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EFFECTS OF SOAKING AND CEMENT-SAND RATIO TO THE BOND STRENGTH OF TILES TO SUBSTRATE

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RINGKASAN: *Jubin yang direndam dan tidak direndam di dalam air bersih diatur di atas mortar simen yang bernisbah simen:pasir yang berlainan dengan menggunakan kaedah separa-kering. Apabila keras, mortar yang mempunyai kandungan simen yang tinggi adalah lebih tumpat daripada mortar yang mempunyai kandungan simen yang rendah. Oleh itu mortar yang mengandungi kandungan simen yang tinggi adalah lebih keras. Bagi kandungan simen yang sama, dengan air yang berlebihan dan sistem tanpa sedutan, jubin-jubin yang direndam atau tidak, tidak menunjukkan perubahan yang ketara di dalam ketumpatan dan kekerasan mortar-mortar. Walaubagaimanapun, bagi sistem tanpa sedutan dalam kes tanpa rendam, mortarnya menunjukkan keretakan lebih kurang 3 mm daripada lapisan simen berhampiran dengan jubin bahagian bawah apabila air hanya mencukupi untuk proses hidrat. Ciri-ciri ini tidak diperhatikan di dalam kes dimana jubin-jubin direndam sebelum diatur dibawah keadaan yang sama.*

ABSTRACT: Tiles with or without soaking in clean water were laid on cement mortars of different cement-sand ratio by using semi-dry method. When hardened, mortars with high cement content are denser than mortars with low cement content. The impact hardness of the mortar with high cement content is thus higher. For a same cement content with excess water and non-suction system, soaked or non-soaked tiles show no obvious difference in density and hardness to the hardened mortars. However, for non-suction system, in non-soaked case, hardened mortar develops cracks of about 3 mm at the neat cement layer near to tile back area when water is just sufficient for the cement hydration process. This feature was not observed in the case where the tiles were soaked before laying under the same conditions.

KEYWORDS: Ceramic tiles, soaking, cement, cement-sand mortar, tiling, buckling, hardness, porosity, impact hardness test, image analysis.

INTRODUCTION

As claimed by the British Standard (BS 5385, 1986), to prevent rapid suction and subsequent failure to bond with the mortar bed, porous tiles with water absorption more than 6% should be soaked before installation. Tiles should be removed from their cartons and completely immersed in clean water for at least 30 minutes. After soaking, they should be allowed to drain properly. It is not necessary to soak non-porous tiles with water absorption equal to or below 6 %. This practice was not really agreed by the tiling experts in Australia. As stated in Australia Standard (AS 3958.1, 1991), in most instances tiles with water absorption of greater than 10%, type BIII (EN 87, 1982), should be completely immersed in clean water for a period appropriate to the method of fixing to be used. This period could be as short as 5 minutes where the background suction is low. From the specifications of the above standards, it is quite confusing whether Group BIIb tiles (EN 87, 1982) with water absorption between 6 and 10% need or need not be soaked before laying on cement-sand mortar.

The purpose of tile soaking is to prevent the absorption of moisture from the cement mortar since water is required for the hydration of cement, which is important to generate bonding systems between cement itself and cement and sand. Nevertheless, soaking of tiles may also inhibit the penetration of cement moisture into the tile back which turns to dendrite morphology when solidified under the hydration process. This dendrite solid forms interlocking system between the rough surface of the tile back and the cement bonding layer. The bonding strength of the constitution may therefore be enhanced.

From the experiments of Norris and Housley (1950), it has been found that soaked tiles do not adhere as strongly as dry tiles. The degree of adhesion obtained depends upon the temperature during settling. The higher the temperature the more rapidly is adhesion developed and the greater is its ultimate value. Further investigation on tile bonding shows that bond strengths as great as those obtained with dry tiles can also be obtained with tiles which were soaked and drained in the conventional manner provided that the backs of these tiles are coated with a thin layer of neat cement paste (about 1 mm) before the mortar is applied (Waters, 1958). This technique combines the advantages of dry tiling, i.e. high bond strength, with those of wet tiling, i.e. ease of placing and adjustment of the tiles.

