waste in the environment. In addition, recycled PET has a lower carbon footprint compared to other insulation materials, which contributes to climate change mitigation.

Figura 01. *Foto del sándwich cerámico, con el nuevo nucleo estructural reciclado.*

PET products use 80% recycled and recyclable material, which would otherwise have become single-use product waste.

The carbon footprint of PET products, manufactured by our partner Diab, is around 4 kg CO_2 equivalent per kg product. Nevertheless, we seek to further reduce their carbon footprint, aiming at a target of 1.5 kg of CO_2 per kg PET core.

2.2. RECYCLABLE AND RECYCLED

Figure 02. *Photo of the material separation process. Laboratory test.*

By means of an innovative process, the different elements that make up the ceramic sandwich can be separated and recycled back into the manufacturing chain. This involves:

- Separation of the resins: the recycled material is used to remanufacture the recycled resins.
- Separation of glass fibre reinforcements: This material is reused in the manufacturing process of glass fibre products.
- Structural core separation: This shall be reincorporated into the manufacturing of recycled PET cores as a post-consumer recycled material.
- Ceramic separation: This shall be reincorporated into the ceramic manufacturing process by grinding, etc.

2.3. LIGHTWEIGHT

Compared to other building materials such as concrete or iron, the ceramic sandwich made with advanced materials allows greater freedom in structural design and reduces the load on the foundation and structure. The cores have densities between 80 and 250 kg/m^3 – the actual density depends on the project involved.

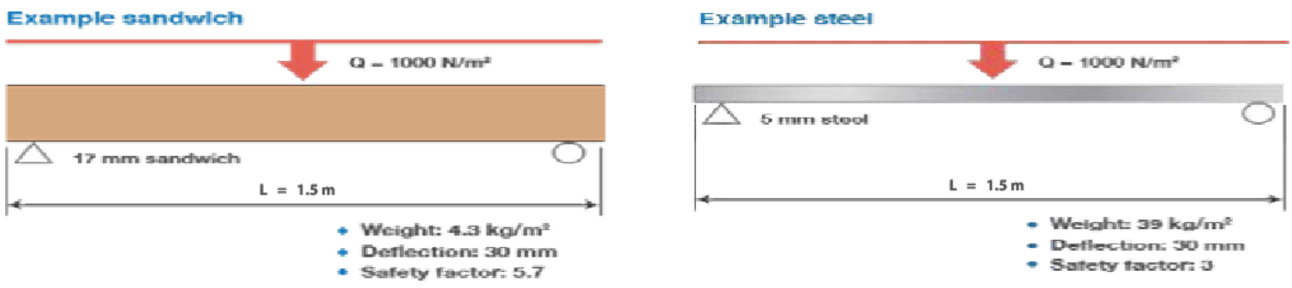

Figure 03. *Difference between a steel sheet and a sandwich using advanced materials.*

3. TESTS

3.1. MODULUS OF RUPTURE AND BREAKING STRENGTH TEST

Determination of modulus of rupture and breaking strength. Samples of Reymansa ceramic sandwiches with core densities of 135 and 150 kg/m^3.

Compared to the tests presented at Qualicer 2022, the modulus of rupture has been improved by 35%.

Tests have continued to be carried out using 6 mm porcelain slabs and 10 mm core from the new recycled series.

sample	support	width	thickness	kg	corrected kg	Mechanical strength	Breaking load	Breaking strength	Note
	mm	mm	mm	kg	kg	N/mm^2	N	N	
1A	260	252.4	17.2	204	200.7	10.3	1969	2028	FRIST FAILURE
1A	260	252.4	17.2	559.8	550.8	28.2	5402	5565	*
1B	260	253	17.3	198	194.8	9.8	1911	1964	FRIST FAILURE
1B	260	253	17.3	557.4	548.5	27.7	5379	5528	*
2A	260	252.1	17.1	183	180.1	9.3	1766	1821	FRIST FAILURE
2A	260	252.1	17.1	537.6	529	27.4	5188	5350	*
2B	260	252.1	17.1	204	200.7	10.4	1969	2030	FRIST FAILURE
2B	260	252.1	17.1	549.1	540.3	28	5299	5465	*

