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DETERIORATION OF THE FLOOR OF INTERIOR COURTYARD OF SULTAN HASSAN MOSQUE IN CAIRO, EGYPT

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ABSTRACT

The college- mosque of Sultan Hassan is considered one of the finest examples of Islamic architecture not only in Egypt but also in the East. Its open interior courtyard is paved with three different types of marble slabs. These marble slabs suffer from severe deterioration. Causes of this deterioration were determined accurately through the ocular examination of the courtyard and confirmed by the laboratory tests which were carried out on samples representing the three common types of marble used in the floor namely the white, the red and the black marble. Sun light and heat are the main deterioration factors and the consequent thermal expansion is the main property which led to the detected deterioration phenomena. Types and mechanisms of deterioration affected the floor were described and explained.

KEYWORDS: Discoloration, Cairo, Sultan Hassan, thermal expansion, stress, deformation

1. INTRODUCTION

1.1. Description of the monument

This building was erected between 1356 and 1361 next to the Citadel of Cairo. It is a huge complex, measuring 65 by 140 m, and four storeys high, making it one of the largest mosques in Cairo. The basic plan of the building consists of a central courtyard (Sahn) leading off into four large halls (Iwans). The area of this courtyard measures 34 meters long and 32 meters wide and completely paved with marble slabs of three different colors (the studied part). In the center of this courtyard is a large ablution fountain that covered by a wooden dome supported on marble columns. Around the base of the dome is a band of inscriptions from the Koran. The dome of this fountain, which is supported on eight marble columns, is bulbous in shape (Fig. 1) (Petersen, 1996).

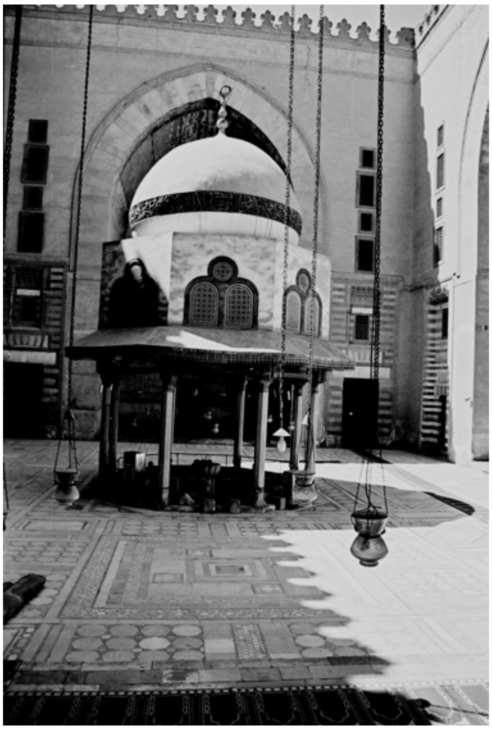

Fig. 1: General view of the studied open courtyard.

2. RESULTS OF OCULAR EXAMINATION:

It is obvious from the examination that all kinds of marble which were used in the pavement of the floor had seriously been deteriorated. According to this state it seems that this floor was not subjected to any maintenance before, besides, the author did not find any knowledge about any restoration and conservation processes carried out in the mosque except restorations of both the present minaret and the dome date to of 1671-1672.

An overall discoloration and colors reduction of the black, red and white marble slabs which represent the most common colors in the floor of the courtyard; were observed. The discoloration was observed in the white marble slabs which have altered to slight yellow color while the color reduction took place in the black and red slabs.

Cracks appear in the all kinds of marble which extend within the cleavage plans and the weakness levels between the crystals (see, Fig. 2).

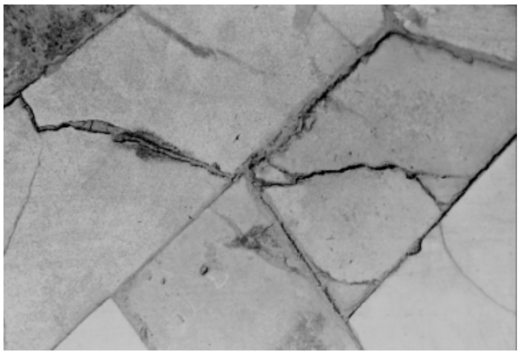

Fig. 2: Cracks extensions in the slabs of marble

Much of the mortar of the setting-bed and of the joint had lost its cohesion and as a direct consequence detachments took place either between the slabs themselves or between the slabs and the statumen (the stone blocks) or both of them as shown in Fig. 3.

