

PHYSICAL, MECHANICAL, CHEMICAL AND VISUAL TESTS FOR TILE FAILURE INVESTIGATION - CASE STUDY

**C.W. Wong,
SETSCO Services Pte Ltd.
SINGAPORE**

SUMMARY

This paper provides a case study which shows how the various tests complement each other to ascertain the causes of tile failure thereby provide an insight into the tiling problems in Singapore. Physical tests characterize some basic properties of the materials used in the tiling works. These include porosity, expansion, shrinkage, modulus and density of the tiles, bedding and render. Mechanical tests on the other hand are used to determine the strength and particularly the adhesion bond strength between the different layers of the tiling system. Chemical analysis ascertains the composition of the different materials used in the tiling system. This would allow comparison to be made with those specified and to detect any deviation or signs of degradation. Other diagnostic tools which have also received immense attention are nondestructive testing techniques including the infrared thermography. Visual examination is probably the most basic and simple of all tests and it would yield information which hitherto would not be shown through other tests. However, visual examination must be conducted by skilled and trained examiner. No one single method can by itself lead to a reasonable and comprehensive conclusion and it must depend on the results from other tests.

1. INTRODUCTION

In the past, ceramic tiles have been used extensively as facades on high rise commercial and residential buildings in Singapore. The popularity of tiles was due mainly to the ease of maintenance as they are not easily soiled. They have good durability since they are not easily attacked by chemicals. In addition, the tiles can be manufactured to deliver an excellent aesthetic value to the building onto which they are laid. The advents of new installation methods such as adhesives have also boosted the popularity of tiles in buildings both internally as well as externally. However, delamination failure of tiles from building facades had created great concern on public safety. Consequently, the popularity of tiles as building facade material took a setback and their uses have been confined to facades below four storeys.

This paper discusses the various diagnostic tools used in the investigation of delamination failure of tiles in a high rise building in Singapore. Such techniques include both field and laboratory-based examinations as well as extensive and meticulous data collection.

2. PHYSICAL TESTS

Physical tests are used to characterize some basic properties of the materials used in the tiling works. Such tests include porosity, expansion due to moisture or thermal variation, Young's modulus and density. These tests may be conducted on the tile itself or the bedding and render behind the tile. Knowledge of the properties of the various components of the tiling system would allow assessment to be made on the quality of the materials and their likely behaviour and interaction between one another when exposed to service condition. A summary of tests is given in table 1.

3. MECHANICAL TESTS

Common mechanical tests used in investigation of tiles delamination failures include the adhesion bond strength test between the different layers of the tiling system, i.e. tile, bedding, render and the background. Two types of adhesion strength tests can be performed; one is the tensile adhesion and the other is the shear adhesion. The tensile adhesion test is more commonly carried out since it is easier to perform. Shear adhesion test on the other hand requires more elaborate set up and thus more expensive. Generally the shear adhesion of a tile to adhesive is higher than the tensile counterpart depending on the tile key backing details. Other types of mechanical tests include strength tests such as flexural strength and compressive strength. Similar to the physical properties, information on the mechanical properties facilitates assessment of quality and likely interaction between the various components in the tiling system. Bond strength meanwhile provides additional insight into the existing interaction between the different layers in the tiling system. Table 2 outlines the tests.

4. CHEMICAL ANALYSIS

Chemical analysis ascertains the composition of the different materials used in the tiling system. This would allow comparison to be made with those specified and detection of any deviation from the specification and signs of degradation. The various types of chemical analysis and the methods are given in table 3. It ranges from simple basic wet chemistry analysis to sophisticated instrumental analysis such as SEM, XRF and FTIR.

5. FIELD NON-DESTRUCTIVE TESTING

Non destructive testing is one of the most popular tests for failure analysis for the simple reason of being non destructive. However, the use of such techniques has to be made with caution as a number of them do require a certain degree of experience and expertise in interpreting the results. Non destructive testings are used basically to scan and determine locations of suspected poor or non adhesion, entrapped moisture, leakages and excessive strain or movement. Probably one of the most well received technique in building facade investigation such as a tiled facade is the infrared thermography. Other techniques include the mechanical tapping with the aid of a robotic climber, strain gauging, ultrasonic and the laser technique. In addition, other insitu tests may also be performed for instance moisture measurement, salt detection, temperature monitoring etc. A list of suitable techniques is given in table 4.

