ANALYSIS OF CERAMIC SLABS IN RELATION TO THEIR USE AS FLOORING

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ABSTRACT

The use of thin slabs as interior flooring satisfies many performance characteristics demanded for such use by their own ceramic nature, though there are others in which their low thickness may act as a restriction. This is why it is necessary to assess the behaviour of slim ceramics both on an individual level and as part of a multilayer ceramic system.

The performance characteristics that are affected by tile thickness and, therefore, need to be considered are as follows:

- Mechanical strength under loading, which may involve static point loads, compressive loads, and also transverse or flexural loads.
- Impact resistance (mainly hard bodies of different sizes).
- Deformability under loading.

The reduced thickness of this type of ceramic slab, compared to ceramic tiles of usual thickness, influences its deformability in relation to stresses stemming from loads and impact. This involves a different behaviour, in turn conditioned by the deformability of the multilayer ceramic assembly and by the possibility of reinforcing the ceramic slab by a mesh backing.

The above opens up a very promising line of work aimed at improving the performance characteristics of this type of product, mainly associated with reinforcements and underlying layers that enable the relationship resistance to loading/deformability and resistance to impact/deformability of the assembly to be optimised.

This study seeks to assess, in relation to their use as flooring, both the own characteristics of slim tiles (on an individual level or with mesh reinforcement) and their achievable performance characteristics as multilayer ceramic systems in combination with other materials. This characterisation will allow identification of the limiting properties to be taken into account when it comes to designing and evaluating existing or potential products and construction systems, thus assuring that slim slabs will meet the required performance characteristics for use as interior flooring.

1. INTRODUCTION

The progressive advances in ceramic tile forming technologies have allowed manufacture of ceramic slabs up to 3.2 m long, with very low thicknesses (even 3 mm) relative to their large size, in the last decade. Although this type of slabs is beginning to be used for new applications such as furniture cladding, the uses for which they are currently being marketed focus mainly on covering interior and exterior walls, as their installation in floors generates uncertainty due to their allegedly limited mechanical behaviour, stemming from their lower thickness.

In order to improve the behaviour of this type of products as flooring, many manufacturers use mesh reinforcement, mainly fibreglass, with a view to enhancing their performance characteristics. However, no in-depth study is available that systematically assesses the intrinsic characteristics of these ceramic slabs, both individually and together with a mesh reinforcement.

At the same time, any product that, upon installation, needs to work together with a set of materials or elements making up a system, must in turn be assessed in relation to that assembly, as the characteristics of each element in the system condition the result of the whole, independently of the own characteristics of each individual element.

The performance characteristics obtained with different ceramic slab thicknesses were therefore examined in tests that enabled evaluation of the individual tile and of the tile as part of a multilayer system. It was thus sought to study the behaviour of thin ceramic slabs and to acquire the necessary insight to improve slab performance characteristics and minimise the risk of problems in service.

2. ASSESSMENT OF MECHANICAL BEHAVIOUR

When a material is subjected to the action of an external force, under static or dynamic conditions, deformation takes place in its structure which may or may not be permanent, depending on the magnitude of the stress and the characteristics of the material[1]. If, when the force is no longer applied, the body fully recovers its original shape, it is considered to exhibit elastic behaviour whereas, if the deformation is permanent, it is deemed to exhibit plastic behaviour. Dense ceramic materials are characterised by exhibiting a rapid transition from elastic behaviour to fracture, owing to the low velocity at which the exerted mechanical stresses can relax, not exhibiting any substantial plastic deformation that could absorb such stresses. These materials are termed brittle, in contrast to ductile materials, whose fracture is preceded by plastic deformation.

