UNIQUE PERFORMANCE OF CERAMIC TILES SHOWN IN JAPAN

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ABSTRACT

The performance and quality of ceramic tiles required here in Japan are different from those required in Europe and United States.

More than 20 percent of all the consumption of tiles in Japan are for the facades of the buildings including skyscrapers. Exterior cladding tiles are utilized to protect the building from being eroded by acid rain or other corrosive materials. In other words, exterior cladding tiles create a shielding effect.To achieve this purpose, we have developed the stringent criteria for exterior cladding tiles and also the unique installation methods.

The functions of interior wall tiles needed in Japan are also particular. Because Japan experiences low temperatures in winter and high humidity, through the year, interior tiles are expected to be not only decorative but also protective. They have functioned to prevent interior walls from becoming wet and protect them from mold.

1. INTRODUCTION

Industrial production and wide use of interior wall tiles in Japan began in the early part of this century. In the beginning, these tiles were mainly used as sanitary tiles in bathes and toilets. Since then, interior tiles in Japan carry the image of being tiles used not so much for interior decoration but for sanitation in locations where water is used, such as bathrooms and toilets. For this reason, the qualities demanded of interior tiles are, protection of the wall surface and durability. Interior tiles with excellent durability have been developed and used over the years.

In the case of exterior tiles too, there has been a trend of development unique to Japan. The Great Kanto Earthquake which occurred in 1923 was a watershed event in the history of exterior wall tiles. The superiority of concrete structures whose walls were clad with thinly sliced bricks was demonstrated by this earthquake. After the Great Kanto Earthquake, brick structures were regulated by low, and the development of exterior tiles was accelerated. Later, because of mechanization, it became possible to mass produce tiles. At the same time, the development of taller buildings promoted the development of tiling methods. At present, exterior wall tiles are widely used in Japan as the protective material for the surface of concrete structures. However, disbonding and fall-off of exterior wall tiles which occurs occasionally is the most important problem with respect to the quality of these tiles.

In this respect, with the unique background to the use of tiles in Japan, the method of evaluation of resistance to frost damage of interior tiles and the philosophy behind the body preparation to obtain good durability, are explained. In addition, the measures that have been taken to prevent disbonding and fall-off of exterior wall tiles are introduced.

2. INTERIOR TILES

High dimensional accuracy is demanded of interior tiles because of the fact that they are usually subjected to visual evaluation at close quarters. For this reason, tiles with low firing condition, i.e. with high water absorption, are used. The high humidity and the large variations of atmospheric temperature occurring through the four seasons in Japan are harsh conditions for tiles with high water absorption, loading to problems of cracking and failure due to frost or moisture expansion. Measures taken to overcome these problems are explained below.

2.1. MEASURES AGAINST FROST DAMAGE

Frost damage refers to hop-up of the surface or crack formation due to repeated cycles of freezing and thawing in tiles which have absorb water. This phenomenon occurs both in interior and exterior tiles in the cold regions of Japan. The frequency of occurrence of frost damage is high in the case of interior tiles used in bathrooms where wide variation of temperature occurs due to the fact that external heat insulation is uncommon in Japanese buildings. Fig.1 shows an example of frost damage in the case of interior tiles of a bathroom.