High bond strength is important to a bedding system to resist adhesion failures such as buckling. Buckling is a result of the development of tensile stresses due to structural settling which become greater than the bond strength between tiles and tile bed or between tile bed and the layer underneath. It can also happen if the tensile stresses are greater than the internal strength of the cement-sand mortar. This later is usual to cases where the cement content in a cement-sand mortar is insufficient. To avoid the buckling failure, the bond strength as well as the internal strength of each constitution must be higher than the tensile stresses.

Soaking of tiles to some extent might lower the strength of the tile bonding. However, if the water content of the cement-sand mortar is insufficient, due to the absorption by the laid tiles, while suction is available, without soaking the tiles might lower the strength of the cement-sand mortar and therefore cause possibly the buckling failure. The purpose of this paper is to show the influence of tile soaking to the tile/tile-bed adhesion at different cement-sand ratio. Tiles need or need not be soaked will be discussed based on the testing results.

MATERIALS AND METHODS

Samples

There were three categories of samples prepared for different testing of impact strength: 1) impact hardness, 2) breaking strength and 3) bond strength. The samples in the first category were made by sandwich structure of three layers, i.e. cement-sand, neat Portland cement and tile (Figure 1a). The second category consisted of tiles cut into small pieces with dimension 40 mm x 115 mm (Figure 1b). The samples in the third category were also made by sandwich structure but consisted of only two distinct layers, i.e. cement and tiles (Figure 1c).

Tile samples used for the tests were embossed glazed floor tiles, made in 1993 with dimension 200 mm x 200 mm and water absorption 7.7 ± 0.2% under BIIb group of the European Standard EN 87.

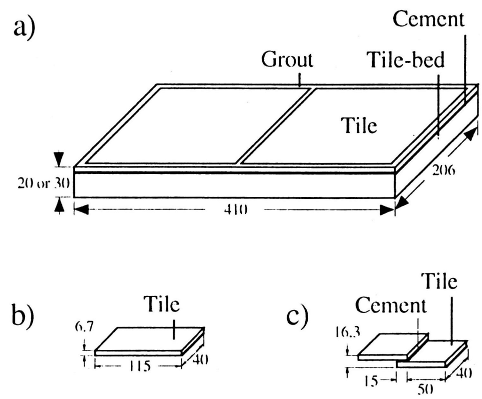

Figure 1. *Types of samples for three different impact tests, (a) impact hardness, (b) shear strength and (c) bond strength.*

Samples for Impact Hardness Test

Semi-dry method was employed for the tile installation. Three mixtures of cement and washed sand, with ratio 1:8 called 8S-mix, 1:4 called 4S-mix and 1:4 with excess water called 4E-mix, were prepared. The grain size of the sand was below 5 mm. The mixtures were added with water at different ratios. The 4E-mix consisted of cement:water ratio of 1.2 kg : 1 litre, while, the ratio for the 8S-mix and 4S-mix are 1.8 kg:1 litre. In these 8S-mix and 4S-mix cases the water was added according to British Standard BS 5385 (1986).

The mixtures were then equally levelled in six rectangular boxes made of acrylic to a thickness of about 30 mm for the 4E-mix and 8S-mix and 20 mm for the 4S-mix. Each mix occupied two boxes. These plastic boxes were impermeable. Their joint edges were sealed with silicon. The tiling system was thus considered as a non-suction system.

In the case where the water was in excess, when a neat cement powder was spread on the cement-mortar, i.e. cement-sand mix, no additional water need to be added to trowel the slurry to a layer of 2 mm in thickness. Nevertheless, some water was needed to facilitate the trowelling work for the 8S-mix and 4S-mix.

In cases where the tiles should be soaked before installation, they were first removed from their cartons and then immersed in clean water for 30 minutes. After soaking, they were drained until no free moisture remained on the backs of the tiles. Only two tiles were laid in one box. Two pairs of soaked tiles and two pairs of non-soaked tiles were placed, with joints about 3 mm in width, and tapped firmly into position. The tiling conditions are given in Table 1. Grouting with neat cement was carried out just after tile laying. The total time for the tiling was about 2 hours.