During the impact of a spherical object on the flat surface of a homogeneous material set on a rigid base, a deformation develops at the surface with the ensuing tensile stress in the contact area between both elements, reaching maximum stress at the circular line bounding this area. When the limit load value is reached, a fine ring crack appears at the surface of the material, coinciding with the perimeter of the contact area where the tensile stresses are concentrated, which can propagate inwards forming a conical fracture, designated a Hertz crack (H-Figure 1a). In contrast, when layer thickness is small and/or the material can deform freely, the tensile stresses concentrate at the surface opposite the impact owing to bending of the test piece, symmetrically to the contact position of the object. If the deformation reached is sufficient to generate a level of stress exceeding the fracture limit, one or more hair cracks are generated that progress radially from the bottom surface of the tile (R-Figure 1a). This behaviour is manifested analogously in the impact phenomena of a spherical object on homogeneous materials (Figure 1b).

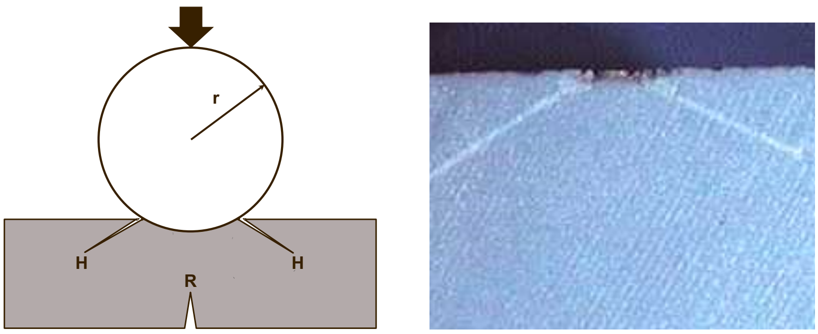


Figure 1. a) *Fracture patterns in an elastic material; b) Hertz fracture by impact*

The mechanical behaviour of flooring products is usually assessed on the uninstalled, individual product, usually by a bending test, from which the characteristic values of the material, such as the force or modulus of rupture, are obtained. However, the performance characteristics of the product in real conditions largely depend on the characteristics of the installation system[2,3] and are mainly related to the resistance to concentrated loads, both static (load-bearing capability) and dynamic (impact).

After analysing the evaluation criteria of the test methods of impact resistance described in the standards on stone and ceramic floorings (Table 1), it was noted that the requirements are mainly associated with the generation of chipping or fracture, though in some cases the presence of Hertz cracks, fissures, and radial hair cracks were found (Table 2). To analyse the mechanical performance characteristics of the flooring systems, steel ball drop and progressive concentrated loading tests were performed (Figure 2), assessing all the types of damage and quantifying the generation of Hertz cracks based on their diameter[4].

Method	Standard	Energy (J)	Damage evaluated	Requirements	Use
Coefficient of restitution	ISO 10545-5	0.27	H (visible at 1 m), I, R, and C	No requirements Indicate damage in report	Light
Light impact	CSTB C3778_V4 Annexe 7	0.49	H, R, and C	No chipping	Light
Raised floor	CSTB C3778_V4 Annexe 11	2.51	H, I, R, C, and F	No fracture	Light
Hard impact	CSTB C3778_V4 Annexe 6	4	H, R, and C	R< 10mm and no chipping	Manipulation of heavy loads
Natural stone Floors and stairs	UNE 22202-1	4 5	F	No fracture	Public interior Public exterior
Natural stone Raised floor	UNE 22202-4	4 5	F	No fracture	Public interior Public exterior
Natural stone	CEN/TR 17024	2.94 4.41 5.88	F	No fracture	Private Public moderate Public intense

Table 1. *Methods of evaluating impact resistance*

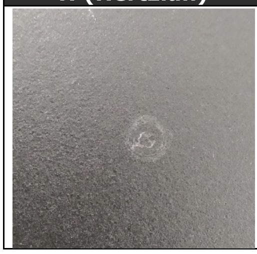
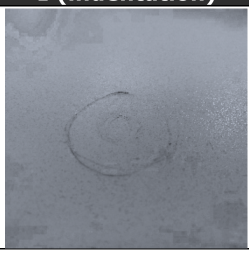
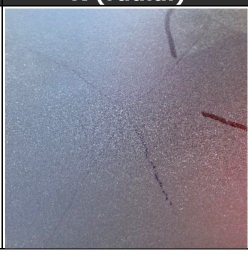
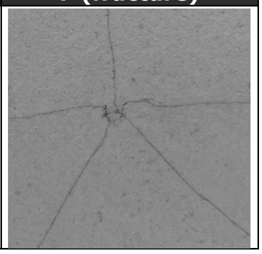
H (Hertzian)	I (indentation)	R (radial)	C (chipping)	F (fracture)
				