1A-1B: TEST ON CORE DENSITY 135 - 10mm THICKNESS
2A-2B: TEST ON CORE DENSITY 150 - 10mm THICKNESS

* REACHES END OF RUN WITHOUT COMPLETELY BREAKING

Table 01. *Modulus of rupture test results, 25x28 cm test specimens.*

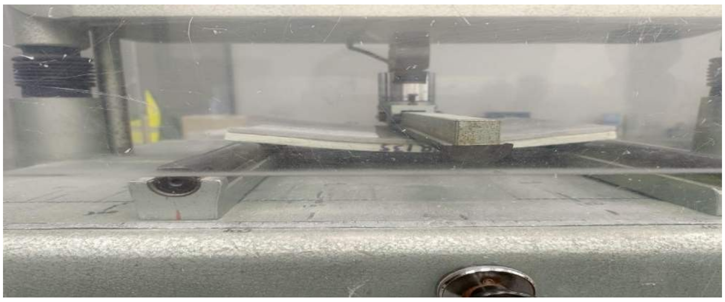

Figure 04. *Photo of ceramic sandwich bending test.*

3.2. TEST OF IMPACT RESISTANCE TO A DROPPED STEEL BALL

Due to its composite structure, this material offers greater mechanical strength and durability than traditional materials. Tests have been carried out at the Institute of Ceramic Technology (ITC) and at other companies where it successfully achieved the maximum rating in standard **UNE 56875 V2 Section 4.7.3.7** "Resistance Test by impact of falling ball. Kitchen furniture".

3.3. THERMAL AND ACOUSTIC EFFICIENCY TESTS

The core of the ceramic sandwich works as an insulating material and contributes to improving energy efficiency, thus reducing energy consumption for heating and cooling and, hence, greenhouse gas emissions.

Tests carried out under **UNI EN ISO 354:2003, UNI EN ISO 11654:1998** and **ASTM C423 - 09a.**