Fig. 3: Mortar of the setting-bed was altered to powder and dispersed on the surface of slabs causing their detachments

Fig. 4: General view of the severe deformations which affect the marble floor of the courtyard

Many slabs are not uniformly flat where a hump running the entire length of the north side of the courtyard. It was observed that the deformations which affect the marble slabs vary between slight and severe degrees therefore and as a consequence of this variation; different types of deformations were produced. The final result of marble slabs deformations is their complete detachment from the statumen (see Figures 4 and 5). It can be said that the size of deteriorated slabs in terms of courtyard floor surface area is not less than 35 %.

Fig. 5: Detail from the last figure from other angle

a) Warp
b) Buckle
c) Hump
d) Outcrop
e) Slide

More extensive definition of these types of deterioration and the mechanisms of their formations are given in Figures 6-10.

Fig. 6: Warp of marble slab.

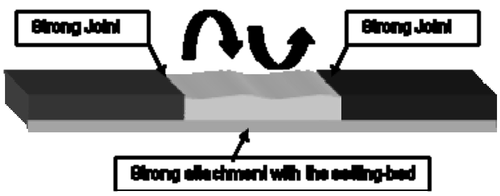

Fig. 7: Buckle of marble slab.

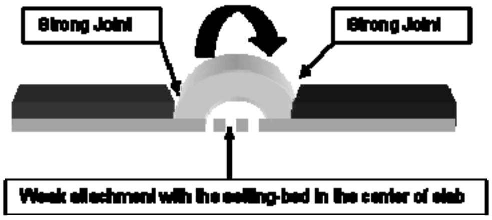

Fig. 8: Hump of marble slab.

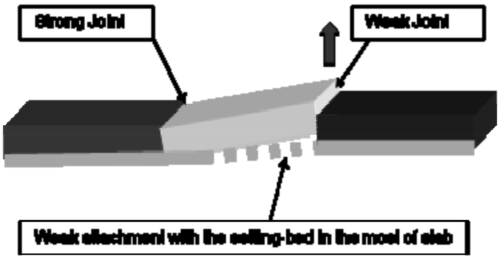

Fig. 9: Outcrop of marble slab.

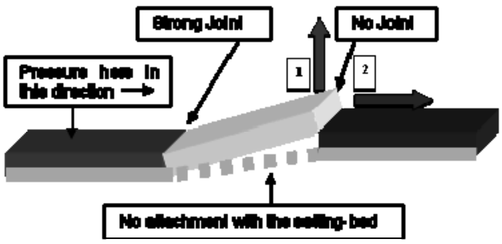

Fig. 10: The advanced stage of outcrop; the slide

3. DIAGNOSIS

From the above mentioned results of ocular examination the deterioration phenomena is attributed mainly to sun light and heat that the courtyard floor is exposed directly daily in the summer season.

The discoloration and colors reduction are due to the light of sun and all other determined deterioration phenomena are due to its heat.

According to Winkler (1973) the amount of transmitted light through crystalline marbles depends on the optical orientation of calcite, micas and other minerals with relation to the slab. Scattering of light occurs along the crystal boundaries, by tiny included gas bubbles and by pigments. Grain size, pigments, inclusions and mean grain orientation are a major factor in the light transmission of marbles. A wet or polished marble surface disperses less light than a dry surface; polishing also increases the light transmission.

We attribute the discoloration and the reduction of marble colors to some photochemical reactions especially in the accessory minerals which play the main role in producing the marble color during its geological formation and before its using and incorporation in the archaeological building.

The climate in Cairo is the typical desert climate contrasts daytime dry heat with cool nights freshened by Nile breezes. Cairo has only two seasons: approximately eight months of summer and four months of winter. In the hottest of the summer months, June, July, and August, the average daily maximum temperature is 95° F (35° C) and the average daily minimum is 70° F (21° C). The summer temperature has reached as high as 117° F (47° C) as (see table 1) (Egyptian Meteorological Authority report).

Month	Average Sunlight (hours)	Temperature			
		Average		Record	
		Min	Max	Min	Max
Jan	7	8	18	2	31
Feb	8	9	21	2	33
March	9	11	24	3	38
April	10	14	28	6	45
May	10	17	33	9	47
June	12	20	35	13	47
July	12	21	36	16	43
Aug	11	22	35	17	43
Sept	10	20	32	14	42
Oct	9	18	30	11	43
Nov	8	14	26	6	38
Dec	6	10	20	1	31

Table 1: shows the month's weather condition readings in Cairo covering average maximum daily temperature, average minimum temperature and average sunlight according to the Egyptian Meteorological Authority.