Table 1. Sample details for semi-dry tiling testing

Sample Label	Soaking	Cement:sand ratio	Cement:water ratio
8SN	No	1:8	1.8:1
8SS	Yes	1:8	1.8:1
4SN	No	1:4	1.8:1
4SS	Yes	1:4	1.8:1
4EN	No	1:4	1.2:1
4ES	Yes	1:4	1.2:1

The samples were demoulded for analysis after two weeks of tile installation. They were cut into small specimens for optical analysis. The impact hardness characterization was made on the bottom surfaces of the tile-beds.

Samples for Shear Strength Test

Tiles as specified previously, i.e. dimension 200 mm x 200 mm, were cut into small pieces of dimension 40 mm x 115 mm. They were tested under non-soaked condition.

Samples for Bond Strength Test

Tiles were first cut into smaller dimension, i.e. 40 mm x 65 mm. They were then separated into two groups : tiles to be soaked and tiles not to be soaked. The soaking procedure for the first group was the same as that for the impact hardness test. One sample consisted of two cut tiles. Each end of the tiles was pasted with a slurry of neat Portland cement. Two tiles with the end pasted with cement were tied together with cellophane tape. The thickness of the neat cement layer was around 2 mm. Both groups of tiles were dried for four different durations, i.e. 2 days, 1 week, 2 weeks and 4 weeks before being tested for impact strength. The cellophane tape was removed just before testing.

Characterization

Optical Analysis

Porosity of the tile was measured by water absorption test. Whereas for the tile-beds, their porosity was determined by using Leica Cambridge Quantimet 570 optical microscope, equipped with True Colour Image Analysis System. Impact resistance of the samples was measured by Free Dropping method.

Impact Resistance Tests

The test methods, i.e. impact hardness, shear impact strength and bond strength tests, used for our present study (Figure 2) are quite similar to the methods mentioned by Hertz (1967) and Benson (1967). The dynamic or impact hardness test is widely employed by the building contractors for the characterization of floor and wall constitutions. A related test so-called rebound method was proposed by various authors (Tabor, 1951; Malhotra, 1976 and; Bowman, 1994) to determine and monitor the condition of tiling installations. In our case, some samples were porous. Their rebound value is small. Therefore, only impact strength was calculated by assuming that the rebound value was negligible. The impact shear strength test is the same as the bond strength test. Instead of measuring the breaking strength of a tile, the bond strength test determines the bond strength of a "sandwich" sample. The latter test has been used by most adhesive manufacturers to show the high strength of the adhesive bond as compared to the weaker neat cement bond strength. Details on these test methods are given in the following sections.

(a) Impact Hardness

For a pyramidal or conical indenter falling from various heights to produce striking energies which give negligible rebound on metals, the volumes of the recovered indentations V_a are proportional to these energies (Martel, 1895). The impact hardness can be calculated by

$$D = m.g.H/V_a$$

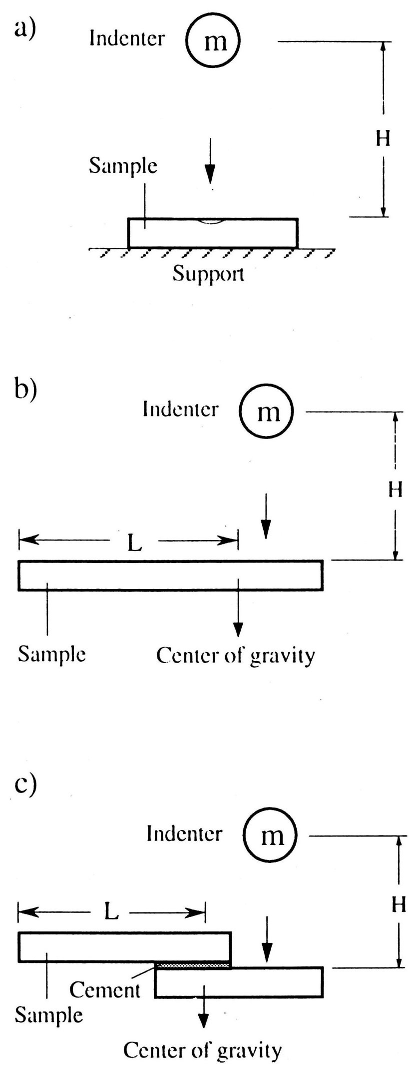

Figure 2. *Schematical testing methods for (a) impact hardness, (b) shear strength and bond strength tests.*