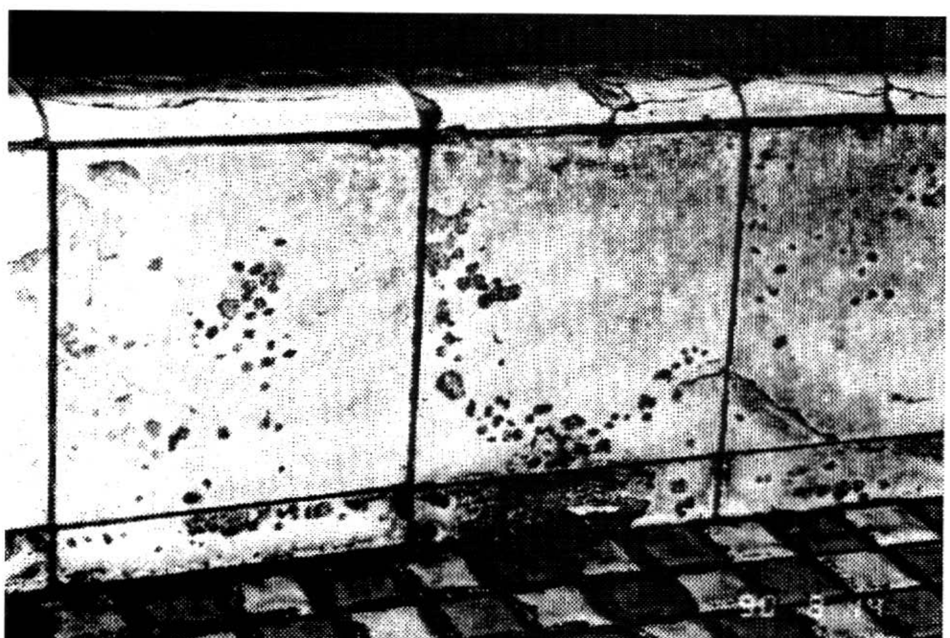


Fig.1 *Frost damage in the case of interior tiles of a bathroom*

Because of the above problem, tiles with high dimensional accuracy and good resistance to frost damage have been developed in Japan, and the method of evaluation of frost damage has been standardized.

2.1.1. Frost damage resistant tiles

In order to prevent frost damage, tiles having pores with controlled shape were developed by using talc as a constituent of the raw material.This tile has a structure consisting of interlocking needle-like crystals of enstatite which results in low firing contraction and low water absorption to be attained at the same time.The low water absorption is due to an increase in the number of closed pores. No damage occurs even after 1000 freezing and thawing cycles.

2.1.2. Freezing and thawing test

Frost damage is caused by the 9% volumetric expansion that occurs as the water absorbed by the tile freezes to form ice. Frost damage occurrence is high in the these regions where the freeze/thaw cycle repetition rate is high Fig.2 shows the regions in Japan classified according to number of days where the daily temperature variation straddles 0 °C. In the cold regions, the numbers of such days is 100 or more, and by experience it is known that there is a high possibility of tiles experiencing frost damage in these regions within 3 years after installation. Therefore, in order to evaluate the resistance to frost damage, it is necessary to repeat the frost cycle at least 300 times. Based on this reasoning, the method of freezing and thawing test (JIS A-1435, 1991) stipulates the fallowing conditions of testing:

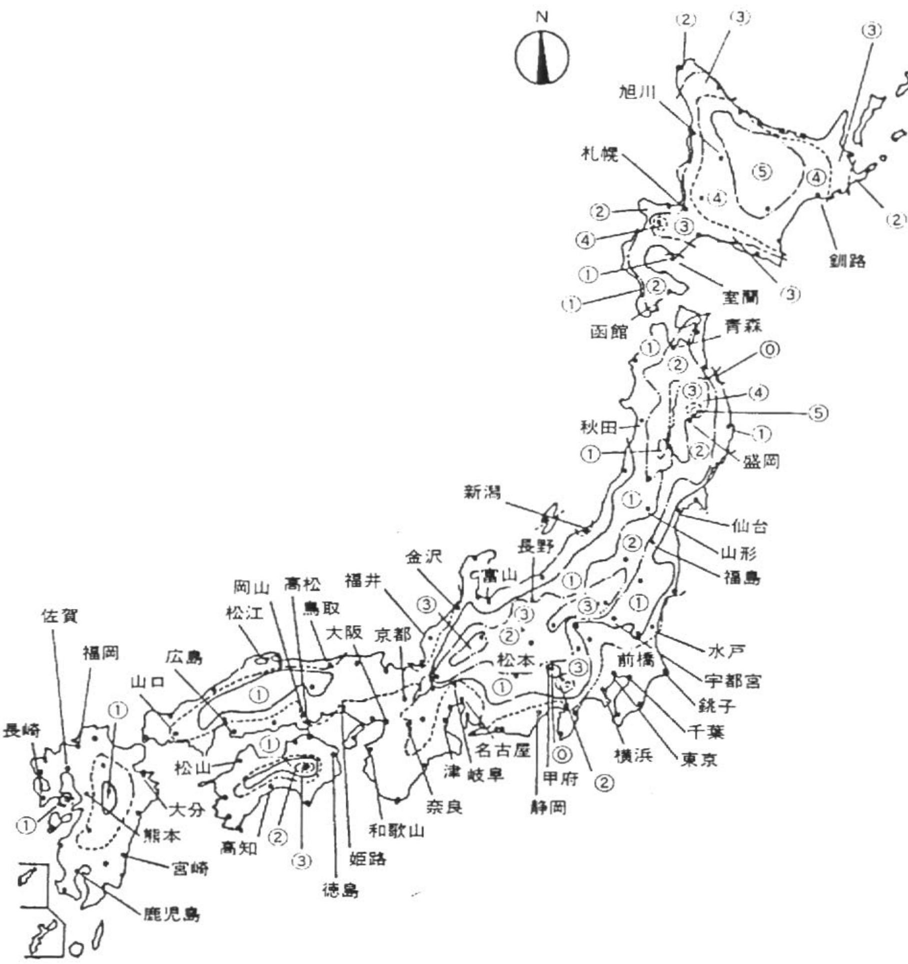


Fig. 2 *The regions in Japan classified according to number of days where the daily emperature variation straddles 0° C*

Atmospheric freezing - Atmospheric Thawing test
(Applicable only to tiles of thickness 20mm or less)

1. Prior treatment
   The specimen is immersed in water at room temperature for 24 hours or more.
2. Freezing condition
   The specimen is kept for 80 minutes in air at -20ºC.
3. Thawing condition
   The specimen is showered with water at +30ºC for 20 minutes.
4. Evaluation
   After 300 cycles of freezing and thawing, the specimen is examined visually for only damage.

Fig.3 shows the percentage of interior tiles that survive the above test and the results of outdoor exposure test. It is evident that the freezing and thawing test is more severe than actual exposure conditions.

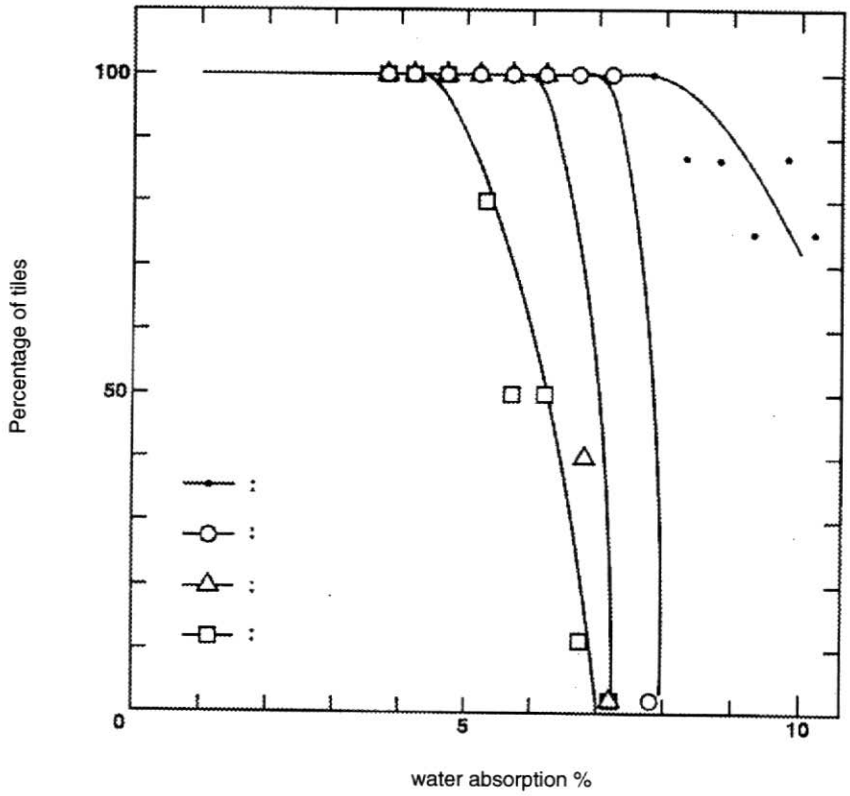


Fig.3 *Percentage of interior tiles that survive the freeze/thaw test and the results of outdoor exposure test.*

2.2. REDUCING THE MOISTURE EXPANSION

The moisture expansion of the tile body, combined with the contraction of the substrata, can cause crazing or other damage to tiles.