Table 2. *Types of damage*

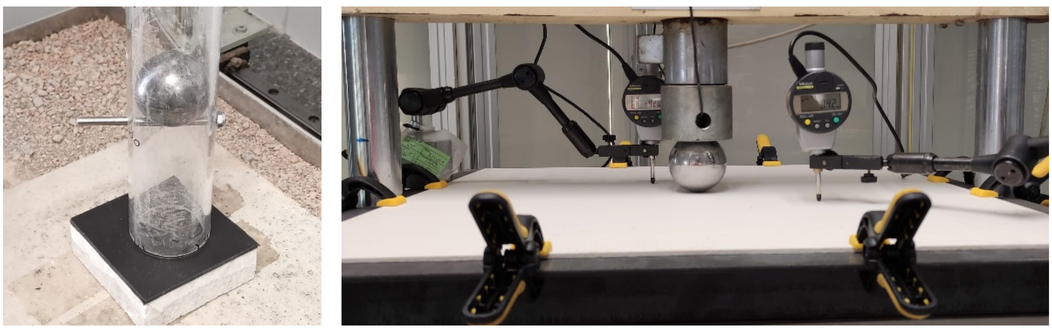


Figure 2. *Tests of impact resistance and progressive concentrated loading*

3. MECHANICAL BEHAVIOUR OF THE CERAMIC PRODUCT

First, the mechanical behaviour of commercial ceramic slabs of different thickness (3L, 6L, and 12L), as well as with back mesh reinforcement (3LM and 6LM), was evaluated. The tests were carried out on products supported at their perimeter in order to determine their impact resistance and load-bearing capability.

Impact tests were conducted on test pieces of 10x10 cm and 60x60 cm to evaluate the energy absorption capability associated with product deformability, in addition to progressive loading (50 N/s) tests to determine the maximum load and deformation before fracture as a function of slab thickness.

As Table 3 shows, the larger-sized tiles require more energy to generate fracture owing to their greater energy absorption capability by deformation. The mesh reinforcement also noticeably improved the impact behaviour in the test pieces without underlying support, the increase in the limit energy in the pieces with the lowest thickness being most pronounced, which in size 60x60 cm even exceeded the impact resistance of the 12-mm slab without mesh reinforcement.

	Impact energy (J)		Progressive loading 60x60	
Sample	10x10	60x60	F_{max} (N)	D_{max} (mm)
3L	0.07	0.47	204	2.99
3LM	0.50	3.14	298	3.69
6L	0.18	0.78	879	2.84
6LM	0.40	2.51	818	2.71
12L	0.50	1.57	3115	1.89

Table 3. *Impact energy limits and maximum load with test piece fracture*

However, in the case of fracture by progressive loading, the influence of mesh reinforcement was not observed, higher maximum loading values being reached at greater thickness of the ceramic slab, whose increase lowered the deformation capability.

