THE IMPACT RESISTANCE OF CERAMIC TILES AND FLOORING

by Roy Harrison and Ralph Brough

Ceram Research, Stoke-on-Trent, UK

SUMMARY

The relative importance of Impact Resistance, Breaking Strength and Modulus of Rupture is discussed. Most strength-related damage in service occurs as a result of impacts but these manifest in various ways. The most common cause of fracture damage is where tiles or areas of tiles are unsupported or have soft or friable underlying layers near to the tiles. As a consequence some damage can be attributed directly to poor fixing techniques or poor supports or backgrounds. The measurement of the coefficient of restitution is not only a means of establishing differences between the strength quality of tiles but also the impact resistance of floor or wall installations.

Floors are more prone than walls to impact damage because of falling objects and the point-load characteristics of some footwear, for example stiletto heels and hobnailed boots. Special techniques simulating this type of impact damage are described. These can classify tiles but, unlike the coefficient of restitution, they do not provide data for an absolute physical property. Nevertheless, application of the measurements enables tiles to be chosen which are most suitable for specific requirements of the best possible impact resistance.

INTRODUCTION

The strength of ceramic tiles is important for their life in service. Stresses are imposed upon tiles as a result of size changes within backgrounds and even from poor quality adhesives. Floor tiles are expected to sustain many types of loads, some of which may be static but impact loads also occur. Impact loads provide the most usual way for breakages on walls.

1.BRITISH STANDARDS

Until the introduction of the European Standard method of test for modulus of rupture (1) there was not a British Standard method for tiles. Modulus of rupture (M of R) has always been accepted as an appropriate means of regulating the production of tile bodies in manufacture. The green strength, that which is obtained on bodies before firing, is used on tile factories as a means of quality control. The minimum M of R is established for each body in each dimension of tile or test specimen. This is comparative only at that point of production on each factory.

When the British Standard for Wall tiles was revised in 1966 (2) it was considered essential to have a method of test for strength but M of R was not considered the appropriate method for tiles in service and a simple pass/fail system based on impact loading, was devised. This used a 19 mm diameter steel ball which was dropped from heights related to the actual thicknesses of glazed wall tiles (Table 1). The philosophy behind the chosen heights was not to achieve fine discrimination between different bodies but to ensure that each thickness of tile was strong enough for service conditions considered to be appropriate to the particular thickness. All the tiles in this standard were porous body glazed tiles so that the distinction made only on the basis of thickness was valid. This would not have been the case with the greater variety of floor tiles available from British manufacturers.

Table 1.

Pass/fail limits for tiles of various thicknesses from British Standard 1281:1966

Tile thickness (mm)	Height from which steel ball is dropped (mm)
4	127
5	229
6	330
10	660

2.AMERICAN STANDARD

An early version of the current American standard, ASTM C648-84, a test method for breaking strength, was investigated. This utilizes support for the tile on three cylindrical rods arranged in an equilateral triangle and applying a force to break the tile at a fixed rate in the centre, coinciding with the centre of the triangular support.

This appeared to be appropriate to many types of fracture seen in service because the tiles break in a number of pieces. This is contrary to EN 100 where tiles are expected to break in two and always in the central portion created by the three-point loading used for M of R. If tiles break under a static load or at a slow rate of loading the breaking strength is more appropriate than M of R. The mode of fracture with the ASTM method is similar to that experienced with impact damage away from the edge of tiles. This is not the case with M of R.

