# IMPACT RESISTANCE OF PORCELAIN STONEWARE TILES: A PHENOMENOLOGICAL APPROACH

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## 1. ABSTRACT

The impact resistance of ceramic tiles is an important technical requirement, especially for large size and/or low thickness slabs. The standard test for ceramic tiles (ISO 10545-5) is non-destructive: it determines the coefficient of restitution of a small sample (75x75 mm) assembled on a concrete substrate under a weak impact energy (0.27 J). This method does not provide an impact strength or information on the way a ceramic tile is broken by impact. In order to fill this gap, an investigation was undertaken to describe, by a phenomenological approach, how ceramic tiles break under different conditions of impact. For this purpose, unglazed porcelain stoneware tiles of different size (12x12, 25x25, 60x60 cm) and thickness (3.5, 5 and 8 mm) were assembled on a concrete base and tested for the coefficient of restitution (ISO 10545-5) and Roesler index. Their impact strength was measured by falling steel balls (50, 80, 200, 500 g) with increasing energy (from 0.2 to 6 J) and with different speed (from 1.9 to 5.5 m/s). The effects caused by impact were visually inspected, revealing for increasing energy the formation of an impact ring, radial cracks, one or two concentric Hertzian cone fractures, a highly fractured inner zone. The resulting damage was quantified by measuring the impact ring diameter as well as the number, length and estimated surface area of radial and conical cracks. A nearly linear dependence on the impact energy was found for crack length and surface, while the ring diameter and crack number seem to follow a quadratic law. The impact strength depends on the tile thickness, but sample size may also in some way affect the mechanical behaviour under impact. A scale of 7 levels of damage was drawn up to better describe tile behaviour in use, thus helping to select the correct type of tile for different applications.

# INTRODUCTION

## 3. EXPERIMENTAL

Three industrially manufactured unglazed porcelain stoneware tiles with different thickness (3.5, 5 and 8 mm, respectively) were used. Samples were prepared by cutting the tiles to different sizes (12x12, 25x25, 60x60 cm) which were assembled on a concrete base according to the specifications of ISO 10545-5.

The behaviour on impact was determined by measuring the coefficient of restitution (ISO 10545-5) and the impact strength by falling steel spheres of different weight (50, 80, 200, 500 g) and diameter (from 10 to 50 mm). Balls were allowed to fall from different heights (from 38 to 135 cm), thus varying energy (from 0.2 to 6 J) and speed at the moment of impact (from 1.9 to 5.5 m/s).

After impact, the tiles were characterized quantifying the damage by measuring the diameter of the impact ring and the inner microfractured area as well as the number and length of radial and conical cracks (Fig. 1). The new surface formed upon impact was estimated by the total length of cracks, assuming a depth of 3 mm. The Roesler rigidity index ($P/R^{3/2}$) was calculated as the slope of the impact energy (P, in J) to imprint radius ($R^{3/2}$, in mm).

## 4. RESULTS AND DISCUSSION

The three porcelain stoneware tiles studied are characterized by different coefficients of restitution, which scale with tile thickness: 0.79±0.02 (3.5 mm), 0.84±0.02 (5 mm) and 0.89±0.02 (8 mm). There is no minimum standard requirement for the $BI_a$ tile group (ISO 13006 and EN 14411).

The degree of damage increases with the impact energy and, according to the appearance of the damage, seven classes can be distinguished (Fig. 2). Even at low impact energy (e.g., 0.3 J) the steel ball can leave an imprint represented by a tiny circle without apparent internal features (class I). The next step is a circular ring with a micro-fractured inner rim (class II). Further, short radial cracks appear (usually four) around the imprint ring (class III). Increasing the impact energy, the number and length of the radial cracks increase, as does the inner fragmentation of the ring (class IV). This process proceeds with the appearance of a first ring (class V) and a second ring (class VI) of concentric cracks, i.e. the intersection of Hertzian