6. VISUAL EXAMINATION

Visual examination is the most basic and probably the most important diagnostic tool in any investigation works. An extensive amount of information can be drawn from such simple method which will not be shown through elaborate and expensive analyses. However, visual examination must be carried out by trained and experience personnel, otherwise, vital information may be omitted which could adversely influence the finding of the investigation. Visual examination should be performed in the field at the site of failure and more importantly when the evidence of failure is still present. Unfortunately, quite often, investigators are called in after rectification works have been carried out or failed components have been disposed off. The examination should be carried out on site on the building which tiles have delaminated as well as on the delaminated samples themselves.

In-situ visual examination should be carried out with the aid of some tools such as a camera, a grey chart, measuring tape, caliper magnifying glass, fibrescope, mirrors etc.

7. SIMULATION TEST

Simulation tests involve a series of experiments to reproduce the failure observed on site and to study the effects of the parameters gathered from the various stages of the diagnosis. Details of simulation tests could normally be worked out once the initial stages of the investigative analysis have been completed or almost completed. In tile failure investigation, it would usually encompass preparation of the substrate, installation of tiles based on materials and methods used on site, accelerated weathering and performance tests. Performance tests are the base which the effects of the various parameters of the performance of the installed tiles are studied. The adhesion bond strength and visual examination are probably the most common assessment criteria.

8. CASE STUDY

8.1 Background Information

A 5-storey commercial building has been designed to be clad with tiles on the external facade. About half a year after the completion of the building, tiles were observed to be delaminating from the building and starting to fall off. This posed a great danger to the public below the premises. Investigation was carried out to determine the cause(s) of the tiles' failure especially in this case where the tiles were falling within such a short time after installation. The investigation programme has been divided into various stages as described in the succeeding sections.

8.2 Field Investigation

The first stage of the field investigation was to visually inspect the site to document the type, mode, extent and pattern of failure. Information was also gathered from the various parties involved in the project on the construction methods, materials, schedules of construction and all relevant and pertinent data regarding the tiling works. Available documents, instruction sheets, reports and drawings were also scrutinised. Photographs were taken on the failure of the tiles and delaminated tiles were collected for subsequent laboratory analysis. The wall, adhesive, tiles, grout and jointing were all inspected.

The tiles used were extruded tiles and a latex polymer was incorporated into the bedding and render layers. The majority of the failure mode was debonding between the tile and the adhesive layer. The patterns on the adhesive with detached tiles were recorded showing the degree of imprint of the back key pattern of the tiles, coverage of the adhesive, signs of efflorescence, colour, thickness, signs of cracking etc. Tiles that were still adhering to the facade were inspected for signs of cracking, efflorescence and soiling, to check the width and condition of grout joint and tile joint and signs of possible poor bonding (by mechanical tapping). Mapping was also carried out to evaluate the degree of delamination, i.e. number of tiles falling off, distribution of delamination (locations, number of detached tiles per facade, height of the facade which tiles were debonded etc.) and type of member where failure occurred (brick wall, column or concrete wall).

Tensile adhesion pull off test was conducted on the remaining adhering tiles on the wall to determine the degree of bonding. A large variation was noted on the adhesion strength from as low as 0.01 N/mm^2 to more than 0.9 N/mm^2 . Other non destructive testings were not performed due to the extensive delamination of tiles.

8.3 Laboratory Analysis

Samples of delaminated tiles and those still intact were recovered for laboratory analysis. In addition, samples of adhesive and render were also removed for analysis. The laboratory tests performed on the site retrieved samples were as follows:

8.3.1 Visual Examination

Samples recovered were visually examined and some with the aid of a microscope to identify any unique features such as signs of weathering, cracking, types of tiles, degree of imprint of the tiles back patterns on the adhesive, efflorescence etc. The examination was carried out on the adhesive, tiles, grout and render.