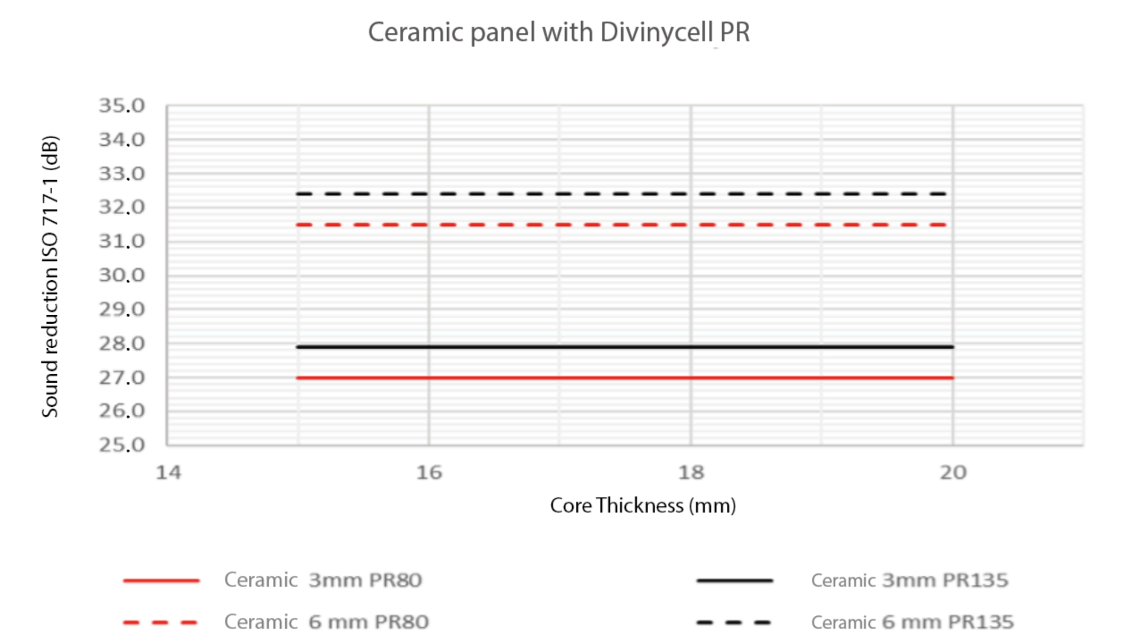

Table 02. *Estimation of thermo-acoustic insulation values (Source Diab).*

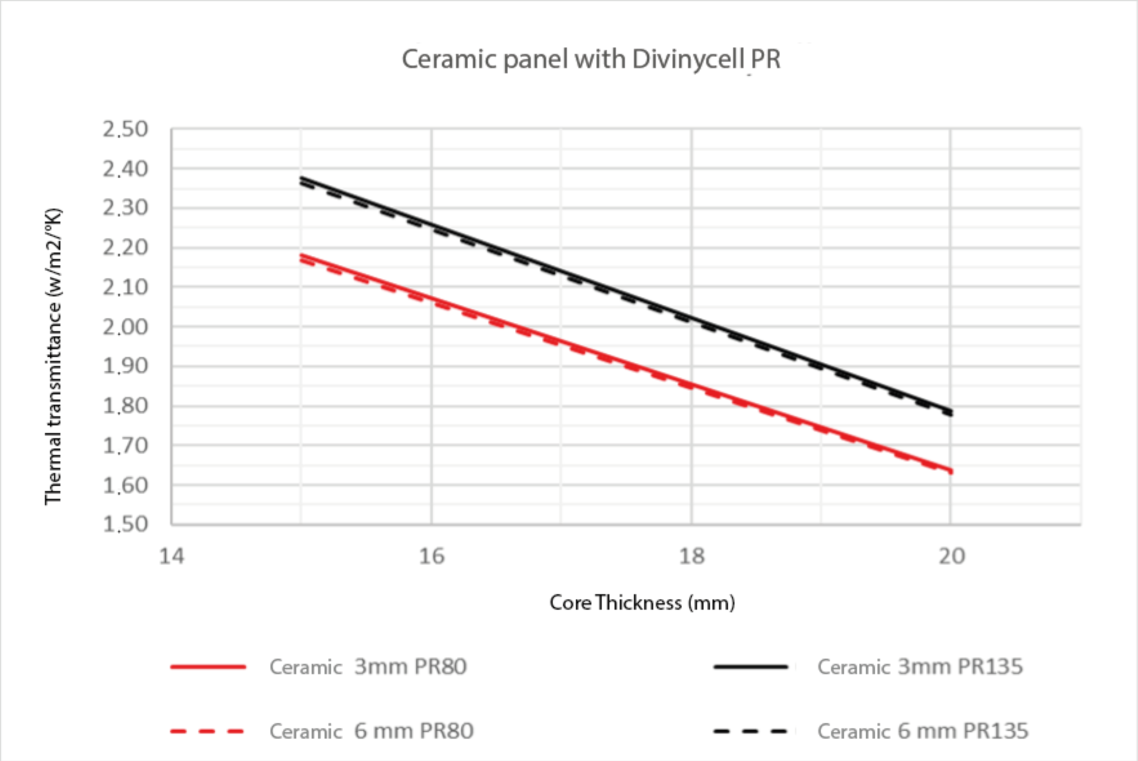

Table 03. *Estimation of thermo-acoustic insulation values (Source Diab).*

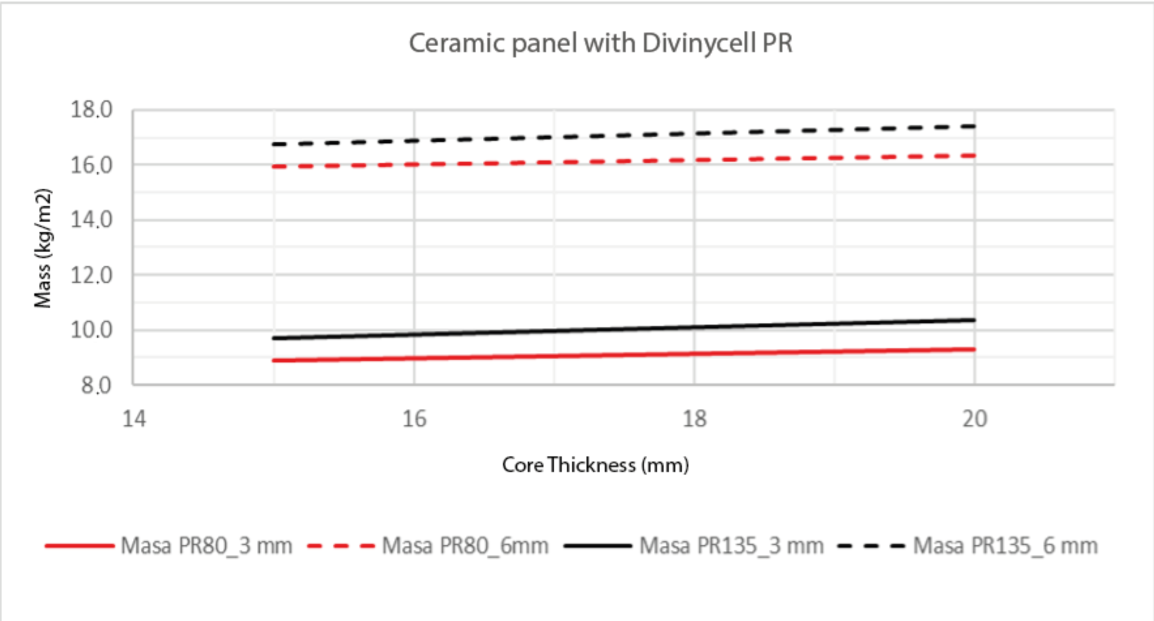

Table 04. *Estimation of thermo-acoustic insulation values (Source Diab).*

Notes

- *The mass calculation assumes the application of 300 g/m² adhesive per skin.*
- *The thermal transmittance calculation considers 1.75 w/m/ºK for conductivity of the skin (porcelain tile).*
- *Sound Reduction Index estimated on the basis of the Law of Masses (F. Fahy, "Sound and Structural Vibration Radiation: Transmission and Response", Academic Press, London, 1985).*

3.4. WATER REPELLENT

Thanks to its composition, the core is not affected by water, does not deform with humidity and does not deteriorate. Its technical qualities are unaffected.

3.5. FIRE RATING TEST FOR CONSTRUCTION PRODUCTS

Flammability when subjected to the direct action of a flame.

The small burner test is based on a European standard developed by the CEN/TC 127 Technical Committee "Fire safety in buildings". It was developed under a mandate given to CEN by the European Commission and supports the essential requirement "safety in case of fire" of the Construction Products Directive (89/106/EEC). AITEX (EN ISO 11925-2:2010/AC:2011).

***Figure 05**. Photo of test specimens in the fire rating test.*

The outcome of the test was a fire rating of **B-s2,d0**.

3.6. SOLVENT AND ADHESIVE RESISTANCE TEST

In the different tests carried out, the ceramic sandwich with PET structural core was not affected by solvents, unlike other types of cores on the market, such as XPS and construction cores.