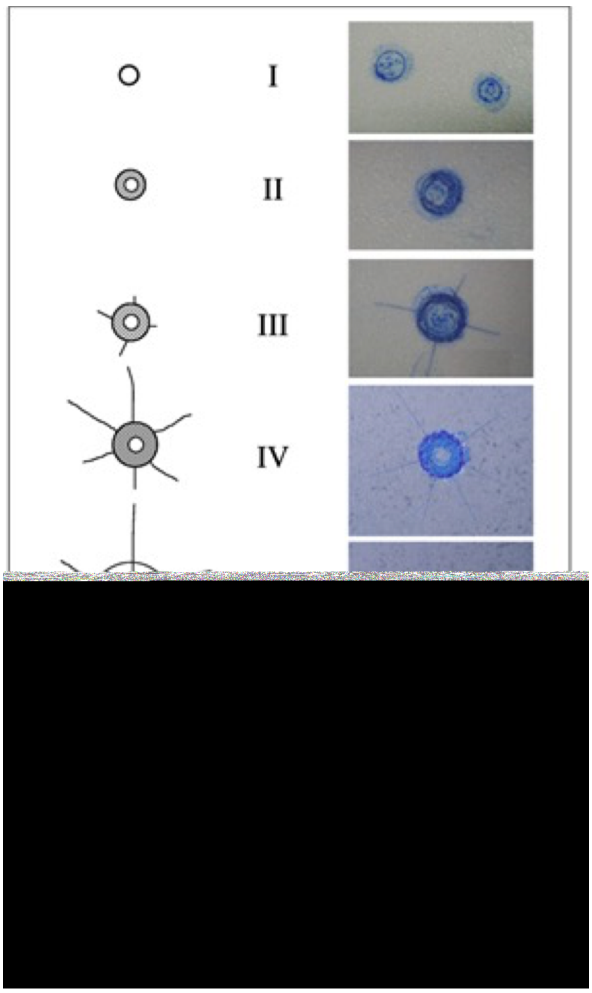


***Figure 2.*** *Classes of damage at increasing impact energy*

Interestingly, a certain dependence on the tile size arose: 60x60 cm tiles suffer more severe damage than the 25x25 cm and 10x10 cm tiles (Fig. 4).

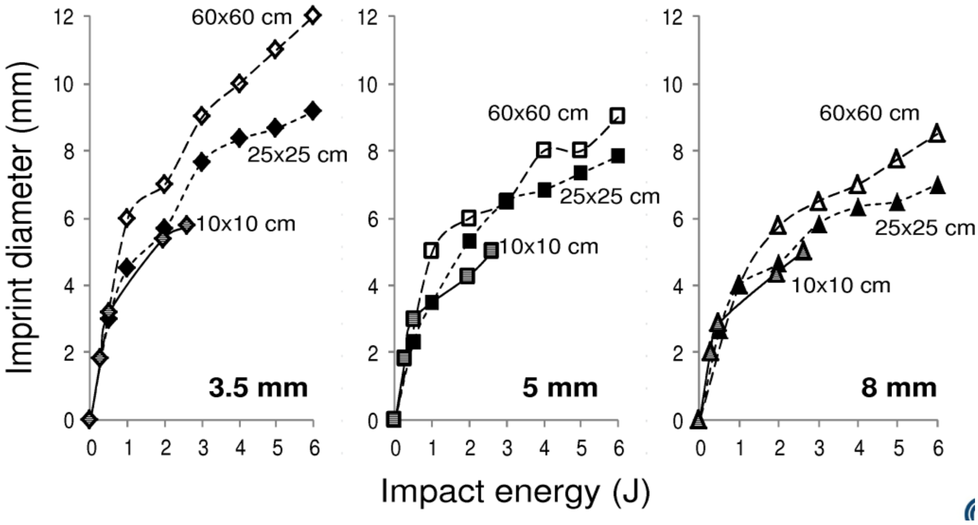


***Figure 4.*** *Imprint ring diameter in function of the impact energy for different tile sizes (10x10, 25x25 or 60x60 cm) and thicknesses (3.5, 5 or 8 mm).*

The impact behaviour depends on the tile thickness with an almost linear trend, as shown by both the Roesler index and the inner micro-fractured zone inside the imprint (Fig. 5). The behaviour of the 5 mm thick tiles is closer to that of the 8 mm thick tiles; the 3.5 mm thick tiles exhibit a higher increase in Roesler rigidity and inner fragmented area. However, at low energies (<3 J) the data are practically overlapping.