Tiles with low moisture expansion have been developed in Japan by the addition of limestone to the tile body composition. Fig.4 shows relation between the moisture expansion and water absorption of feldspathic tile body and limestone type tile body. Feldspathic tile bodies which have high K+ ion content, exhibit high moisture expansion compared to limestone type tile bodies.

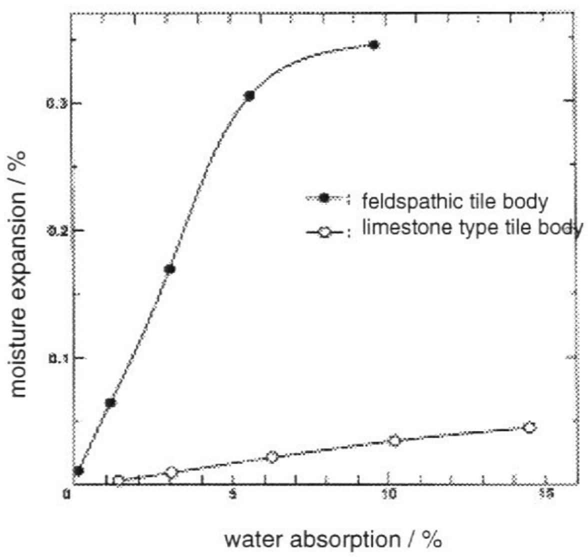


Fig.4 *Moisture expansion behavior of feldspathic tile body and limestone type tile body*

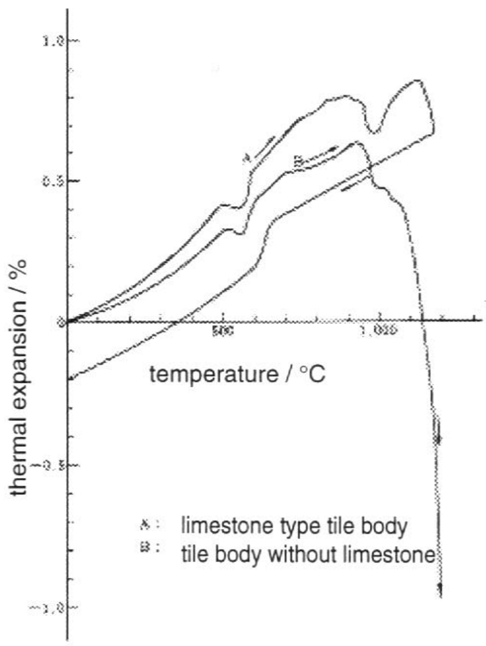


Fig.5 *The thermal expansion curves of tile bodies with and without limestone addition*

In addition to the above effect of reducing moisture expansion, limestone addition also helps to reduce the firing contraction. Fig.5 compares the thermal expansion curves of tile bodies with and without limestone addition. The expansion observed in the case of the limestone-added body from 1000 oC acts to reduce the contraction after firing. This temporary expansion from 1000 oC is due to the precipitation of gehlenite crystals caused by the presence of CaO.

3. EXTERIOR TILES

Exterior tiles are used not only for decorative effect but also as a protective shield for buildings. Fig.6 shows the results of a survey regarding the effect of exterior tiles on the inhibition of carbonation of concrete. Generally, almost all finishing materials help to reduce the permeation of carbon oxide into concrete, but the effect of tiles is markedly high. Exterior tiles also protect concrete because of their resistance to permeation of moisture, resistance to ultra-violet radiation damage, resistance to chemical attack, resistance to corrosion, etc. However, along with the advent of high rise buildings in recent years, it has become quite obvious that exterior tiles must be prevented from disbanding and fall-off. The measures taken regarding this problems are discussed below.