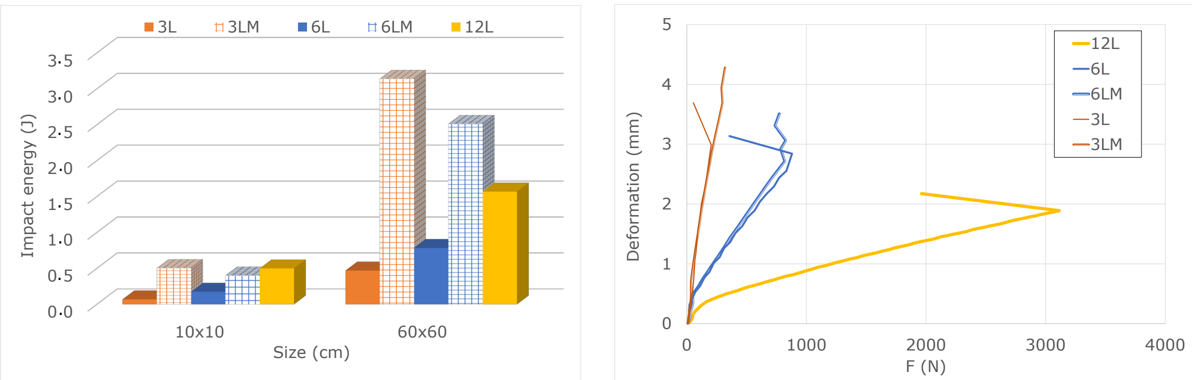


Figure 3. a) *Impact fracture energy; b) Force/deformation on concentrated loading*

4. INFLUENCE OF ADHESIVE TYPE

To evaluate the influence of the adhesive layer on impact resistance, scale models were prepared with 6-mm slab on a rigid base (A), adhered with three types of ceramic tile adhesives with a decreasing level of deformability (R2>C2S2>C2S1) in two application layer thicknesses (3 and 5 mm). Using ball drop tests, the limit energies for the appearance of Hertz and radial cracks were determined.

The results (Table 4) confirmed that the increase in deformability slightly lowered the proneness for Hertz cracks to appear, without any significant influence being noted when adhesive layer thickness was modified. In contrast, the proneness to generate radial hair cracks was favoured in the case of adhesive R2, a light improvement in impact resistance being observed in the case of the cementitious adhesives (Figure 4a).

System	Hertz energy (J)	Radial energy (J)
6L-R2 (3 mm) A	1.25	1.75
6L-C2S2 (5 mm) A	1.00	4.75
6L-C2S2 (3 mm) A	1.00	4.50
6L-C2S1 (5 mm) A	0.75	4.00
6L-C2S1 (3 mm) A	0.75	3.25

***Table 4**. Influence on adhesive impact resistance and thickness on a rigid base*

Scale models of 6-mm slab with mesh reinforcement were prepared on a deformable base (B), on which impact and concentrated load resistance was assessed, raising the levels of energy or force until radial hair cracks (R>10 mm) and/or indentation (I) appeared in the ceramic pieces (Table 5). The results confirmed that, in installations on a deformable base, the increase in adhesive deformability did not noticeably change the impact energy or maximum force values (Figure 4b), though it did contribute slightly to increasing the diameter of the arising Hertz cracks and the generation of indentation.

System	Impact energy (J)	H diameter (mm) + damage	Force/deformation (N) / (mm)	H diameter (mm) + damage
6LM-R2 B	8.83	H (17)+R+I	4660/2.36	H (14)+R+I
6LM-C2S2 B	8.83	H (9)+R+I	4568/2.39	H (9)+I
6LM-C2S1 B	8.83	H (7.5)+R	4693/2.04	H (8.5)+I