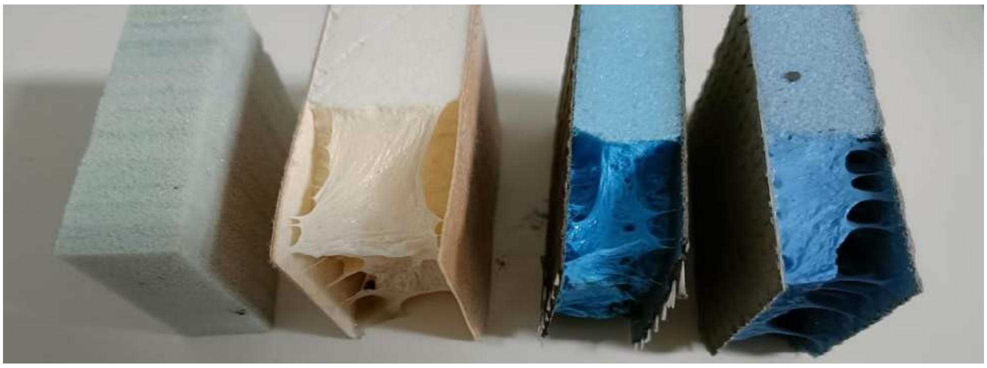

Figure 06. *Photo of cores affected by solvents or adhesives.*

3.7. CERAMIC THERMAL SHOCK RESISTANCE TEST

Different tests were carried out in accordance with the method described in standard **UNE-EN ISO 10545-9:2013** "Ceramic tiles - Part 9: Determination of resistance to thermal shock.

Immersion test: for tiles with water absorption of less than or equal to 10%. It consists of immersing 5 tiles in water at 15 ±5ºC for 15 minutes. After that, they are placed in an oven at 145 ±5ºC until they reach a uniform temperature. This process is repeated 10 times. In each cycle, methylene blue is applied to check for possible cracks, but no defects were observed during the cycles in the various tests.

XPS-type cores can only withstand up to 75ºC or 80ºC.

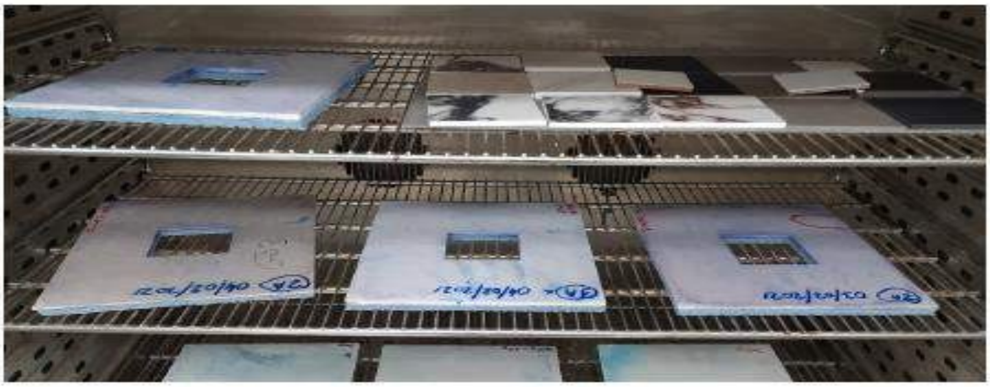

Figure 07*. Photo of specimens during the tests.*

3.8. TEST TO DETERMINE INTERLAYER ADHESION STRENGTH

Adhesion strength was determined by tensile adhesion testing. The specimens consisted of a fraction of ceramic slab and 10 mm core. The tensile adhesion determination method is based on the **UNE-EN 12004-2:2017** standard. It consists of gluing a steel pull head on the proper surface of the slabs and a fastening block on the front face where the PR135/10mm core is glued, using an epoxy adhesive that is assumed to be stronger than the adhesive used to join the slab and the mesh and on which a force can be exerted perpendicular to the gluing surface, as shown in Figure 08.

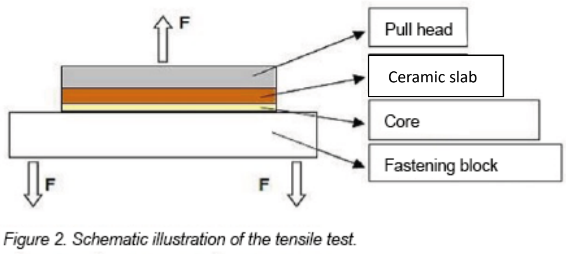

Figure 08. *Description of the test.*

The tests were carried out on a mechanical testing machine at a constant deformation rate of 10 mm/min on 10 specimens.

