DETERMINATION OF IMPACT RESISTANCE BY MEASUREMENT OF COEFFICIENT OF RESTITUTION

W. L. WALTERS
British Ceramic Research Ltd.
Queens Road, Penkhull. Stoke on Trent, ST4 7LQ

1 INTRODUCTION

Experience in the investigation of floor-tile failures involving damaged tiles has indicated that the major contributory factors to failures are high intensity loadings, and impact damage. The damage usually takes the form of cracked or splintered tiles, and complete adhesion failure of whole tiles has also been encountered. This type of failure is invariably confined to heavy duty situations, such as factory floors, bakeries, industrial kitchens, and latterly, supermarkets.

It appears that load intensities in these situations are on the increase, and that more and more demands are being made on floor-tiling. Failures have been observed with all types of tiled floors and fixing systems.

The support provided by the substrate is clearly a critical factor in this type of failure, and it has long been considered desirable to have a simple test to establish whether a floor has adequate strength to withstand the intended loads. This report describes the development of such a test for assessing the impact strength of tiled floors.

2 COEFFICIENT OF RESTITUTION

A suitable property to measure would be the coefficient of restitution, *e*, between the floor and a steel ball. The coefficient of restitution between two impacting bodies is defined as the relative velocity of departure divided by the relative velocity of approach. For a ball impacting a flat static surface

$$e = v / u$$

Now $$v = \sqrt{2gh_2}$$

and $$u = \sqrt{2gh_1}$$

therefore,

$$e = \sqrt{\frac{h_2}{h_1}}$$

where: h_1 = height of drop
h_2 = height of rebound

In a purely elastic impact with no energy losses due to heat, sound or friction, *e* would equal 1. However, all impacts are less than perfect and a value of *e* less than 1 is always obtained. The lower the value the more energy has been permanently lost at impact. If the impact is not 100% elastic then energy will be used in rupturing the surface or causing a permanent plastic deformation. In the case of a steel ball impacting ceramic tiles it can be assumed that heat, sound, and friction losses are constant and so the value of *e* will give a measure of the permanent damage sustained at impact. Thus a quantitative assessment of the ability of the tiling to withstand impact can be made.

3 APPARATUS

A diagram of the original apparatus is shown in Figure 1. It consists of a steel bar, 4 ft (122 cm) long, to which is attached an electromagnet. The magnet slides up and down the bar and can be set to any desired position. A scale, clamped to the bar, is calibrated in centimetres and it is also adjustable in height. The base of the apparatus is fitted with levelling screws. A subsidiary part of the apparatus is a small stand with three short steel cylinders with hemispherical tops set at the apexes of an equilateral triangle with sides 5 cm long. This is to provide a standard base for testing individual tiles or small samples of flooring not *in situ*. The magnet is capable of holding steel balls of up to 2 inches (5 cm) diameter. The standard base is sited so that on release the steel ball impacts the exact centre of the equilateral triangle formed by the three studs.

