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LESSONS FROM FLOORING FAILURES

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ABSTRACT

Two major food industry flooring failures are described, one of a ceramic tiled floor, and the other of a polymer concrete floor. The factors causing these failures are discussed in the light of design, material specification, and installation. These factors are 'typical' of a number of failures investigated. Sources of information useful in avoiding such failures are indicated.

KEYWORDS

Abattoirs; Abrasion; BRANZ; Concrete; Construction; Dairy factories; Failures, Fired clay; Flooring tiles; Floors; Food processing; Impact; Polyesters; Polymer concretes; Resins; Slip; Specifications; Standards.

INTRODUCTION

Outright failures of flooring in food industry buildings are rare. This is fortunate because such failures are very expensive both in terms of floor replacement, and more particularly because of lost production time. Short of outright failure, deficiencies in flooring materials, specification, or installation also cause problems in plant operation.

Two outright failures, one of a ceramic tiled floor, and one of a polymer concrete floor are described. Reasons for the failures are suggested, as well as remedial measures. Methods of avoiding similar failures by the use of appropriate materials, specification or installation are discussed.

CERAMIC TILED FLOOR FAILURE

The Installation

The floor examined was approximately 300m^2 in area and was four years old. Ceramic tiles (100 x 100 x 10mm) were laid in a 25mm thick cement/sand bed (specified to be 1:3). Carborundum-impregnated PVC sheet was laid on a cement/sand screed in an adjacent sector. The concrete base slab under the ceramic tiles was in two sections: a 150mm thick slab on ground (450mm footings) on the outer sector, and a suspended slab on beams supported by columns from a 2.7 metre thick concrete raft two floors below. The PVC sheet was laid only on the suspended slab.

The original specification called for the ceramic tiles to be laid over a slip membrane but this was not done as the concrete base slab surface was broomed during laying. Instead, a PVA bonding agent was used in an attempt to adhere the tile bed to the base slab. The ceramic tiles were laid in panels 30 tiles on a side (approximately 3m square), with a 10mm wide expansion joint between adjacent panels. No expansion joints were seen around the floor drains or at the junction between ceramic tiles and the PVC sheet.

The Problem

Considerable heaving of the ceramic tiles was evident, particularly in one quadrant of the installation. This heaving occurred over the junction of the slab-on-ground/suspended slab as well as on the suspended slab itself. The ceramic tiles, with or without attached bedding, had become detached from the structural slab and formed dome-type structures within the confines of the 3m x 3m expansion joint squares. In many cases these domes had been partially collapsed by trolley traffic or moving of heavy equipment. A number of random cracks extending through several tiles were evident.

Examination

Removal of tiles adjacent to an expansion joint showed that the tiles and mortar had come away together. The expansion joint material was in good condition, but the joint only appeared to be the depth of the ceramic tiles themselves without any back-up material extending through the mortar bed.

Heaving of the floor was also evident under the PVC sheet at approximately the mid-point of the span between the radial beams.

Cause of Failure

There were several reasons for the failure of the ceramic tiled floor. It could not be attributed to any one factor, rather to combinations.

Firstly, shrinkage of the mortar bed had occurred. The specified bed (1:3 cement:sand) was very cement-rich and would be subject to high shrinkage. A further corollary was that a comparatively strong tile bed would result which could not easily accommodate movement, but would transmit it to the ceramic tiles, resulting in their cracking.

Secondly, there was the problem of building movement. The raft supporting the suspended slab was reported to have sunk 8-9mm over the four year life of the floor. Some of this movement might have been eased if the slip layer (separating membrane) originally specified had been installed. This had not been proceeded with because of the rough surface produced by brooming.

The third factor was the failure to carry all joints in the structural slab up through the bedding mortar and ceramic tiles, particularly at the junction between the structural slab and the slab-on-ground. Isolation joints were not provided at columns and walls, nor at drain edges, nor at the junction of the tiles and vinyl sheet.

Recommendations

The original tiled floor was to be removed, the ceramic tiles cleaned, and relaid. It was suggested that the strength of the tile bed be reduced to 1:4 cement:sand maximum. In addition, all movement joints in the base slab were to be carried through the tiles and bedding, additional movement joints were to be provided against all features interrupting the floor surface (e.g. British Standards Institution CP 202 1972), as well as on the 3m centres originally specified. Movement joints were to be carried the full depth of tiles and bedding.