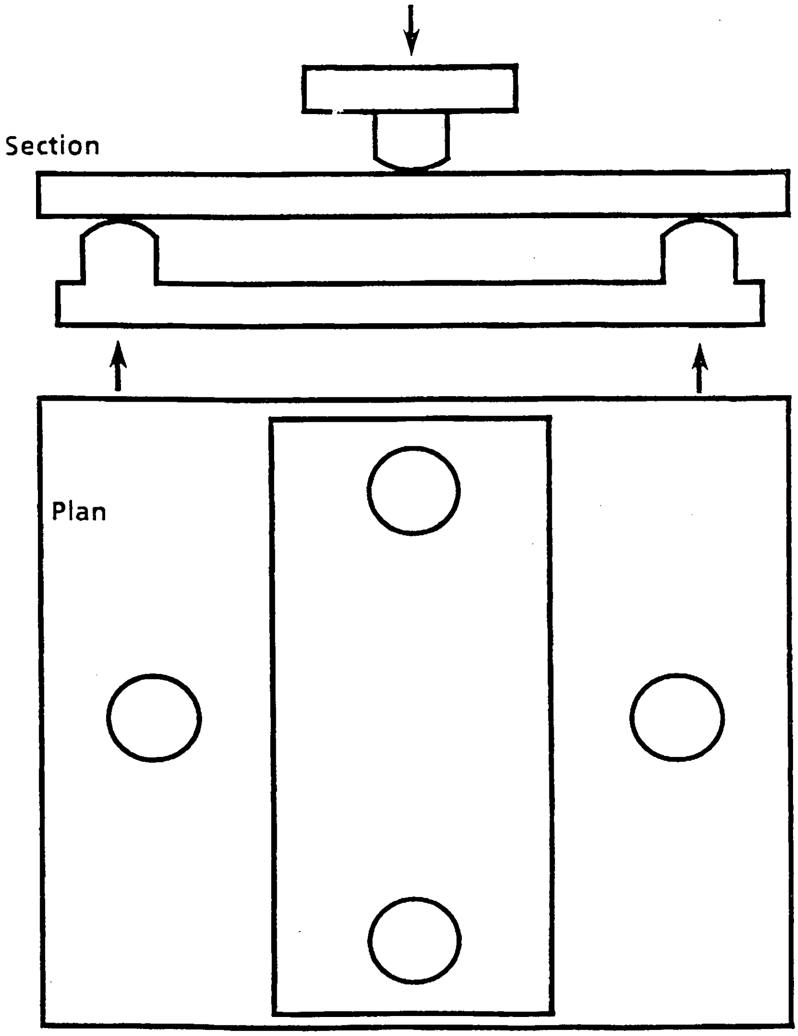
3.MODULUS OF RUPTURE MEASUREMENTS

One of the problems with M of R has always been to obtain consistent results with tiles that are not perfectly flat.

Since glossy glazed tiles with concave surfaces are aesthetically poor the preferred shape of such tiles is to have convexity at the glazed face. This is more satisfactory for service conditions than attempting to achieve perfect flatness. Therefore glossy glazed tiles are not usually flat. The roller hearth system of firing helps to achieve flatness, especially with large tiles but even so dimensional tolerances have still to accommodate changes caused by firing shrinkage and glaze/body strains.

In EN 100 correction for measurements on non-flat tiles is made by having one of the three-rods used for the 3-point loading rotatable and another slightly pivotable. In addition the rods are covered with soft rubber. Although allowing non-flat tiles to fit more easily on the rods the latter detracts from the strict physical requirements of 3-point loading.

In attempts to overcome this problem in the strength measurements conducted during preparation of the 1966 BS1281 ⁽²⁾ the best system for 3-point loading for M of R with whole tiles was found to be the use of four steel studs as illustrated in Figure 1.



1.3 point Modulus of Rupture loading with 4 steel studs.

For measurements for research and development in the laboratory 25 mm - wide strips are cut from tiles. This is performed dry and there is no necessity to grind the edges smooth. The test bars are then broken by 3-point loading. This eliminates the problem of non-flat tiles which is one of the main disadvantages of whole-tile measurements. The results are more consistent and there is the enormous advantage over whole-tile testing that variations across a tile can be detected. It is not unusual to find tiles with harder and stronger edges than centres and if the M of R results are significantly different this may indicate a need to investigate the firing schedule and atmosphere conditions. Breaking strength data can obviously be analysed in the same manner but if M of R data has to be given test bar data are preferred to whole tile data.