8.3.2 Composition Analysis

The composition of the adhesive and render were analysed to determine the cement content, polymer content, insoluble residue or sand and other constituents such as sulphate, lime, deleterious substances and degraded components. The analysis on cement content was based on BS 4551: 1980 while the polymer content was based on combustion. Other instruments were also utilised to identify the presence of other constituents such as the Fourier Transformed Infrared Spectrophotometer, X-Ray Fluorescence Spectrophotometer etc. The type and composition of each constituent determined were then compared against those specified or said to have been incorporated and assessed for degree of degradation or attack. Varying quantity of the constituents were detected, however, the types of primary constituent were generally found to be consistent with those specified or said to have been used.

8.3.3 Physical Tests

The porosity and density of the render layer were determined on samples selected and retrieved from various locations. The porosity was determined by means of a simple water absorption test and the results showed variation in the consistency of the render layer since wide range of water absorption values and densities were obtained.

8.3.4 Simulation Tests

Based on the findings of the preceding investigative analysis, simulation experiments were designed in an attempt to reproduce the failure mode as discovered and to search for answers to questions raised in the process of the investigation. The simulation tests in this case were designed to study the effect of the following parameters on the adhesion bond strength between the tile and adhesive:

- i) different back key patterns
- ii) presoaking the tiles
- iii) different direction of laying of the back key patterns
- iv) different direction of notching of the adhesive
- v) "open time"
- iv) use of sand in the adhesive
- v) accelerated weathering
- vi) different dosages of the polymers (latex) in the adhesive
- vii) different methods of laying or installation

The accelerated weathering test was designed to simulate the suspected site condition under which the failed tiles were exposed to prior to delamination. In all the above simulation experiments, the adhesion bond strength was used as the primary parameter for evaluation and comparison.

At the end of the simulation tests, the tested samples were visually examined to see if the failure mode and degradation features produced in the laboratory were comparable to those observed on site. It was apparent that a number of the features found on failed samples on site were successfully reproduced in the lab. Conclusion was subsequently able to be drawn on the likely causes of the failure of the tiles laid.

8.4 Findings

From the varied type of analysis and diagnostic methods used it was found that the delamination was randomly distributed to different locations, types of building members with no specific pattern. Composition analysis on the render indicated large variation in the composition and characteristics. Similar variation was also noted in the composition of the adhesive. However, the types of constituents incorporated into the render and adhesive were consistent with those specified, except that sand was not included into the adhesive as recommended. Simulation tests showed that deep back keys on tiles produced higher bond strength than shallow back keys. Presoaking of the tiles meanwhile did not show any significance difference in the bond strength as compared to unsoaked tiles before laying. Open time was proven to be very critical to the bond strength and an open time of about 10 minutes could reduce the bond strength up to 40%. Skinning of the adhesive was also observed after prolong open time and this has resulted in extremely poor bond strength. Slippage of tiles due to their self weight was discovered to cause difficulty in the installation. Accelerated weathering appeared to have adversely affected the bond strength especially those with initially lower bond strength before weathering. The modes of failures after the pull off test was mostly between the tile and adhesive and this was consistent with most of the failure observed on site. Finally the degree of imprint of the back key pattern of the tiles, surface of the adhesive where the tiles were pulled off and the backs of the pulled off tiles were examined and compared to observations made on site. Appreciable correlation could be made based on laboratory produced specimens to surmise/speculate what took place on site during installation such as slippage, open time, re-tempering etc Figures 1 to 4 illustrates some of the findings obtained.

9. CONCLUSION

From this investigation work, the interrelationships between the different types of diagnostic tools are extremely vital in arriving at a reasonable conclusion on the causes of the tiles' failure. The selection of the suitable investigative techniques, proper designs of simulation experiments and trained visual examination are probably the most important tools in the diagnosis programme. An in-depth and comprehensive understanding of the tiles and tiling industry including local practices, environmental condition and materials science are all but vital resources for investigation of tiles' failure.

ACKNOWLEDGEMENT

The author would like to thank Dr. Henry Ong W.K. a private consultant, for his guidance and continued support during the investigation of the building described and preparation of this paper.