The change of temperature in Cairo between day and night is very high and this makes the exposed floor of the open courtyard heats in the day and cools in the night by radiation towards the black sky. This change of temperature in one day can be considered one cycle of expansion and contraction. Such daily cycles according to Torraca (1982) are important sources of stress.

Two somewhat different phenomena due to fluctuation of temperature are recognized: stresses may be set up either by the unequal expansion and contraction of the component minerals or by the expansion and contraction of the surface layers relative to the underlying stone (Schafferr, 1932).

The author attributes strongly all deformations types of marble slabs in the studied courtyard floor to the thermal expansion and not to the moisture expansion because the ocular examination proved that no deformations were found in the marble slabs around the ablution fountain centralized in the courtyard which is used up till now for washing (wdoa) before every prayer as shown in (Fig 11).

Fig. 11: The slabs which are around the fountain and always exposing to the water do not suffer from any deformations produced by expansion.

An example of the effect of thermal changes on marble is quoted by (Kessler, 1919, 123) "Certain marble tombstones were found to have developed a curvature".

Kessler (1919) showed that, after heating, marble does not contract to its original length, but suffers a permanent set, a further deformation being produced at each repetition of the experiment (Schafferr,1932).

The expansion and contraction because of the change of temperature cause serious movements in the floor structure and if a slab is restricted between other slabs and joints neatly with them they cause stresses resulting in deformations and cracks.

According to Joseph (1982) the cracks and pores in rock form a continuous, interconnected network. One side of a crack slips over opposite side under differential stress.

4. EXPERIMENTAL:

4.1. Definition of the measured property

Thermal expansion property can be defined as follows; if the variation of linear dimension of a solid is $\Delta l / l = f(t)$, the expansion coefficient is:

$$\alpha = \frac{\Delta l / l}{dt} = \frac{df(t)}{dt} *$$

It is expressed in relative variation of length by degrees for a given temperature. Naturally when $f(t)$ is a linear function in a certain temperature interval, the coefficient α is a constant in that interval (RILEM, 1980).

* l is the initial length and Δl is the change of length.

4.2. Preparation of the tested samples

Fifteen samples from the three different colors of marble; the white, the red and the black; were brought from the detached damaged marble slabs of the courtyard floor, five samples from each color. The all collected samples were cut in the cylindrical shape with 5 cm diameter and 10 cm long.

4.3. Test method

4.3.1. Apparatus

The apparatus used for the determination of the thermal expansion is that one recommended by DIN 5245 (1988).

4.3.2. Procedure

The procedure which was followed is according to RILEM (1980) where the samples were placed after drying in the apparatus. The apparatus samples assembly was placed in a thermal chamber where temperature was 10 °C.

The temperature was made to vary from 10 to 50 °C at a rate not exceeding 10 °C/h. Simultaneous recordings were made of temperature changes and deformation of the samples.

4.4. Formulation of results

The expansion coefficient was expresed by the ratio of the relative deformation of the sample to the temperature variation. It was expressed in m/m.°C.

5. RESULTS AND DISCUSSION:

The results obtained from the measured property can be shown in Table 2 and Fig.12.

Table 2: The thermal expansion coefficient values of the tested samples of marble

Sample No.	Thermal Epansion Coefficient (x 10^{-6}/°C)
WM1	6.9
WM2	6.5
WM3	7
WM4	6.7
WM5	6.9
RM1	7.1
RM2	6.7
RM3	6.8
RM4	6.4
RM5	6.9
BM1	7
BM2	6.2
BM3	6.5
BM4	6.9
BM5	7.1

Legend: WM: White Marble, RM: Red Marble, BM: Black Marble

The experimental confirmed the presented scientific view of the author concerning the attribution of the deformations types and cracks to the thermal expansion due to the temperature degree where the obtained results showed that the thermal expansion coefficient values of the three different kinds of marble according to their colors which range between 6.2 and 7.1 x 10^{-6}/°C are high and as a consequence the increase in their lengths which can be considered serious movements is enough to cause stresses. Such these stresses lead to the detected different types of deformations and cracks.