Additional Comments

The recommendations above were not followed when the floor was relaid. A stronger tile bed of cement:sand 1:2 was specified in an attempt to improve the bond between the tiles, bedding, and base. The same type of failure as previously described re-occurred, but time-to-failure was three weeks rather than four years.

There are several points that arise from this particular study which should be considered in all food industry ceramic tile installations.

Materials

There is no current New Zealand standard for ceramic floor tiles. The British Standard (BS 1286 1974) sets out common dimensions, types and degrees of vitrification. The degree of vitrification (literally, length and temperature of firing) is critical, only 'fully vitrified' or 'vitrified' tiles are strong enough to resist food industry conditions. The 10mm thick tiles used in the case described were on the thin side for a food industry installation. Thicker quarry tiles or pavers are much more suitable because the added thickness increases impact resistance (see BRANZ 1980 a & b, Sharman 1983).

The cement:sand ratio of 1:3 specified is a common specification ratio in New Zealand, and also occurs in overseas codes of practice (e.g. British Standards Institution CP 202 1972). Generally however New Zealand cements are ground more finely than British ones (compare Table 2 of NZS 3122 (Standards Association of New Zealand 1971) with paragraph 5 of BS 12 (British Standards Institution 1978)) so that more shrinkage occurs (Firth 1984). In the author's experience, use of a 1:3 ratio has caused problems in cases other than just the one described above. For this reason the strongest bedding mortar that can be recommended is 1:4 cement:sand (e.g. BRANZ 1980b).

Alternative bedding methods for ceramic tiles are given in the above references. Design considerations are discussed in British Standards Institution CP 202 1972 and Sharman 1983. Additional tests for ceramic tiles are given in BS 6431 (British Standards Institution 1983). Basic UK specification clauses are given in Specification 84 1983, but if these are used the appropriate cement: sand ratios described earlier must be substituted.

POLYMER MORTAR FLOOR FAILURE

The Installation

The area of flooring inspected was a processing hall of approximately 350m^2 containing two large ovens and sundry other equipment. The maximum working temperature in the area was stated as 35^{o}C, cooling to ambient at night during summer or winter when not in use. The temperature of the water used in daily washing down was 60^{o}C. No expansion joints had been provided at any point in the floor. The flooring itself was a polyester based mortar 2-3mm thick; in some areas there was an underlying layer of glass fibre-reinforced polyester mortar also 2-3mm thick. The age of the underlying concrete base varied from over 40 years to a matter of months. The base had been acid-etched prior to the laying of the polyester mortar.

The Problem

The polyester mortar had detached itself from the concrete base, particularly in the middle of the area between the ovens; over a quarter of the total area was drummy. In some smaller areas water had penetrated between the polyester mortar and the base, and was pumping under the action of passing trollies. In one area there was a linear fracture 10m long.

Examination

Initially, several small drummy patches were simply opened up with a hammer and cold chisel. These showed that bond failure had taken place at the interface between the concrete and polyester mortar. The polyester mortar itself was translucent, and had a conchoidal fracture (like impacted glass) suggesting a high polyester resin content. The area of linear fracture was also opened up to reveal a construction joint between new and old concrete base.

Next, tensile adhesion tests were carried out on sound areas of the floor in order to determine the bond strength between the polyester mortar and the concrete base. The method used was based on that of the American Concrete Institute Committee 403 (1962). A core drill was used to drill just through the polyester mortar into the concrete, isolating a 50mm diameter plug of the polyester mortar. To this a clean 50mm diameter steel pipe cap was bonded with two-part epoxy adhesive. After the epoxy adhesive had set, a 50mm diameter pipe plug was screwed into the cap and linked to a load cell and a screw jack. A steadily increasing tensile force was applied via the screw jack until the plug of polyester mortar separated from the base, and the maximum force was recorded.

A minimum tensile bond strength of 1 MPa is recommended by ACI Committee 403 (1962). None of the 20 plugs tested achieved more than 0.7 MPa, the majority were 0.3 or below. In contrast 10 tests on other polymer concrete samples supplied for the BRANZ research programme yielded values between 1.4 and 4.0 MPa. In some areas it was impossible to core drill the floor successfully as the polyester mortar plugs sheared during drilling. It was noticeable that new areas of the underlying concrete base had a very dusty surface, whereas old areas were hydrophobic (water-repellent), dark coloured, and appeared slightly greasy.