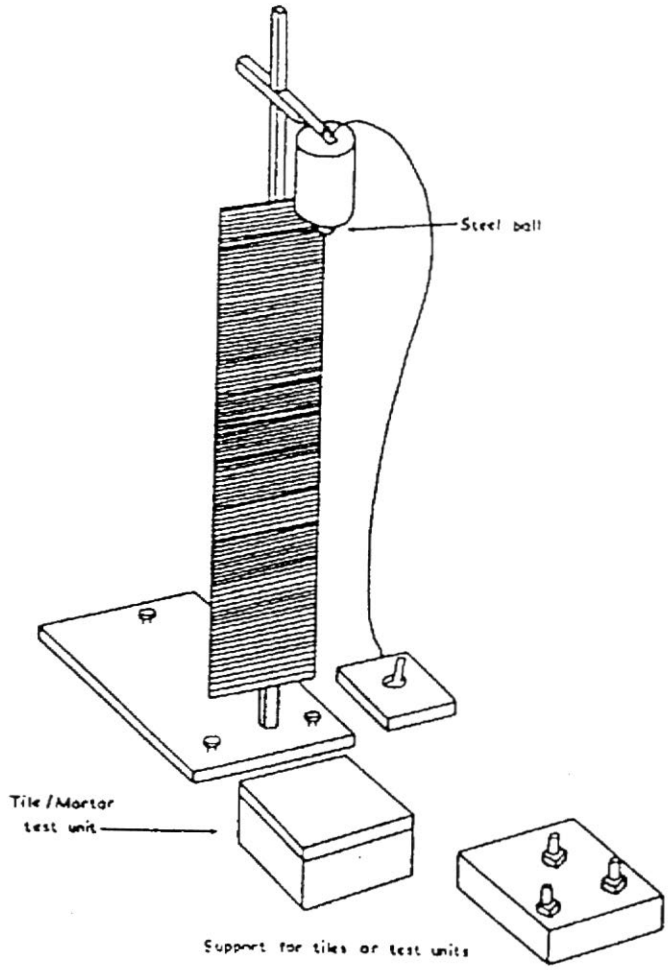

FIGURE 1 - Diagram of dropping-ball apparatus.

When conducting experiments the ball is dropped from a height of 1 m on to the sample under test, its trajectory passing about 5 cm in front of the scale. The height of rebound is noted and read when the eyes are level with the top of the rebound trajectory. This is quite easily done after an initial trial drop, good repeatability being achieved in practice. Alternatively, when measuring small samples, the experiment can be performed in a dark-room with a strong light illuminating the scale from the front. The rebound height is read directly from the bottom of the shadow of the ball. The light is set sufficiently far away (3 m) to eliminate parallax errors. With practice an accuracy of 0.5 cm is easily obtained. When testing a floor an average of 10 drops on different tiles for each type of ball is considered sufficient to produce a representative value for the coefficient of restitution. When testing individual tiles on standard backings five samples are used, impacts from the different balls being obtained on each tile although on different sites. Drops with the smaller balls are done first as less damage is produced on the tile, thus ensuring that there is no interference on subsequent impacts from the larger balls. Usually no more than three different sized balls are used: 1/2 inch, 3/4 inch, and 1 1/4 inch diameters.

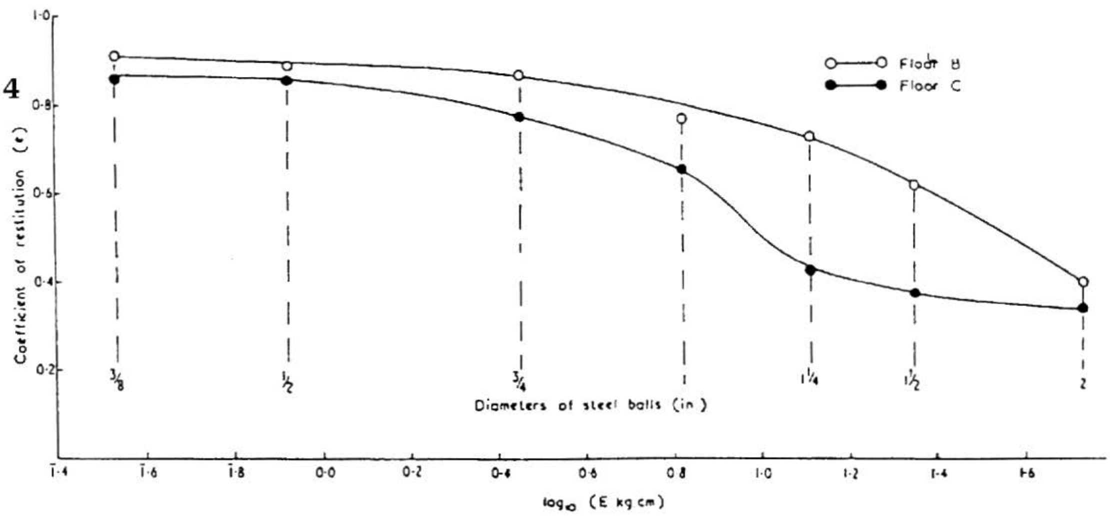

FIGURE 2 - Coefficients of restitution measured with various sizes of steel balls

PRELIMINARY EXPERIMENTS

In the course of research into systems of fixing, standard BI unglazed floor tiles (9.5 mm thick) were used on a series of floors.