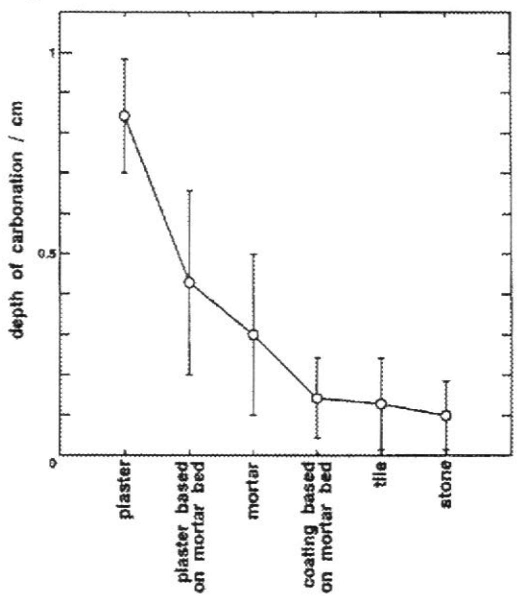


Fig.6 *The results of survey regarding the effect of exterior tiles on the inhibition of carbonation of concrete.*

3.1. MECHANICAL COUNTERMEASURES AGAINST DISBANDING

The adherence between exterior wall tiles and mortar is more strongly influenced by the mechanical bonding rather than by the adhesivity of the cement. Because of this reason, it is likely that from 1994, JIS A-5209 will include new specifications regarding the grooves in the back surfaces of exterior tiles, as shown in Table 1.

Surface area of tile	Depth of groove in the backsurface of tile (h)
< 15cm^2	0.5mm ≤
15cm^2 ≤ , < 60cm^2	0.7mm ≤
60cm^2 ≤	1.5mm ≤

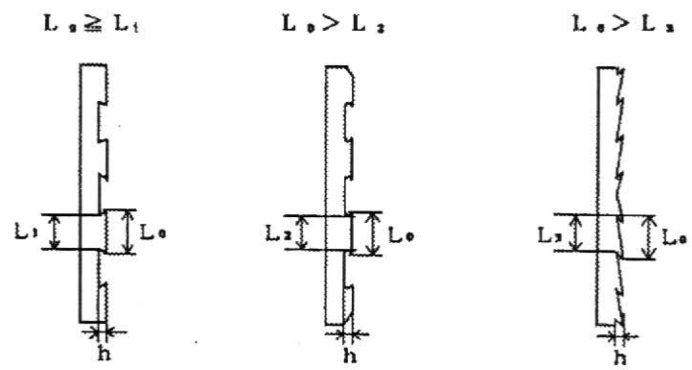
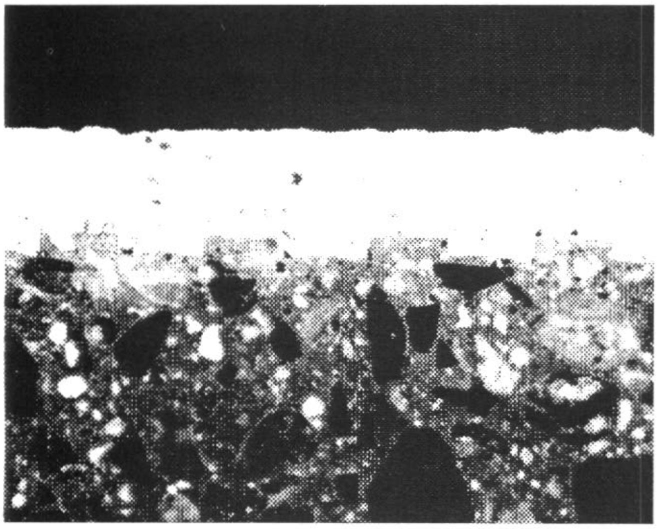
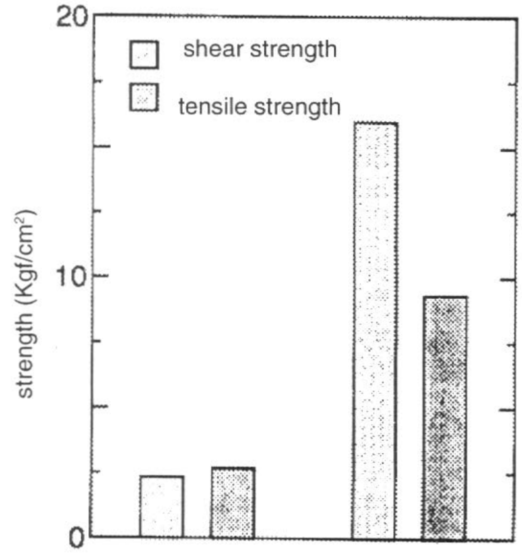