Another major problem with M of R is its unfortunate relationship to the thickness of tiles. Typical results for one porous-body wall tile with different thicknesses of body but the same type and thickness of glaze are shown in Table 2.

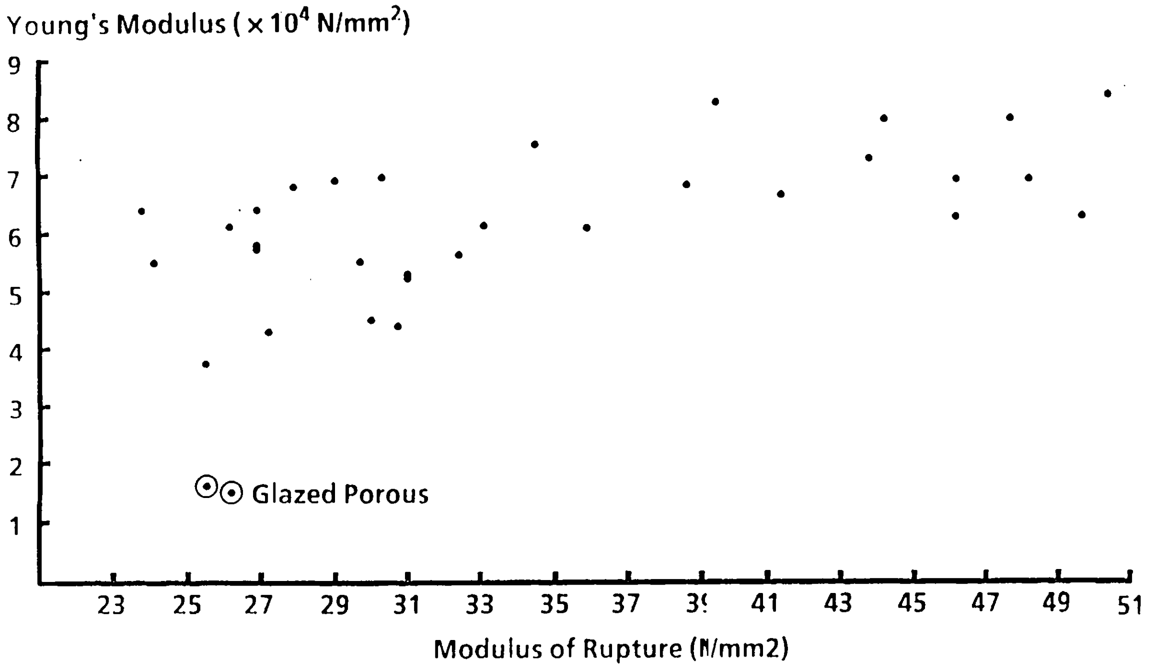
Table 2.

Thickness v breaking strength and M of R

Tile thickness (mm)	Breaking strength (N)	M of R (N/mm^2)
0.95	1628	15.2
0.64	1165	21.3
0.48	721	22.2
0.40	325	24.8

Thus the thicker the tile the lower the M of R yet in service the thicker the tiles withstand greater loads, whether static or impact, before fracture. For heavy duty requirements as in some work places it is usual to specify thick tiles in order to prevent damage. In places such as shopping malls where isolated loads are usually relatively low, that is equivalent to the weight of one person, the effect of high density pedestrian traffic demands tiles of 8 mm thickness and greater. The problem of thickness is further illustrated by the difficulty some thick unglazed floor tiles have had in meeting EN limits. Thus a tile at 15 mm or 19 mm thickness specified for heavy duty requirements may not meet the EN limit but by reducing the thickness 1 or 2 mm it will comply. This is a silly situation. The problem does not arise with breaking strength and impact resistance measurements. Modulus of rupture is a body property and not a tile property.

It is of interest to see the relationship between Young's modulus and M of R. In Figure 2 all but two of the points are for vitrified dust-pressed and extruded unglazed floor tiles with most water absorptions being below 3%. The range of Young's moduli is $3.75 \times 10^4 N/mm^2$ to $8.3 \times 10^4 N/mm^2$ with a wide range of M of R values from $23.8 N/mm^2$ to $50.2 N/mm^2$. Two results for glazed porous-body tiles are shown for comparison.