Test results:

The results obtained are detailed below.

Determination of tensile adhesion strength.

- Sample: Ceramic sandwich with 3 mm porcelain tile - PR135/10mm core bonded with Core System 02 resin.
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Test specimen	Tensile adhesion strength (N/mm^2)	Type of failure*
1	1.09	AF-T
4	1.43	CF-A / AF-T
5	1.28	AF-T
6	1.60	CF-A / AF-T
7	1.36	AF-T
9	1.55	CF-A / AF-T
10	1.16	AF-T
Mean value	**1.35**	
Standard deviation	**0.19**	

*AF-T: Adhesive failure between tile & PR135/10mm core

*CF-A: cohesive failure in the PR135/10mm core

Table 05. *Adhesion strength test results*

Figure 09. *Photo of the adhesion strength test specimens.*

3.9. MODULUS OF RUPTURE AND BREAKING STRENGTH TEST FOR INDUSTRIALISED CONSTRUCTION FLOORS

We performed different bending tests to find the right combination to meet project requirements. The test was carried out in accordance with the method described in **UNE-EN ISO 10545-4:2019 standard** "Ceramic Tiles - Part 4: Determination of modulus of rupture and breaking strength".

Figure 10. *Photo of the bending test on the raised floor sandwich.*

Piece	Support (mm)	Width (mm)	Thickness (mm)	Module (N/mm^2)	kg	Corrected kg	Load (N)	Force (N)
1B	270.0	201.1	12.5	36.1	291.8	285.7	2802	3761
1A	270.0	200.9	12.4	46.0	365.4	357.7	3508	4715
2B	270.0	199.0	12.6	38.0	308.8	302.3	2965	4023
2A	270.0	200.9	12.5	49.0	395.4	387.1	3796	5102
3B	270.0	201.0	12.3	34.7	271.1	265.4	2603	3496
3A	270.0	201.1	12.4	34.0	270.5	264.8	2597	3487

Table 06. *Results of the test with no ceramic.*

3.10. THERMAL SHOCK RESISTANCE TEST OF CERAMIC FLOOR TILES FOR INDUSTRIALISED CONSTRUCTION OF BATHROOMS AND KITCHENS.

Different tests were carried out in accordance with the method described in standard **UNE-EN ISO 10545-9:2013** "Ceramic tiles - Part 9: Determination of thermal shock resistance.

Immersion test: for tiles with water absorption less than or equal to 10%. It consists of immersing 5 tiles in water at 15 ±5ºC for 15 minutes. After that, they are placed in an oven at 145 ±5ºC until they reach a uniform temperature. The process is repeated 10 times, and no lamination was observed between the layers during the cycles in the various tests.

***Figure 11**. Photo of the test specimens after the tests.*

3.11. TEST OF CERAMIC SANDWICH RESISTANCE TO HOT / COLD CYCLES FOR INDUSTRIALISED CONSTRUCTION

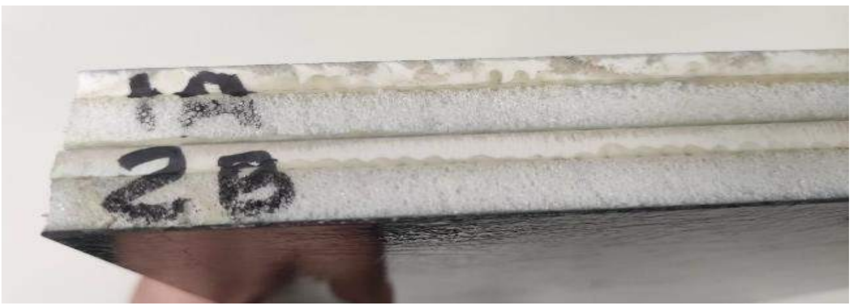

***Figure 12**. Test specimens subjected to the hot / cold test.*

In this test, specimens are subjected to heat cycles at 75ºC in an oven, followed by cold cycles at -15ºC. They are left for a minimum of 30 minutes, both in the oven and in the freezer, to allow the working temperature to be reached. The samples withstood 30 hot / cold cycles well, with no cracks or deformations found.