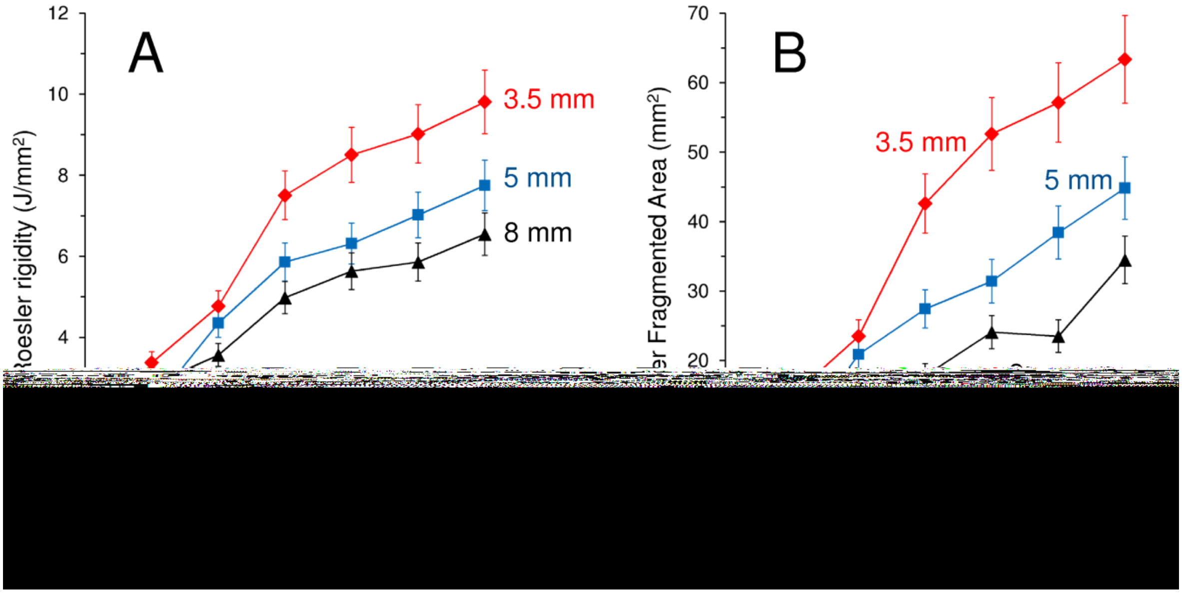


***Figure 5.*** *Roesler rigidity index (A) and area of the fragmented inner ring (B) in function of the impact energy in 25x25 cm tiles.*

With regard to radial cracking, a non-linear increasing is observed in function of impact energy (Fig. 6). Data trends of tiles with 5 and 8 mm thickness are mostly superimposed, since the number of cracks, their mean length and the total length of radial fractures all lie within the experimental uncertainty. Thin tiles are characterized by a larger number of radial cracks, even at low impact energy, when short cracks developed; their fractures are longer both as mean and total values.