TABLE 1 : PHYSICAL TEST

TILES	ADHESIVE	RENDER
1) Porosity (water absorption)	1) Porosity (water absorption)	1) Water absorption
2) Coefficient of thermal expansion	2) Coefficient of thermal expansion	2) Coefficient of thermal expansion
3) Moisture expansion	3) Moisture expansion	3) Moisture expansion
	4) Setting time	4) Petrographic examination
	5) Workability	5) Drying shrinkage
	6) Petrographic examination	6) Density (specific gravity)
	7) Drying shrinkage	
	8) Density (specific gravity)	

TABLE 2 : MECHANICAL TEST

TILES	ADHESIVE	RENDER
1) Flexural strength	1) Flexural strength	1) Flexural strength
2) Young's modulus	2) Young's modulus	2) Young's modulus
	3) Adhesion bond strength (tensile and shear)	

TABLE 3: CHEMICAL ANALYSIS IN ADHESIVE AND RENDER

1) Cement content
2) Sand content
3) Polymer content
4) Types of polymers used
5) Presence of deleterious constituents
6) Composition of efflorescence and soiling matter on tiles surface
7) Scanning electron microscopic examination
8) Energy dispersive X-ray analysis
9) X-ray dispersion spectrophotometric analysis
10) Fourier Transformed Infrared spectrophotometric analysis
11) Thermal gravimetric analysis

TABLE 4: NON DESTRUCTIVE TESTS

1)	Infra red thermography
2)	Mechanical tapping
3)	Probing radar
4)	Laser
5)	Strain monitoring
6)	Temperature monitoring
7)	Moisture measurement
8)	Visual examination and mapping