Table 1. *Standard of the grooves in the back surfaces of exterior tiles(JIS A-5209)*

There have been several instances of tile disbonding reported in recent years. In most of these cases, the disbonding has occurred not between tile and mortar, but between mortar and concrete. Because of this reason, a new tile-laying method(called MCR method) has been developed in Japan. In this method, the concrete surface is intentionally made indented so as to improve the bonding between concrete and mortar. Fig.7 shows the interface between concrete and mortar in the MCR method, as well as the results of shearing and tensile tests carried out after curing. It can be seen that compared to the conventional tiling method, the shearing strength between mortar and concrete is higher and the tensile strength is higher in the case of the MCR method.



a)



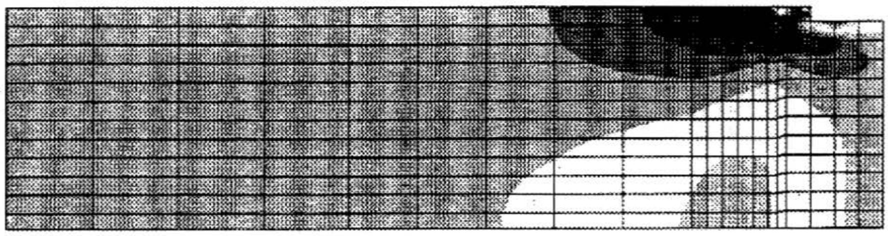
b)

Fig.7 *a) The interface between concrete and mortar in the MCR method*
b) The results of shearing and tensile tests carried out after curing

3.2. PHYSICAL PROPERTIES (THERMAL EXPANSION) OF TILES AND DISBONDING

In almost all past instances of tile disbonding, the cause of disbonding cannot be directly attributed to the physical properties of the tiles used. However, there have been some cases where the physical properties of the time have been indirectly related to the disbonding phenomenon. Normally, a tiled wall consists of three different materials, namely, concrete, mortar and tile. In many cases of disbonding accidents, the cause of disbonding is attributable to the mutual relationship between the properties of the three materials. It is therefore necessary that these mutual relationships be clearly understood in order to prevent disbonding accidents.

The stresses caused between mortar and concrete due to the difference in the coefficient of thermal expansion of tiles was analyzed by the finite element method (FEM). Fig.8 and Table 2 show the model used for FEM analysis and the physical properties of the materials used. In this model, simulations were carried out to determine the stresses when the temperature of the external and internal wall surfaces rises to 60°C and 30°C respectively from an initial temperature of 20°C, and also when the external and internal wall temperatures fall to 0°C and 10°C respectively. Fig.9 shows the shearing and tensile strengths calculated with respect to the coefficient of thermal expansion of the tile. The tensile stress at the interface between concrete and mortar becomes smaller as the coefficient of thermal expansion of the tile becomes smaller when temperature rise occurs. On the other hand, when the temperature falls, this tensile stress tends to increase as the coefficient of thermal expansion becomes smaller. It is intended to investigate in the future the range of coefficient of thermal expansion of tiles that would be most suitable for preventing disbonding.