***Table 5** Influence of the adhesive on a deformable base*

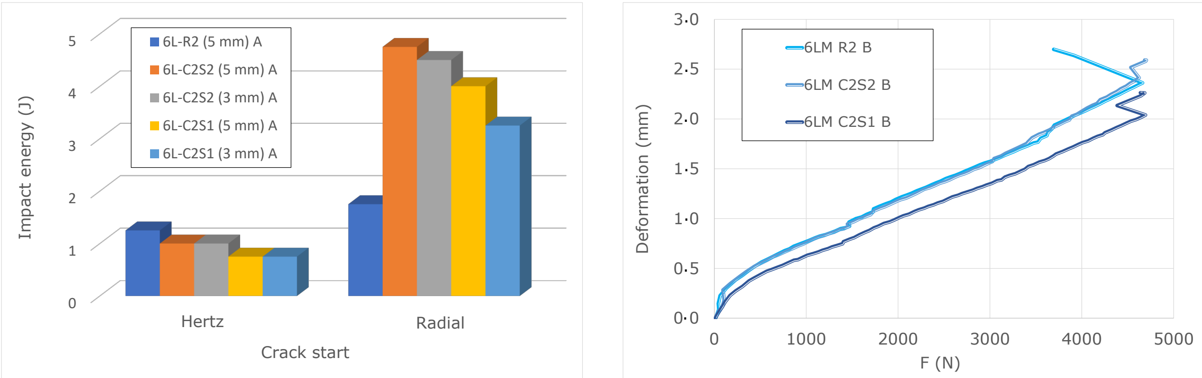


Figure 4. a) *Impact energy; b) Force/deformation in concentrated loading*

5. MECHANICAL BEHAVIOUR OF CERAMIC SYSTEMS

As the rehabilitation of floors with ceramic tiles of low thickness could be one of the most widespread market applications, it was decided to analyse two installation systems on a rigid base (A) of terrazzo floor tile, size 30 x 30 cm, using a cementitious adhesive (C2S2) and an organic adhesive with high deformability (AAD). For comparative purposes, equivalent scale models were prepared using ceramic slabs (12L, 6LM, and 3LM) installed with C2S2 adhesive on a deformable base (B). Table 6 and Table 7 detail the results of the impact energy and force required to generate radial hair crack (R>10 mm) and/or fissure.

System	Impact energy (J)	H diameter (mm) + damage	Force/deformation (N) / (mm)	H diameter (mm) + damage
12L C2S2 A	7.90	H (9.5)+R	19000/1.10	H (6.5)
6LM C2S2 A	4.50	H (7.5)+R	19000/1.17	H (10)+R
6L C2S2 A	4.50	H (7.5)+R	19000/1.11	H (9.5)+R+C
3LM C2S2 A	2.50	H (8.5)+R	19000/1.88	H (17)+R+I
3L C2S2 A	2.25	H (8.5)+R	19000/2.05	H (17)+R+I
12L AAD A	1.75	H (3.5)+R	7856/1.02	H (12)+F+I
6LM AAD A	1.50	H (3.5)+R	9801/1.55	H (8)+R
6L AAD A	0.50	H (3)+R	5826/1.09	H (12)+F+I
3LM AAD A	1.50	H (3.5)+R	4982/1.25	H (7.5)+R
3L AAD A	0.50	H (5)+R	2641/0.82	H (11)+F+I

Table 6 *Influence of the system for rehabilitating rigid floors*

System	Impact energy (J)	H diameter (mm) + damage	Force/deformation (N) / (mm)	H diameter (mm) + damage
12L C2S2 B	2.94	F	-	-
6LM C2S2 B	8.83	H (9)+R+I	4568/2.39	H (9)+I
3LM C2S2 B	3.92	H (8.5)+I	2288/2.52	H (19)+I

Table 7 *Behaviour on a deformable base*

Figure 5a shows that impact energy exhibited an increasing trend in relation to the thickness of the ceramic slab with both types of adhesives, but with much higher values in the case of C2S2, and the influence of the mesh reinforcement was not observed, except slightly for AAD albeit in lower energy ranges.

In the progressive loading tests with C2S2, it was not possible to determine the force at which damage started as no changes were detected in the evolution of force throughout the test (Figure 5b), which was extended to the limit of the measurement device. Analysing the damage obtained at the same maximum force revealed that the reduction in thickness tended to increase the diameter of the Hertz cracks and the generation of indentation.

The results of the scale models with AAD on a rigid base confirmed that the excessive deformability of the adhesive lowered the load-bearing capability of the system which, in the case of the tiles without mesh reinforcement, tended to fracture with indentation. Unlike the systems on a rigid base, the impact resistance in the tests of systems on a deformable base did not exhibit a linear trend with regard to thickness, this being greater in the slab with an intermediate thickness and minimum for that with maximum thickness (Figure 6. a) Impact energy; b) Maximum force/ deformation in concentrated loadinga). In contrast, in both cases maximum force decreased on reducing ceramic slab thickness, particularly in the case of the deformable base (Figure 6b).