2. Relationship betweenYoung's modulus and Modulus of Rupture for floors tiles.

4.DAMAGE IN SERVICE

The British Standard Code of Practice for flooring BS5385, Part 3 recommends that floor tiles should be laid solid-bedded, whether by means of adhesives or by cement-sand mortar, without all but minor air bubble voids. Nevertheless tiles are occasionally laid on adhesives with notched trowel application. There may also be the wrong choice of adhesive so that it does not provide rigid support. Furthermore, tiles may be at an angle when placed on adhesive so that one side or one corner of adhesive or mortar is depressed, leaving a void beneath the tile. The latter is particularly prone to happen to the largest sizes of tiles.

Where there are voids the tiles are most prone to impact damage. In some instances the points of impact are detected but the impactors may not be pointed. Small area top-pieces of ladies' shoes are known to have caused some damage. In the instances of angled placing leading to voids some floor installations have been examined with a high proportion of tiles with the corners cracked off, even with well filled and well adhered grouted joints.

Impact damage is sometimes detected at the edges of tiles adjacent to flexible movement joints. This is another situation where there are voids beneath the tiles, in this instance because of failure to support the tiles at those edges. The force required to break the pieces of tile away is derived from impacts and not from slow development of bending movements.

Another cause of floor damage is from moving heavy loads across floors before they have developed sufficient strength. High energy impacts occur when objects roll over or are pushed over projections. This type of damage can be reproduced in the laboratory with Robinson trolley (5) types of test.

The positions most prone to impacts with walls are where there are pillars or pilasters or at doorways, especially in industry with vehicles passing through.

5.MEASUREMENT OF IMPACT RESISTANCE

5.1.Coefficient of restitution

5.1.1.Theory

The most suitable property to measure is the coefficient of restitution, **e**, between the floor or tile 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

$$e = \frac{v}{u}$$

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

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

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

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.

5.1.2.Apparatus

A diagram of a basic form of apparatus is shown in Figure 3. The vertical steel bar supports an electromagnet used to release steel balls at particular heights and may also hold a scale for determining heights of rebound. In the version proposed for standardization the height of drop (h_1) is fixed at 1 m and the rebound height (h_2) is determined by means of timing the difference between the first and second bounces and converting this electronically to the coefficient of restitution. Individual tiles may be measured by support on three studs in the form of an equilateral triangle but the preferred method uses tiles adhered with a rigid epoxide resin adhesive to concrete blocks. The steel ball impactor is 19 mm diameter, with a mass of 28 g.

5.1.3.Applications

The technique is primarily used in the laboratory for assessing the strength, as the coefficient of restitution, for tiles. For this, the concrete blocks and epoxide resin adhesive are constant while the only variation is in the tiles. Some comparative results are shown in Table 3.

Table 3. Examples of Coefficients of Restitution (c) for Tiles in Standard Test Units

Description	e
152 x 152 x 7 mm	0.87
Buff vit.*	
152 x 152 x 10 mm	0.87
Buff vit.	
152 x 152 x 8 mm	0.91
Grey fully vit.	
152 x 152 x 11.5 mm	0.93
Grey fully vit.	
152 x 152 x 16.5 mm	0.94
Grey fully vit.	
152 x 152 x 7 mm	0.90
Red vit.	
152 x 152 x 11 mm	0.91
Black vit.	
108 x 108 x 3.5 mm	0.59
152 x 152 x 5.5 mm	0.66
152 x 152 x 7 mm	0.69
152 x 152 x 10 mm	0.63
Glazed wall tiles	
202 x 202 x 8.5 mm	0.73
Glazed floor tiles	
152 x 152 x 8.5 mm	0.91
Engobed vit.	

* Vitrified dust-pressed floor-tiles

The effect of increased thickness can be seen for tiles which are otherwise similar. In the case of the glazed wall tiles the 10 mm - thick tiles do not have the same body formulation as the other thicknesses.