Figure 1

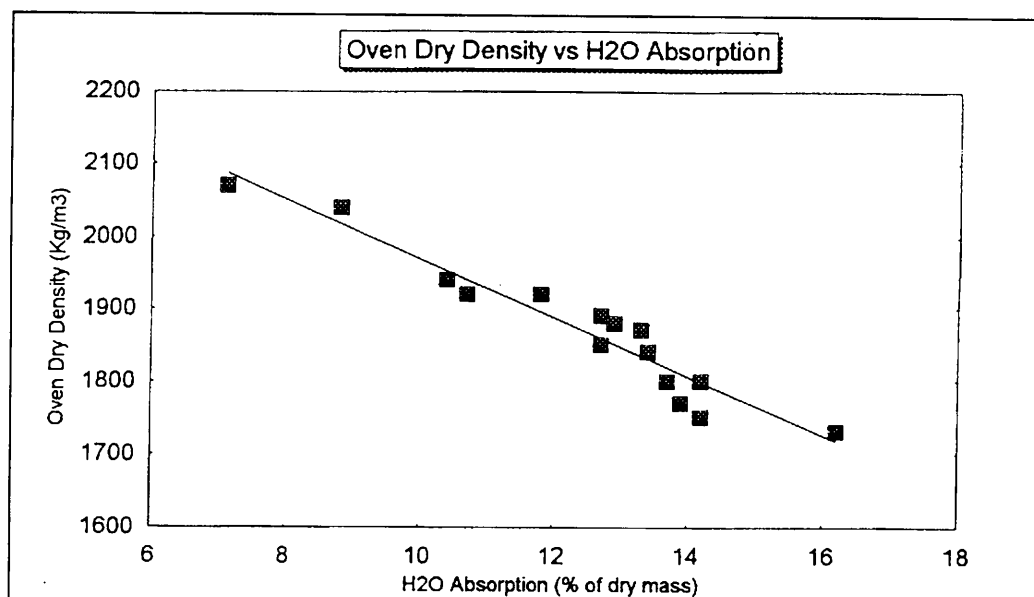


Figure 2

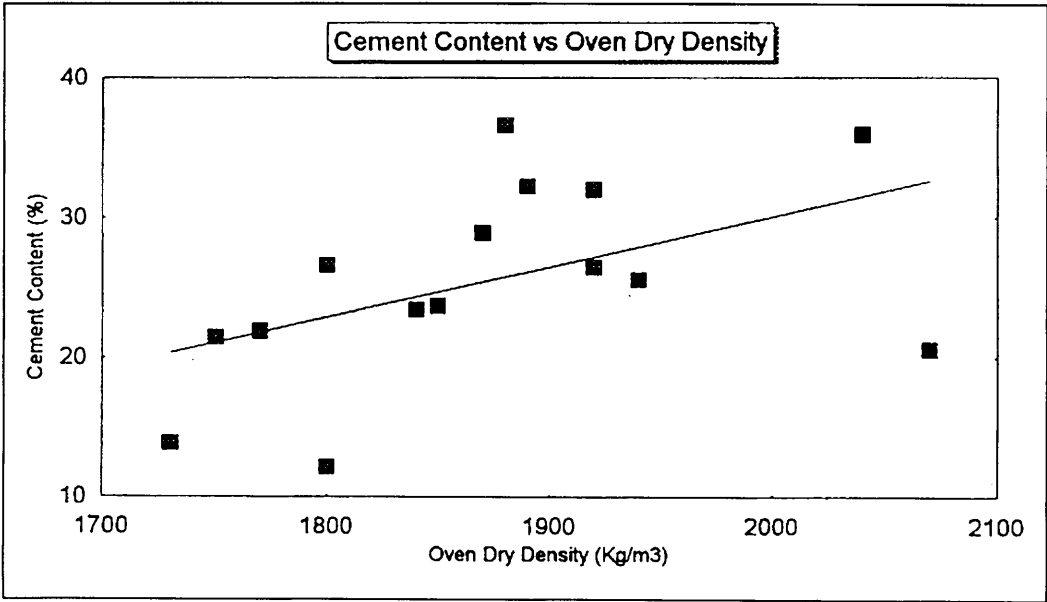


Figure 3

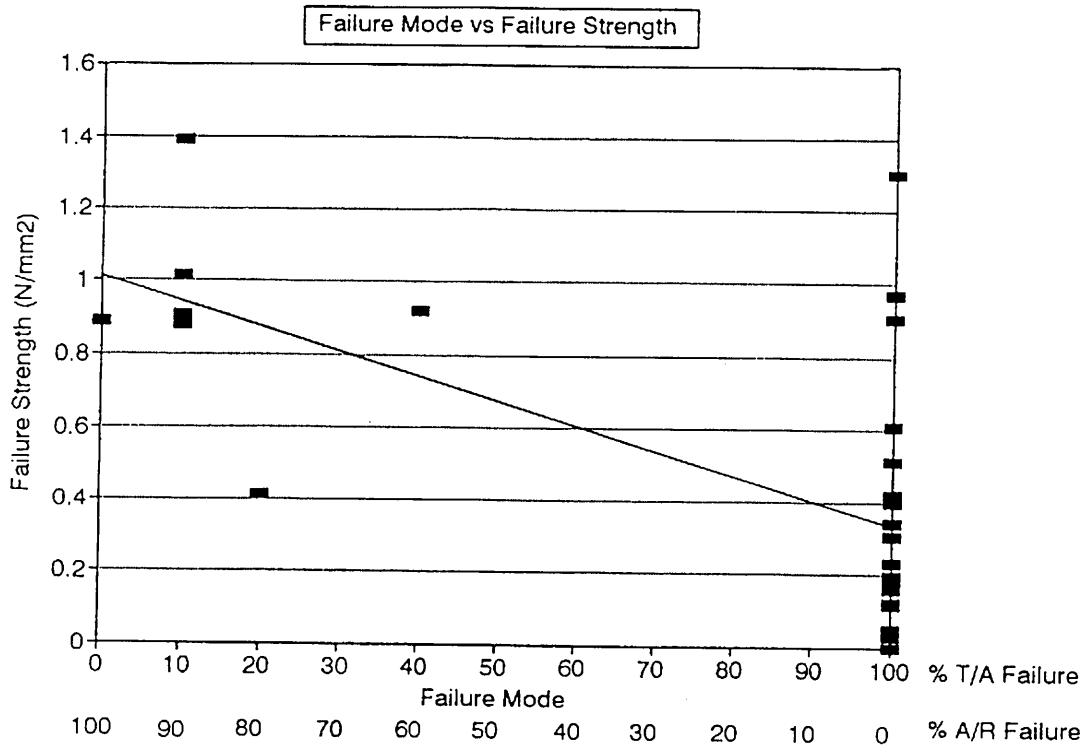


Figure 4