Steel balls with various diameters were dropped from 1 m on to the approximate centres of a large number of the tiles and the height of rebound measured. The values of *e* were calculated and are shown, related to the logarithm of impact energy, in Figure 2.

FIGURE 3 - Hertzian cracks in vitrified floor-tile surface (x36)

Each point is the mean of five readings. From this graph three ball sizes were selected for use in future experiments - the 1 1/4 inch diameter ball for the discrimination of stronger floors and the 3/4 inch diameter and 1/2 inch diameter balls for weaker floors. In testing a floor or a type of tile at least two adjacent sizes of these balls would be used. Close examination of the floors after these tests revealed that without exception all impacts had produced visible permanent damage in the form of Hertzian cracks of the type shown in Figure 3. The smaller impact energies gave the more perfect circles, the greater impacts sometimes producing associated radial cracking. For any particular size of ball the Hertzian cracks are fairly constant. For different *e* values therefore, varying damage must be produced that is not visible, presumably to the backing below the tile. It is possible also that the rear face of the tile sustains damage, this face being in tension at impact. We have no direct evidence for this, however.

Experiments on small test samples of semi-dry mortar flooring with similar tiles showed that the *e* value of the system increased rapidly during the first few days after fixing. The results for an average semi- dry mix are shown in Figure 4. The importance of a «waiting time» before heavy loading on the floor is at once obvious from the graph.

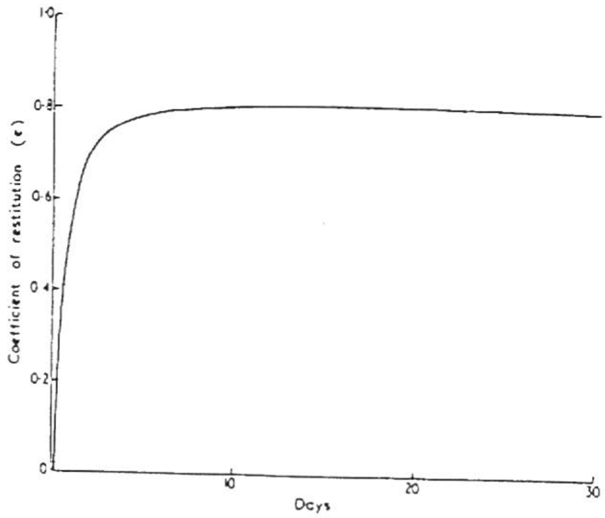

FIGURE 4 - Change in the coefficient of restitution with maturing for test unit consisting of tile on semi-dry mortar.

There is no doubt that many reported cases of damage are caused by initial carelessness. When a problem is under investigation after months or even years it is difficult to prove that heavy trucks or machinery were moved over tiles within 2 days after they were laid. This has nevertheless been observed directly, and there has been sufficient evidence in a few other cases to be certain that loading too early has been responsible for damage. The measurement of the impact resistance on undamaged areas may in many instances show that the floors are sound and that the damaged parts must have resulted from unusual treatment.

5 RESULTS

Apart from a series of experiments on floors in-situ it was decided to measure a range of floor-tiles in «standard» conditions of fixing and base. Tiles were fixed with a cement-based thin-bed adhesive to a 5 cm thickness of compressed concrete paving slab. All samples were allowed to age for 7 days before testing.

Table 1 gives a selection of results for floor-tiles under constant conditions of fixing and base.