If a comparison between the effects of different adhesives is required then the tiles and concrete base are standardized. The technique has also been used in the laboratory to establish the degree of support given by different types of base or background. For example plaster-board, polystyrene and mortar supports have been compared by means of this technique.

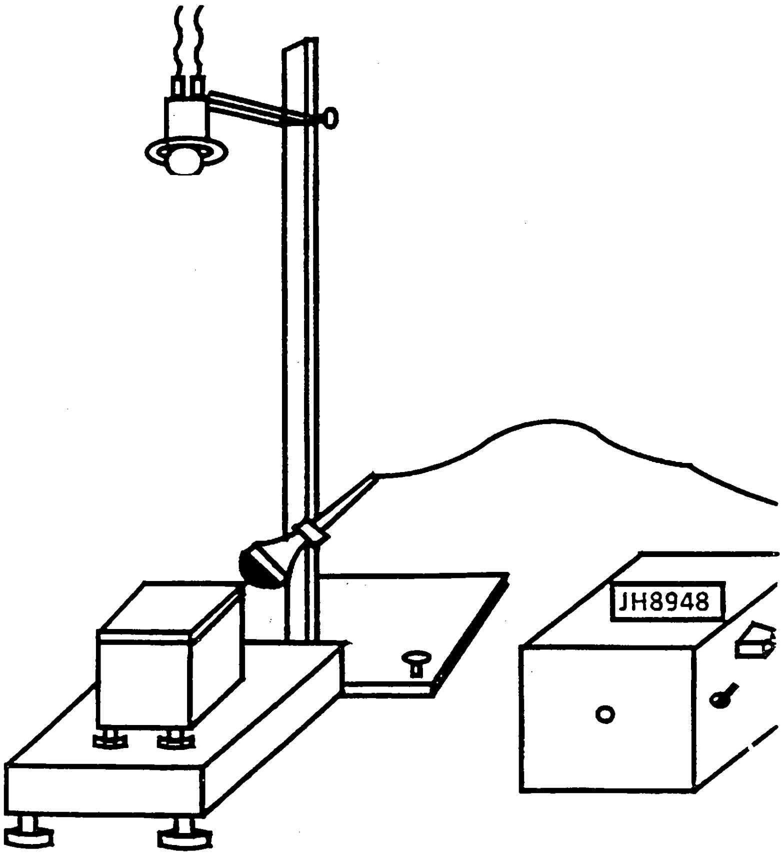
5.2.Point and Edge Impacts of Glazed Floor Tiles

5.2.1.General

Glazed floor tiles, especially those with the more porous bodies are prone to damage from pointed objects whereas unglazed vitrified floor tiles are rarely damaged in this way.

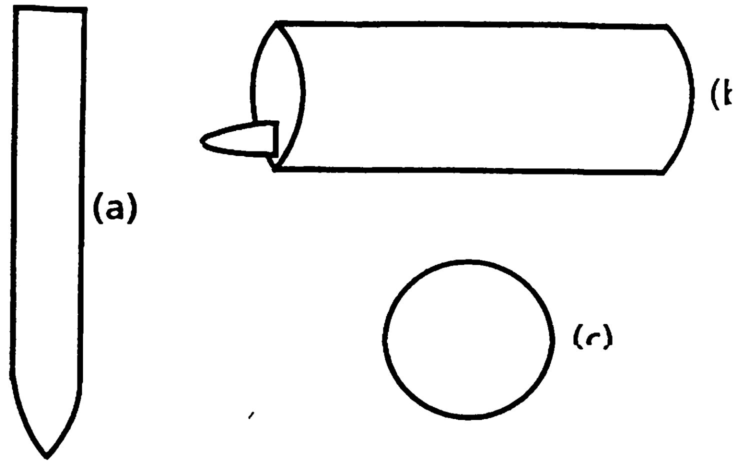
5.2.2.Point Impacts

To stimulate point damage on the face of tiles the coefficient of restitution apparatus (Figure 3) is used but the ball impactor, C in Figure 4, is replaced by a bullet-shaped piece of hardened steel (a) 56 mm long, 6 mm maximum diameter and 12.5 g mass. The impacting head has a radius of curvature of approximately 1 mm.