It may be observed that the different layers remain joined, porcelain tile to the PET core and the skin of the flat composite to the PET core. No defects of any kind were found in the bonding system.

4. INDUSTRIALISATION OF PRODUCTION PROCESSES

Mass production of the ceramic sandwich allows greater quality control and faster, more efficient construction compared to traditional construction methods.

Work is already taking place on an industrial level in large firms where the joining process between the structural core and the porcelain tile slab is being industrialised, enabling production of a significant volume at a lower cost.

Figure 13. *Illustration of an industrialisation line for ceramic sandwich.*

The use of thin ceramic slabs also provides design flexibility and structural optimisation possibilities, enabling greater architectural creativity.

Once the ceramic sandwiches have been manufactured, they can be more easily handled and worked with different machines to form the end products.

Figure 14. *Photos of ceramic sandwich slabs for drywall cladding.*

They enable folding industrialised balcony (FIB) designs to be linked to machines for making the measurements and for the machining operations envisaged, thus achieving perfect integration between design and finished product.

Figure 15. *Photo of a ceramic sandwich cut with a five-axis water jet machine.*

5. NEW USES FOR THE CERAMIC SANDWICH

5.1. STRUCTURAL RAISED ACCESS FLOOR WITH CERAMIC SANDWICH

Self-supporting ceramic sandwich for industrialised bathroom floor. Replaces 6 cm thick concrete flooring, with a core thickness of 1.2 cm plus 10 mm ceramic slab.

Material	Thickness (mm)	Weight (kg/m^2)
Ceramic sandwich panel	22.4 + 10	34.65
Concrete flooring	60 + 10	178
Cross laminated timber (CLT) panel	60 + 10	58

Table 07. *Comparative table of floor weights in industrialised construction*

The table illustrates the significant difference in weight between the ceramic sandwich panel and the materials (concrete or CLT) being used at present

Figure 16. *Photo of a ceramic sandwich on an industrialised bathroom floor (1.2 cm).*

Figure 17. *Photo of an industrialised bathroom.*

5.2. DRYWALL CLADDING WITH SANDWICH PANEL, FOR INDUSTRIALISED CONSTRUCTION

It enables use of thin ceramic thicknesses, while affording thermal and acoustic properties. It expedites the installation process thanks to its dry construction or mechanical anchoring. It reduces weight and process times compared to traditional methods and increases sustainability in the construction sector. It provides the porcelain slab with greater rigidity.

***Figure 18**. Drywall cladding.*

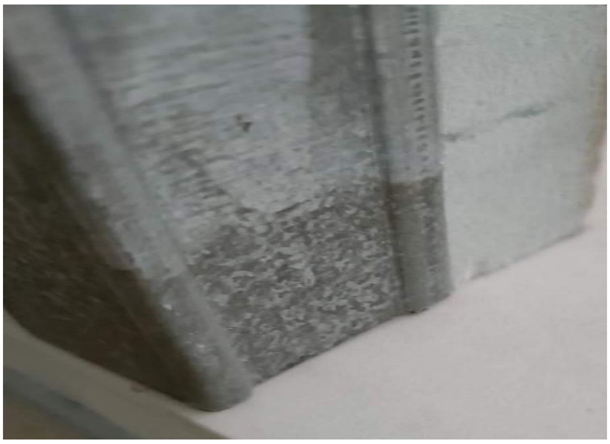

***Figure 19**. Drywall cladding.*

Tests carried out:

	TEST	TESTING ENTITY	COUNTRY	RESULT	VALUES
1	Bending strength	ITC-AICE	Spain	✓	
2	Heat / freezer thermal shock	URBATEK	Spain	✓	> 25 cycles
3	Bending strength	X TONE	Spain	✓	
4	Drop ball impact resistance	REYMANSA	Spain	✓	> 2 joules
5	Heat / water thermal shock	URBATEK	Spain	✓	> 70 cycles
6	Sound absorption measurement	Z Lab, S.R.L.	Italy	✓	
7	Bathroom accessories resistance	URBATEK	Spain	✓	> 10 kg

5.3. VENTILATED FAÇADE

A series of tests were carried out on ventilated façades to technically validate the product. The tests conducted were considered necessary to validate the façade system as a whole, not just the ceramic sandwich.