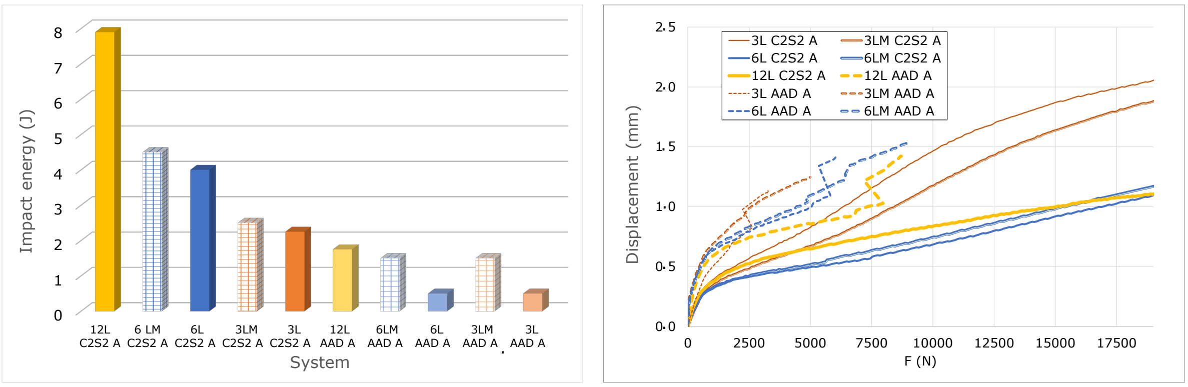


Figure 5. a) *Impact energy; b) Force/deformation in concentrated loading*

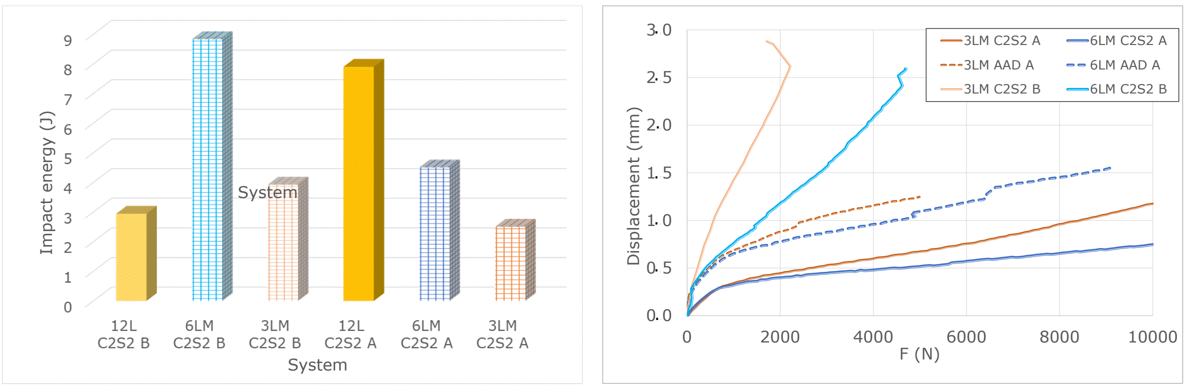


Figure 6. a) *Impact energy; b) Maximum force/ deformation in concentrated loading*

6. CONCLUSIONS

- In general, the test methods of impact resistance do not include a particular description of the types of damage that are to be evaluated, so that the requirements relative to this performance characteristic are usually limited to chipping and/or global fracture of the product.
- The use of a ceramic slab mesh-reinforcement backing does not contribute significantly to improving impact resistance and load-bearing capability in rigid systems, thought it does in deformable systems, in addition to limiting the proneness to fracture.
- In rigid systems, an increase in slab thickness usually improves both impact resistance and load-bearing capability. In contrast, in deformable systems, impact resistance depends on the compatibility of the level of deformation of the different layers. In contrast, the increase in a system's deformability and the reduction in tile thickness generally tend to lower resistance to concentrated loading.
- Given the opposing character of the stress generation mechanisms between the (high speed) impact phenomena and progressive (low speed) loading, it would be feasible to design systems, optimising the combination and deformability of the layers in accordance with the type and thickness of the ceramic material, in order to balance these two performance characteristics or to favour the most relevant one as a function of intended use.

7. ACKNOWLEDGEMENTS

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