TABLE 1
Examples of Coefficients of Restitution (*e*) for Tiles in Standard Test Units

Description	*e*(1/2)	*e*(3/4)	*e*(11/4)	Comments
7 mm Buff vit		0,87	0,73	Similar body. Increased thickness improves e(11/4)
10 mm Buff vit		0.87	0.79	
8 mm Grey fully vit		0.91	0.76	Improvement with increased thickness.
11.5 mm Grey fully vit		0.93	0.79	
16.5 mm Grey fully vit		0.94	0.88	
7 mm Red vit		0.90	0.76	Different manufacturers. Similar types of tiles from all sources give similar results.
11 mm Black vit		0.91	0.82	
3.5 mm Glazed	0.70	0.59	0.38	Similar body. Improvement with increased thickness
5.5 mm wall-	0.73	0.66	0.46	
7 mm tiles	0.73	0.69	0.54	
8.5 mm Glazed floor- tiles	0.82	0.73	0.59	
8.5 mm Engobed vit	0.93	0.91	0.78	

Some of these values are remarkably high. Many of these test specimens approach what can be regarded as an ideal flooring system. Even on such a sturdy backing as pressed concrete there is an increase in the coefficients of restitution with an increase in the thickness of tiles. This effect will be even more marked on weaker flooring.

It appears from these results that the thicker the tile the more the system behaves like a monolithic layer. As might be expected this behaviour becomes more obvious the smaller the impacting ball.

For rebounds from smooth surfaces the coefficients of restitution reduce as the dimensions of the steel balls are increased. That is, $e\,(1/2) > e\,(3/4) > e\,(1\ 1/4)$. Occasionally this order has not been maintained and examination of the surface has shown that it was rough. In overcoming the roughness a substantial fraction of the energy is absorbed. Successive impacts on rough parts would therefore be likely to produce fractures or chipping. This conforms with observations in practice.

6 ISO/DIS 10545-5

Measurement of the coefficient of restitution requires only a simple technique and produces single values which could be used to classify floors in terms of their suitability for various service conditions.

Comparisons are clearly also possible between different types of tiles or indeed adhesives or any other layer within the total floor section. The results for test specimens given in this paper were obtained with tiles fixed to the solid support of dense concrete. These results are therefore near to the maximum attainable values and this should be remembered in any comparisons that may be made.

Thus it is seen how the ISO standard 10545-5 has evolved. It was thought that the use of the 3/4 inch (19 mm) ball would be most suitable. Smaller balls would not differentiate, larger, and the test would be a destructive test.

We put forward the following classification.

TABLE 2
Tentative Classification of the Impact Resistance of Floors

Floor	Minimum Coefficient of Restitution for Steel Ball of Diameter 19 mm
Heavy duty Normal duty	0.85 0.70
Light duty 0.50	

Certain changes have been introduced into the standard and the design of the apparatus has been upgraded. Figure 4 shows a diagram of the modern apparatus and figure 5 a photograph. The main improvement of course is the use of an electronic timer to obtain an accurate measure of the rebound height.