However, in practice the rebound of indenter always exists, especially if the object is not ductile as metals, e.g. ceramic materials, due to the relaxation of elastic stresses caused by the collision of the indenter with the object. The relation between the energy of impact E_i and the energy of rebound E_r is thus on the basis

$$E_i - E_r = P.V_a$$

The dynamic hardness D, expressed in pressure unity (MPa or N/mm²), as suggested by Tabor (1951) is

$$D = m.g(8H - 3h)/8V_a$$

where P is dynamic yield pressure; V_a is apparent volume of indent; m is mass of indenter; g is gravity and; H is height of fall and h is height of rebound.

The applicability of this Tabor's equation can be reviewed from the references - Tabor (1951) and Hertz (1967). The test method is schematized in Figure 2a. The results are given in Table 2. The dynamic hardness of the samples is calculated according to the equation suggested by Martel. This is due to the small value of the rebound energy (h < 40 mm), caused by the porous structure of the cement-sand materials, as compared to the impact energy (H = 2000 mm).

Table 2. Porosity and impact hardness measured from the 4S-mix and 8S-mix samples

Sample	8SN	8SS	4SN	4SS	4EN	4ES
Porosity (%)	22	23	12	9	12	10
Hardness (MPa)	100	110	420	350	300	280

(b) Impact Shear Strength

This test determines the shear strength of a tile by evaluating the energy of a steel ball dropping from different heights. The test method is schematized in Figure 2b.

The shear strength S, expressed in force unity (N), can be calculated by means of the equation

$$S = (m.g.H + M_t.g.H_o)L/a_t$$

where M_t is the mass of the tile; H_o is the height of the tile from the base; L is the center of gravity and; a_t is the sectional area of the tile (width x thickness).

The breaking strength of the BIIb group tiles as measured and calculated under this test method is 30 ± 2 N. The parameters m, M_t, H_o and a_t are constant. They are respectively fixed at 25 g, 45 g, 100 mm and 6.5 x 40 mm².

(c) Bond Strength

As for the impact shear strength test, the force was applied dynamically to the tiles at a fixed distance from different heights H (Figure 2c). The samples for this test were made into a sandwich structure. This test is specially used to determine the bond strength of two different materials, e.g. tile-cement, at a fixed width of bond strip.

The bond strength B, expressed in force units (N), is calculated by means of the equation

$$B = (m.g.H + M_c.g.H_0)L/a_b$$

where M_c is the total mass of tile and bond layers and a_b is the section area of the bond layer (width x length).

The results are given in Table 3. The fixed parameters m, H_0 and a_b are respectively 25 g, 91.5 mm and 15 x 40 mm^2.

Table 3. Bond strengths for soaked and non-soaked tiles bonded with neat cement

Sample label	Soaking of tiles	Cement settling (days)			
		2	7	14	28
CN	No	< 8 N	< 8 N	< 8 N	< 8 N
CS	Yes	< 8 N	8.5 ± 0.5N	10.5 ± 0.5N	10.5 ± 0.5N

RESULTS AND DISCUSSION

Figure 3 shows the typical structures of the tile beds for the 4E-mix, 4S-mix and 8S-mix specimens.

With sufficient cement in the cement-sand mortar, i.e. 4E-mix and 4S-mix, the structures after cement settling are more compact than the structure with insufficient cement, i.e. 8S-mix. The porosity is higher at the bottom area of the tile-bed than at the area near to the tile back. For the 4S-type samples (Figure 3a) it averages 11% whereas for the 8S-type samples (Figure 3b) it is more than 22% (Table 2). The photograph taken from the bottom surface of the tile-bed shows, the 8S-mix specimen has a quasi-isolated grains structure. Cracks can be seen in the areas near to the tile back for both non-soaking (Figures 3b and 4a) and soaking (Figure 4b) samples. This type of morphology has low bond strength because the grains have a small contact surface between them due to the small amount of cement which is not enough to fully fill the voids surrounding the grains. Their impact hardness, i.e. 100-110 MPa, are thus lower than those of the 4S-type samples, i.e. 350-420 MPa (Table 2).