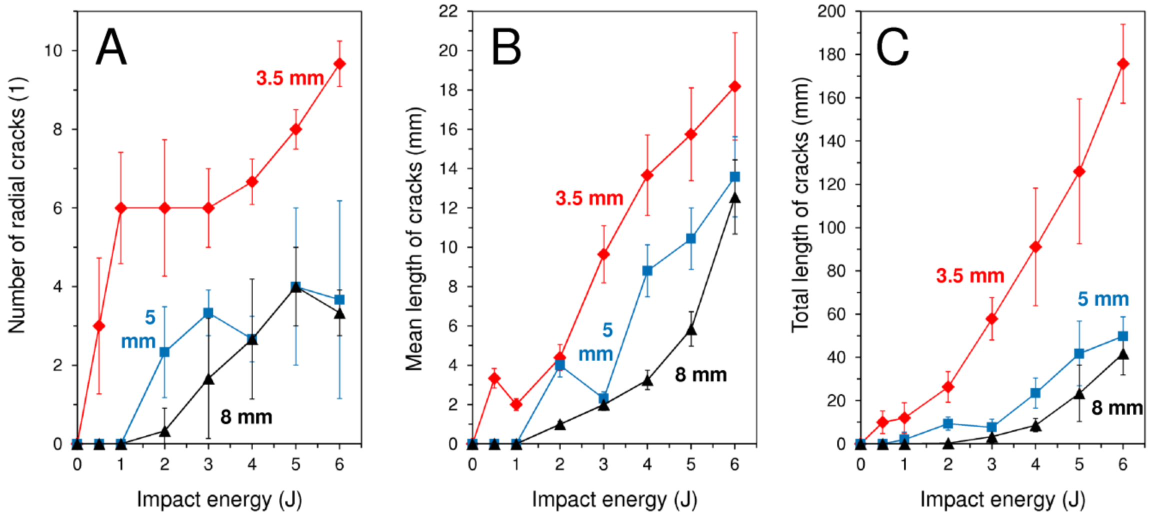


***Figure 6.*** *Number (A), mean length (B) and total length (C) of radial and concentric cracks in function of the impact energy in 25x25 cm tiles.*

An attempt was made to estimate the new surface formed under impact by assuming a constant depth of radial and concentric cracks (Fig. 7). Within the uncertainty of this assumption, the new surface created by impact was practically the same, in all the types of tiles, in the low energy field (<2 J). For higher energy, thin tiles have a wider fracture surface than those with a thickness of 5 and 8 mm, which present similar data.

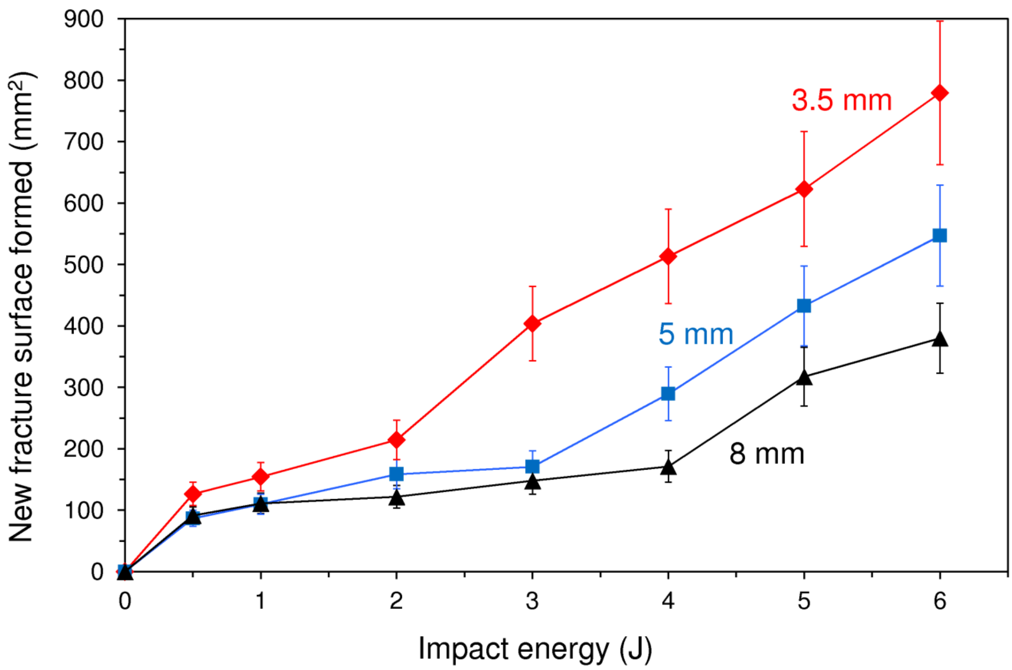


***Figure 7.*** *New surface formed by cracking in function of the impact energy.*

## 5. CONCLUSION

Porcelain stoneware tiles exhibit a complex behaviour under impact with distinct damage features for increasing energy. The impact resistance depends on tile thickness, but not linearly: more severe damage occurs for thickness below 5 mm.

The impact strength is affected by the tile size as well: large formats seem to suffer more severe damage. It is confirmed that this also depends on speed (and size) of the falling object.

In agreement with the literature, both elastic and pseudoplastic phenomena can occur simultaneously in the impact of objects on porcelain stoneware tiles.

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