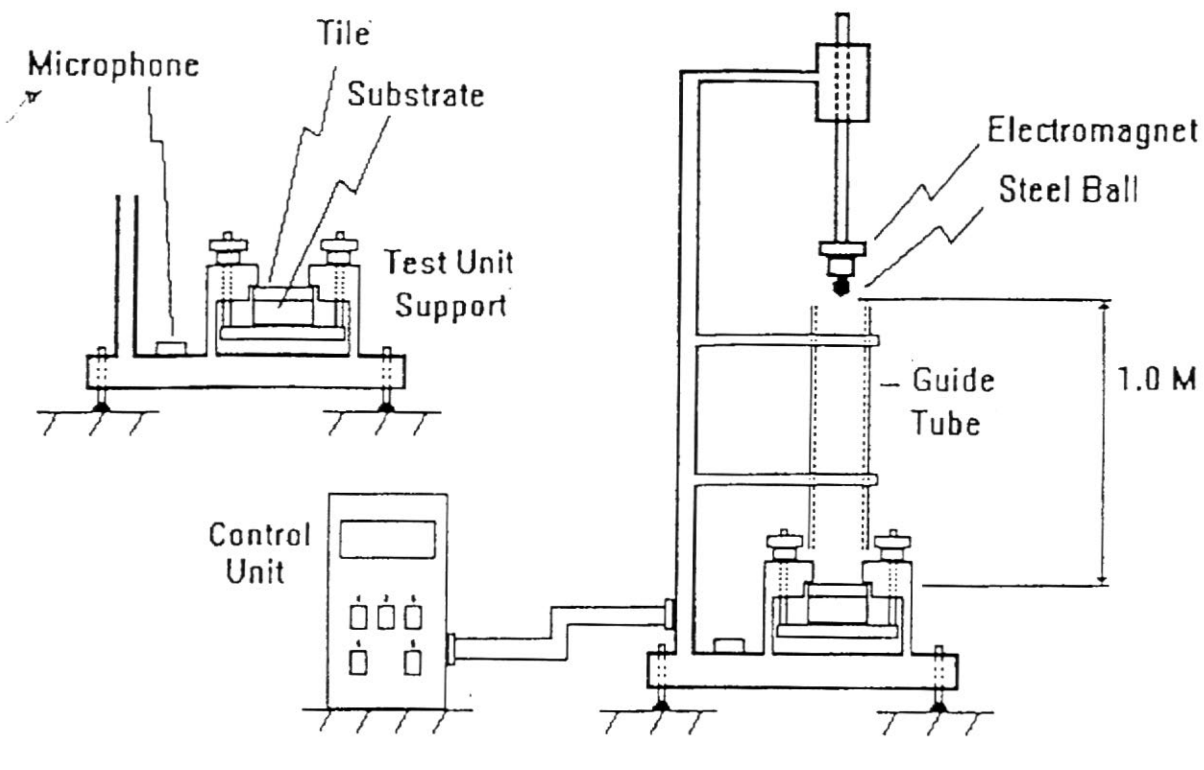

Figure 5 Schematic of Apparatus for Determining the Coefficient of Restitution of Ceramic Tiles

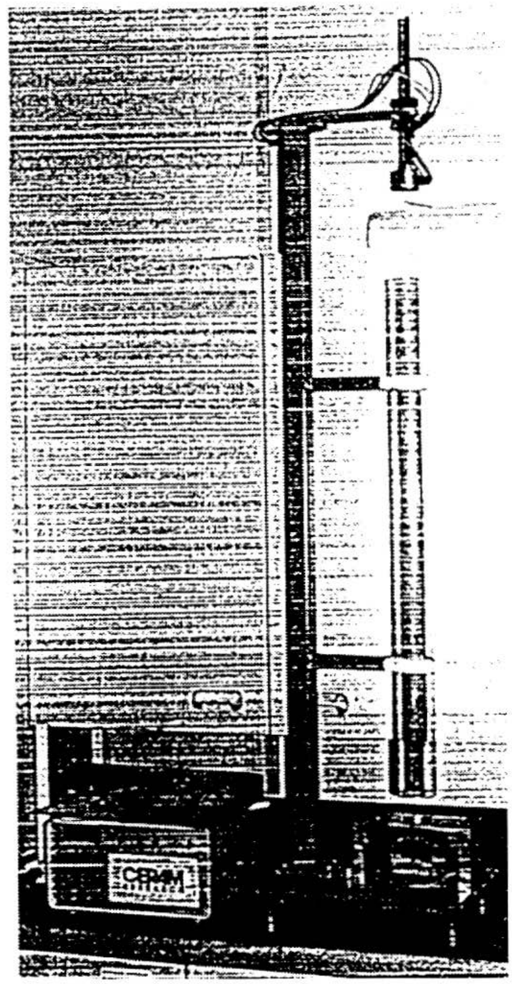

Figure 6 Coefficient of Restitucion Apparatus

7 CONCLUSIONS

Measurement of the coefficient of restitution by means of the dropping- ball procedure is useful for assessing the impact resistance of tiled flooring and also for testing individual floor-tiles.

In the standard however, it must be remembered that this is a means of differentiation of tiles for various environments. The measurement is not sensitive enough say to differentiate between two equal thickness fully vitrified tiles from different manufacturers.