Detached plugs of polyester mortar were taken back to the laboratory, and their polyester resin content determined using the pyrolysis method of MacGregor and Sharman 1983a. Resin contents ranged between 25 and 70% by weight, but were predominantly in the range 40-70%.

Cause of Failure

There are several reasons why this floor had failed. Firstly, there was no provision made for thermal expansion or the absorption of movement from other causes; construction joints in the base concrete were overlaid with the polyester mortar floor.

Secondly, the polyester mortar had a very high resin content compared to the more usual levels of 15-20% (Sharman 1983). The coefficient of thermal expansion of unfilled polyester resin at $50\text{-}100 \times 10^{-6}$ (Roff and Scott 1971) is five to ten times that of concrete at 10×10^{-6} (Taylor 1977). The incorporation of a filler lowers the expansion coefficient of the polyester towards that of concrete (Sharman 1983). Use of a polyester mortar with a high resin content thus greatly increased the chance of differential thermal movement and subsequent shear failure between polyester mortar and concrete base.

Thirdly, the low tensile adhesion strength values suggest inadequate concrete surface preparation, which is supported by the appearance of the concrete base in cored areas. The dusty appearance of the new concrete suggests either inadequate curing when it was laid, or failure to remove the residue resulting from acid etching. The hydrophobic dark appearance of the old concrete implies absorbed fats and oils. These are not removed by acid-etching.

Recommendations

It was recommended that the unbonded areas of polyester mortar floor be removed. Expansion joints were to be cut through sound areas adjacent to the ovens, walls, drains and other areas of restraint (e.g. Sharman 1983). Where areas of polyester mortar were removed, the underlying base was to be mechanically hacked back to sound, uncontaminated concrete. Any acid-etching of new concrete areas was to be carried out using recognised procedures (e.g. Sharman 1983).

In addition, it was suggested that any new areas of polymer mortar or polymer concrete that were laid should be a minimum of 6mm thick since thicknesses over 5mm were shown to prevent penetration damage to polymer concretes tested for impact resistance (Table 4 of Sharman and Cordner 1979). The resin-to-filler ratio of the polymer concrete was to be in the range 1:4 - 1:5 to minimise the likelihood of differential thermal movement.

Additional Comments

The polyester mortar described had been used in other smaller installations where the temperature is relatively uniform with success. The combined factors of poor substrate preparation, high resin content, high differential thermal movement, and lack of provision for the absorption of thermal movement were sufficient in this case to cause failure. This particular floor failure points up factors also implicated in lesser failures investigated, namely:

> Before laying a floor topping in a food processing area the nature of the processing operations must be known, particularly whether they involve heat or cold; temperature cycling; require water or chemicals; also their mechanical requirements such as abrasion, impact and vibration resistance. These must be accommodated in the final material/design combination.

The fact that acid-etching does not remove fats and oils is not always appreciated. Even the use of caustic and/or detergent washes may not be entirely successful as there is the likelihood of carrying contaminants further into the concrete as well as removing them. For this reason mechanical preparation is preferred.

If acid-etching is used, it is important that neutralisation and removal of waste material is thoroughly carried out.

Polymer concrete floors have their own peculiar set of properties and requirements. In the past little attention has been paid to this, and they have not been well documented, in contrast to existing specifications for Portland cement concrete or ceramic tiled floors.

The elements which should be checked in designing and installing flooring have been summarised in Sharman 1983. A model specification for polymer mortar or polymer concrete flooring now exists (MacGregor and Sharman 1983b) as well as additional information available from the National Association of Corrosion Engineers 1976, and the Federation of Resin Formulations and Applications 1983. Concrete floor surfaces to receive polymer concrete floors can be specified using NZS 3114 (SANZ 1980). The type of checklist given by Jolly (1984) is very useful.

CONCLUDING COMMENTS

The reason for selecting the two failures described above is not to denigrate those two particular installations. Both contain elements pertinent to their failure which have been found common to other failures, namely: differential movement, and the failure to eliminate it or allow for it; wrong or inadequate material specification; failure to allow for particular factors in the food processing environment at the design stage.

Reference should be made to the material cited to gain a better understanding of the design, specification and installation of ceramic tiled or polymer concrete floors in food processing environments.

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