Figure 20. *Multi-layer façade.*

Figure 21. *Multi-layer façade.*

Tests carried out:

	Test	Testing entity	Country	Result	Values
1	Reaction to fire	Aitex	Spain	✓	B-s2,d0
2	Thermal shock	Ginger / CEBTP	France	✓	
3	Ageing	Ginger / CEBTP	France	✓	
4	Wind fatigue	Ginger / CEBTP	France	✓	
5	Wind load resistance	Ginger / CEBTP	France	✓	
6	Flexure	Ginger / CEBTP	France	✓	
7	Impact	Ginger / CEBTP	France	✓	
8	Rivet strength	Ginger / CEBTP	France	✓	
9	Spacers	Ginger / CEBTP	France	✓	

5.4. LIGHTWEIGHT RAISED ACCESS FLOORS

***Figure 22**. Photo of raised access floor.*

Raised access floors made of ceramic sandwich are very lightweight compared to conventional proposals. They are more sustainable, highly resistant to impact and bending, in addition to providing thermal and acoustic properties.

We have PET structural cores with fire retardants.

Tests carried out:

	Test	Testing entity	Country	Result	Values
1	Bending strength / F+ option	ITC-AICE	Spain	✓	> 13,680 N
2	Heat / freezer thermal shock	URBATEK	Spain	✓	> 25 cycles
3	Bending strength	BUTECH	Spain	✓	> 16,000 N
4	Drop ball impact resistance	REYMANSA	Spain	✓	> 2 joules
5	Heat / water thermal shock	URBATEK	Spain	✓	> 70 cycles

5.5. FOLDING INDUSTRIALISED BALCONY (FIB)

As part of our industrialisation efforts, we have created an innovative proposal using ceramic sandwich to clad FIBs (folding industrialised balconies), as presented at the Cevisama 2022 trade fair (Figure 23), which brings lightness and decoration to a basic architectural element in façade compositions. These lightweight balconies are proposed for both new construction and the renovation market, so they can be attached or anchored to façades like large shelves. That enables a deficit in many existing buildings to be corrected, by providing them with outside spaces.

Initially it was thought that the ideal cladding to cover the metal structure would be wood, but the new ceramic sandwich is practically as light as wood, much more resistant to the sun and requires much less maintenance.

Figure 23. *Photo of the folding industrialised balcony (FIB) prototype, Cevisama 2023, clad with porcelain tile, thanks to the structural ceramic sandwich.*

6. CONCLUSIONS

The ceramic sandwich panel offers great flexibility in terms of design and architecture. The ceramic layer or layers can have different finishes, thus allowing a wide variety of design options and architectural styles. It also provides a unique combination of sustainability, performance and lightness in industrialised construction.

As an advanced material, it has the potential to contribute to the construction of more sustainable and efficient buildings, driving innovation and progress in the construction industry.

In industrialised construction, ceramic sandwich flooring can provide a significant reduction in carbon footprint by replacing concrete flooring.

In coverings for industrialised construction, in addition to contributing to overall lightness and reducing the carbon footprint, it is sought to eliminate the bottlenecks that today have moved from the building site to the production centres where industrialised bathrooms and kitchens are manufactured. This is due to the continued use of traditional ceramic tile fixing procedures and lack of skilled personnel in those trades.

Another objective is to increase use of ceramic materials in different architectural or decorative proposals, which would otherwise be very complicated or impossible.

7. REFERENCES

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