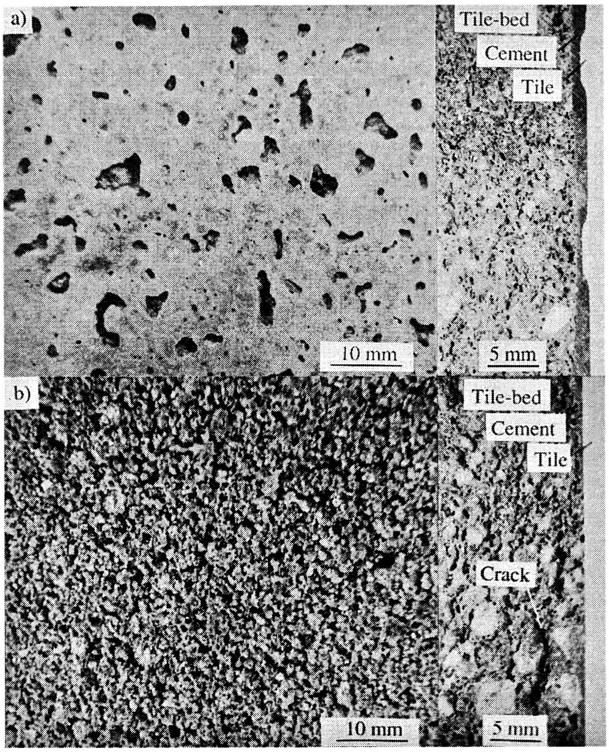

Figure 3. *Typical structure of the tile beds made by cement-sand ratio (a) 1:4 called 4S-type mix and (b) 1:8 called 8S-type mix. The left section was taken from the bottom-surface of the tile-beds. The right portion was taken from the sectioned area showing the sandwich structure.*

With excess water in the cement-sand mortar of sufficient cement, i.e. 4EN (Figure 4c) and 4ES (Figure 4d) cases, two features can be observed. First, during installation, a film of excess water was formed between the tile-bed and the soaked tiles. Second,after installation, the tiles soaked before laying have very low bond strength with tile bed. They could be easily detached by hand from the tile bed when cut into small sections. Although mechanical cutting can introduce significant disturbance to such an extent that the eventual bond strength barely represents the original one, in fact, the second phenomenon is a result from the first. The water film formed between the soaked tiles and tile bed inhibits the penetration of cement moisture into the tile backs to create interlocking bond once hardened. The bond strength was thus low as compared with the 4SN and 4SS cases where water was just sufficient for the tiling.

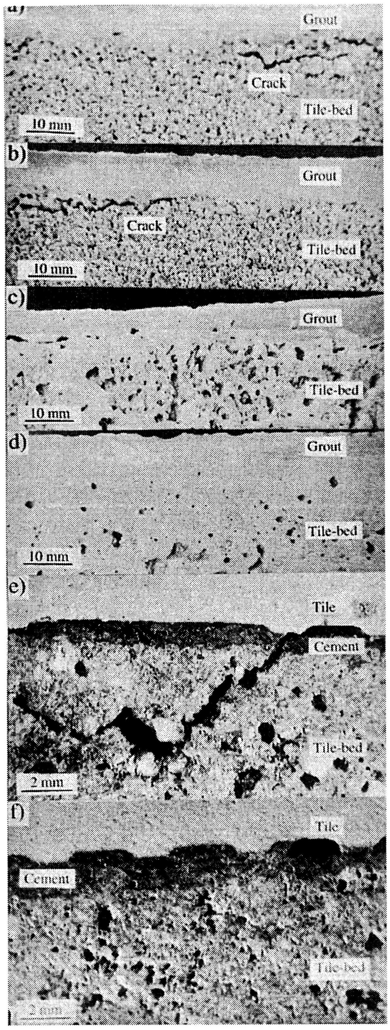

Figure 4. *Sectioned samples for the sandwich constitutions of (a) 8SN-mix, (b) 8SS-mix, (c) 4EN-mix, (d) 4ES-mix, (e) 4SN-mix and (f) 4SS-mix. Refer to Table 1 for the details of the labels.*