3.Diagram of dropping-ball apparatus for measuring the coefficient of restitution.

Tiles are assessed for resistance to point impact damage by comparing the damage sustained against four types of tiles which were selected from a range of tiles subjected to the standard point impacts. This enables a classification of 1 to 4 to be assigned, class 1 having craters of approximately 3 mm diameter and the glaze completely removed, and class 4 having craters confined to the glaze only, with a maximum diameter of 1.5 mm.



4.Different types of impactor.

5.2.3.Edge Impacts

Resistance to edge impacts is assessed by means of the steel impactor (b) in Figure 4. The maximum diameter is 19 mm and the barrel length 60 mm. The mass is 127.3 g. The impacting point has a radius of curvature of 1 mm. the method utilizes a pendulum apparatus (6) and impacts are made with the point of the impactor striking the tile surface at right angles. The first impact is made at a site approximately 1 mm from the edge of the tile and, choosing fresh sites for each impact, the distances from the edge are increased by 1 mm at a time until impacts fail to chip the tile. The distance from the edge is therefore a measure of the edge impact resistance, the lower the value the better the impact resistance.

In practice some resistance to edge damage is provided by the type of grouting material, the width of the joint and the efficiency of the filling. Considerable variations can therefore occur in service but the measurement technique enables tiles to be compared and their vulnerability to damage assessed where joints are poorly filled.

5.3.Measurements of Floors

5.3.1.Coefficient of Restitution

The apparatus described in 5.1 has been used extensively to measure the coefficients of restitution on individual tiles fixed on floors. The method is then being used to measure the floor system unlike the method in the laboratory where standard test units are used in order to compare tiles. Selected results from a number of installations are shown in Table 4.

Table 4.

Coefficients of restitution of floors

Brief description of floor	Approx. age (yr)	Coefficient of restitution (e)
Red vit UGL	26	0.55
White vit UGL	33	0.58
Quarries UGL	26	0.86
Red vit UGL	10	0.65
Red vit UGL	10	0.74
Dense Concrete	20	0.71
Wood Blocks	26	0.49
Mosaic floor UGL	26	0.86

These were all installations in service and they were not measured as a result of complaints. When the technique is used to assess floors which are showing progressive increases in impact damage and tiles becoming loose the average coefficients will invariably be lower than the typical results of satisfactory floors shown in Table 4. If the range of coefficients is large this is also a matter of concern.

The technique has been used to assess the strength development of floors and can thereby be used to decide when the floor can be put into service. This is particularly useful for heavy duty requirements in work places.

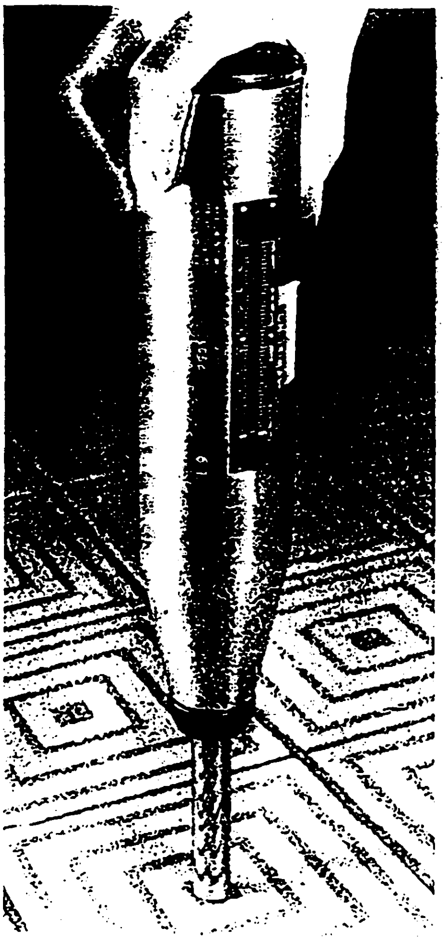
Two results are shown in Table 4 for floor not surfaced by ceramic tiles. Dense concrete, terrazzo and most natural stone floor in good condition have coefficients of restitution similar to tiled floors. Wood block surfaces and resilient tiles, e.g. vinyl, tend to have smaller coefficients.