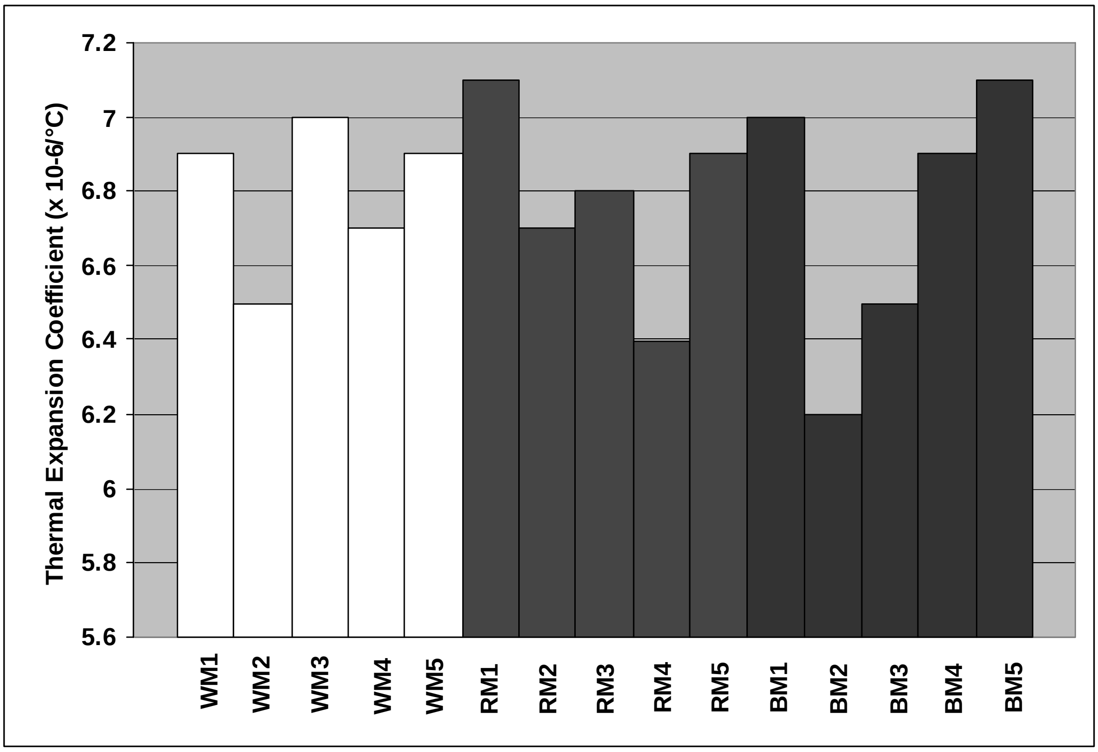

Fig. 12: A comparison between the thermal expansion coefficient values of the measured marble samples of the different three colors.

The comparison between the thermal expansion coefficient values of the five samples of each color on one hand and between the values of the three studied different colors of marble on the other hand showed that the differences between them are relatively small and this is due to their same mineralogical composition; where marble is composed of large crystals of calcite (calcium carbonate). The slight differences between them can be due to the accessory minerals, the impurities and to the weathering products which can be formed in marble before cutting from the quarries and incorporated in the pavement of the floor of courtyard.

One red marble sample and one black; RM1 and BM5 respectively have 7.1 x 10^{-6}/°C and this is the highest thermal expansion coefficient value between the all values of the measured samples of three colors and this means an increase of 0.1 x 10^{-6}/°C for them more than the others. This difference is considered very slight and also was found in only one sample from five measured samples in each color; therefore the author can not say that the red and the black marble are more sensitive to the temperature and as a consequence more thermal expansive.

6. CONCLUSION

The author recommends do not leave the courtyard of the mosque continuously open especially in the summer season in order to avoid the very serious effect of the sun light and heat on the marble floor. Such this recommendation can be achieved by using mobile shelter which can be opened and closed at the suitable times according to the temperature degree.

The study of the effect of sun light on stone generally and on marble especially needs more efforts and experiments from the specialists because very few literatures mentioned it and at the same time many factors play important roles in this process should be determined. Such these factors may determine to what extent the stone color is altered by sun light.

The study of the differences between the thermal expansion coefficients of the different kinds of marble due to their colors needs more investigations to determine surely which kind has the higher thermal expansion coefficient and which has the lower and which compound or element is responsible for this.

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