With sufficient cement in the cement-sand mortar and as required quantity of water, i.e. 1.8 kg cement to 1 litre of water, for the tiles without soaking the structure of the tile-bed (Figure 4e) is less compact than in the case (Figure 4f) where the tiles were soaked in clean water. However, the impact strength of the tile-bed would have been lower if the tiles were soaked before installation. The same results are shown by the 4EN and 4ES samples for the tests where cement-sand mortar consisted of excess water. Non-soaking of tiles for a tile-bed with just sufficient water may be detrimental to the strength of the tile-bed. Large cracks will be formed in the tile-bed if tiles are not soaked before installation. This is mainly due to the heterogeneous contact between the tile-back and tile-bed. Tiles that absorb water from the contact area make the cement underneath dry and settled much sooner than the areas where tiles are not in contact with its tile-bed. Since the bond strength will be high if the penetration of cement moisture is achieved, the material which dried at the contact area will be held in its position. Nevertheless, the cement-materials in the late drying part will shrink. This may induce differential shrinkage force between the early drying area and late drying area. Cracks can thus be formed which lower the bond strength of the constitution. In the areas where the tiles were tapped firmly, less cracks were observed. However, in practice, no perfect contact between tiles and tile-bed can be achieved. In this sense, soaking of tiles may be safer than non-soaking of tiles.

From the other results obtained from bond strength tests, the tiles bonded only with neat cement shows better resistance to impact energy if the tiles were soaked before coating with cement. Some samples for the non-soaked tiles failed to bond together by neat cement because the cement dried up almost instantly when buttered on the tiles. Although they were then tied with cellophane tape to ensure better contact between cement and tile backs but when the celllophane tape was removed the tiles separated without external force being applied. Some other samples seemed well bonded but when tested with impact energy, the bond strengths were very low (< 8 N). They were less than 4/5 of the value of the samples prepared with soaked tiles (10.5 ± 0.5 N) and 1/4 the value of the breaking strength for a single tile (32 ± 1 N) (Table 3).

Soaking of tiles can avoid moisture from being taken away from the mortar. This is especially important when the tiles are porous. The cement hydration process can be fully achieved only if the water content in the cement-sand mortar is sufficient. Although the water in the cement mentioned previously is sufficient for cement settling but due to the non-soaked tiles which are able to absorb water during installation from the cement slurry the water becomes insufficient. This is why the bond strengths of the non-soaked tile samples are low.

The best way of tiling for BIIb tiles by semi-dry method seems to be as that specified in British Standard BS 5385 (1986). The cement : sand : water ratio should be 1.8:5.4-7.2:1 and tiles should be soaked sufficiently and drained dry until no free water remained at the tile backs. However, if the water in the tile-bed is in excess, tiles are preferably not to be soaked. Moreover, if the tiles were not soaked before installation and the tile-bed contains just enough water for itself, extra water should then be applied liberally over the tile floor and be absorbed by the floor constitution.

It is important to know how much extra water is absorbed by the non-soaked tiles. As given in Table 2, tile-beds in excess of water have lower impact hardness for the same settling duration. The maximum quantity of extra water (MEW) can be calculated by means of the simple equation

$$MEW = W. N$$

where W is the quantity of water that may be absorbed by an individual tile, related to the water absorption of the tile, and N is the number of the tiles to be applied.

Though there are many possibilities to apply extra water to the bedding system, it is however advisable to soak the tiles before installation. Details on the tiling procedure can be referred to British Standard BS 5385 (1986).

CONCLUSIONS

Tiles with water absorption higher than 6% should preferably be soaked in clean water for at least 30 minutes and drained until no free water remains on the backs of the tiles before installation on cement-mortar. This step is taken to avoid the excessive absorption of moisture from the cement-mortar bed by the laid tiles. If tiles are not soaked before installation, water should then be applied either in a slurry of neat cement or liberally over the tile floor to facilitate absorption by the floor constitution. Cement : sand ratio should be 1:4 by volume in order to enhance the strength of the cement-mortar. Cracks will form at area near to the tile backs if the cement content is low, e.g. 1 part of cement to 8 parts of sand.

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