5.3.2.Classification of floors

Ceram Research has adopted a classification with requirements for heavy duty floors, such as factory loading areas and garages, and floors in normal or medium duty service, such as those for pedestrians and lightweight trolleys only. The classification limits are shown in Table 5.

5.3.3.Schmidt concrete test hammer

For more rapid assessments of the potential resistance to impact damage of floors a Schmidt concrete test hammer is used. This gives impacts of 0.735 N.m which is only slightly above the impact energy of the standard coefficient of restitution apparatus. The principle of the hammer is to strike the surface with a vertical steel rod, controlling the impact force by means of a spring. The rebound, which relates to the quality of the floor, is indicated on a scale. Figure 5 shows a Schmidt concrete test hammer just prior to applying pressure to operate the instrument.



5.Type LR Schmidt concrete test hammer.Introduction

The minimum requirements used by Ceram Research are given in Table 5.

Table 5.

Minimum values for coefficient of restitution of floors

Type of service expected	Coefficient of restitution (e) Dropping ball apparatus	Rebound reading (%) Schmidt hammer
Heavy duty	0.85	60
Medium duty	0.70	45
Light duty	0.55	-

In reality Ceram Research find no demand for assessing floors described as for light duty only but the minimum value of 0.55 represents the expectation for all mature ceramic tiled floors.

Occasionally Ceram Research is required to measure every tile on a floor but usually the customer agrees to a reduced number of measurements, e.g. 1 in 5 or 1 in 10, in a regular grid over the whole floor. The readings are used to produce contour maps which highlight the variations in the floor and identify the most vulnerable areas to damage or adhesion failure. It is usual in these surveys to measure each tile at the centre but complaints or signs or damage which has already started may require the corners to be measured.

This system of checking floors is a regular feature of the service provided by Ceram Research and from these surveys judgments can be made as to the future of the floor. For example, the values may be so low that complete relaying is necessary. alternatively, it could be shown that damage that has already occurred probably resulted from too rapid loading after laying but the damage should not be progressive since the rebound values for the floor have now achieved a satisfactory level. The method often provides reassurance to the customer and protection for the tile layer but if there are voids, poor adhesion or soft support areas these can be identified.

6.CONCLUSIONS

1.In laboratory bending strength measurements, unlike breaking strength data, modulus of rupture data obscure the benefits of increased thickness.

2.For both M of R and breaking strength, measurements of test bars cut from tiles are preferred to measurements of whole tiles.

3.The measurement of impact resistance by means of the coefficient of restitution is the best method of assessing the relative strengths of tiles and floors.

Acknowledgement

The authors acknowledge permission from the Chief Executive of Ceram Research, Dr. N. E. Sanderson, to present the paper.

References

1.Ceramic Floor and Wall Tiles. Method for Determination of Modulus of Rupture. EN100, (BS6431, Part 12) 1983.

2.Specification for Glazed Ceramic Tiles and Tile Fittings for Internal Walls, British Standard, BS1281, 1966.

3.Standard test method for Breaking Strength of Ceramic Tile, ASTM C648-84.

4.British Standard. Wall and Floor Tiling BS5385, Part 3. Code of Practice for the design and installation of ceramic floor tiles and mosaics.

5.Standard Method for Evaluating Ceramic Floor Tile Installation Systems using the Robinson-type Floor Tester, ASTM Standard C627-84.

6.Standard Test Method for Impact Resistance of Ceramic Tableware, ASTM Standard C368-77 (Reapproved 1982).

Section
Plan