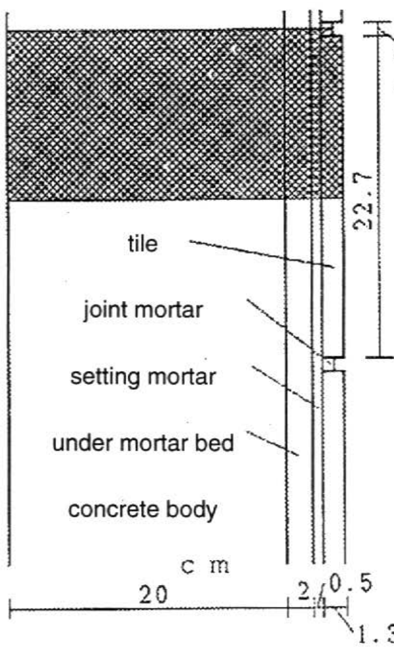


Fig.8 *The section model of the tile shielding wall for FEM analysis*

material	tile	concrete	under mortar normal	under mortar ligth weigth	setting mortar	joint mortar
Young's modulus x 10^8 kgf/cm²	4.7	2.4	1.9	0.3	1.9	1.4
Poisson's ratio	0.16	0.17	0.19	0.2	0.2	0.2
drying shrinkage x 10^{-4}	0	-5	-10	-14	-14	-14
thermal expansion x 10^{-5}	0.66	1.1	1.2	1.3	1.5	1.6

Table 2. *Physical properties of the materials used in analysis*

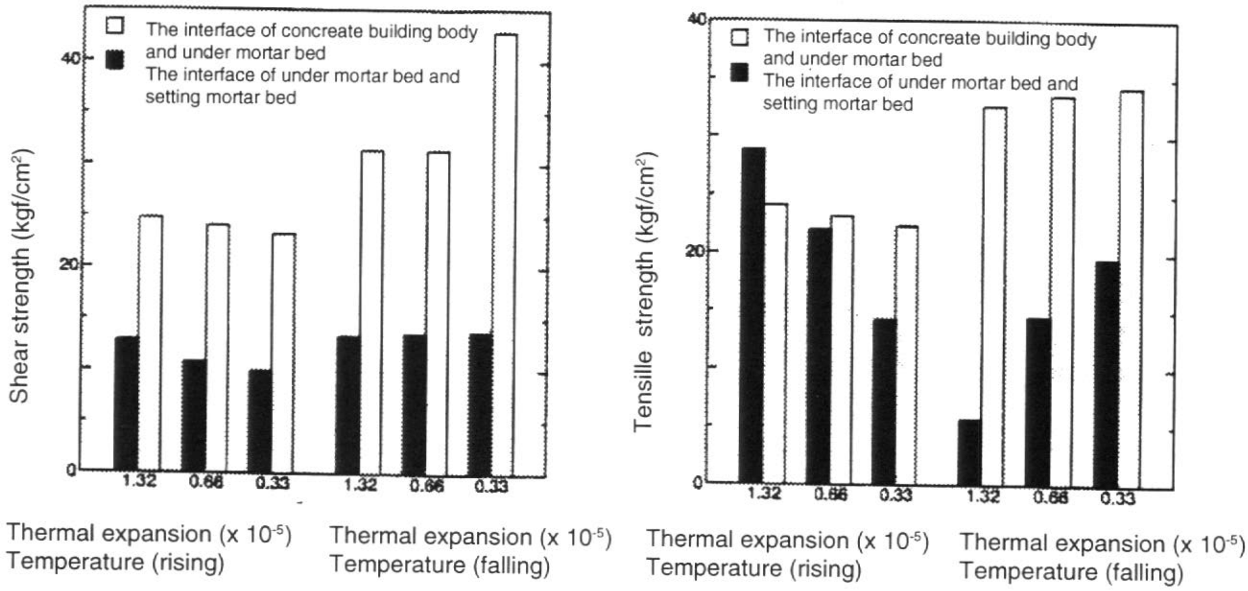


Fig.9 *The shearing and tensile strengths calculated with respect to the coefficient of thermal expansion of the tile.*

4. CONCLUSION

Some of the methods of evaluation of tile quality in Japan and the development of tile production technology have been introduced briefly in this report. The parts of buildings in which tiles are used in Japan are different from those in the case of Europe and United States, and are often unique to Japan. For example, exterior tiles for individual homes have been developed in Japan. In the future, we intend to pursue not only further improvements to tile quality and promote the appeal of tiles, but also pursue opening up of new areas in which tiles can be used. tiles, as shown in Table 1.