Investigations into the causes of failure of a Jerusalem Limestone floor

INTRODUCTION

Honed Jerusalem Limestone tiles have severely pitted in a residence after only a few months of service. Although failure commenced adjacent to north-facing windows pitting progressed rapidly to all parts of the room including areas covered by rugs. The honed finish was achieved by acid-washing the original polished surface rather than through the usual methods of production. After laying the tiles were sealed as an aid to cleaning and the prevention of stains.

GENERAL

Both downstairs and upstairs sections of a residence have been tiled with a light tan-coloured limestone generally known in the trade as Ramon Yellow or Ramon Gold Limestone. It is quarried from the Ramon Mitzpah in the Neger Hebron area and is one variety of a group of limestones under the umbrella of Jerusalem Limestone.

The choice of this light coloured stone was to create space and provide a bright environment to a large focal area. Additionally, the colour was chosen in the design to complement and blend in with the associated furnishings.

TECHNICAL AND MACROSCOPIC CHARACTERISTICS

Technically, much of this limestone has an extremely fine grainsize which means that in a domestic situation it should be acceptable in terms of wearing characteristics. Scattered, whitish fossils are an integral feature of the limestone and are usually quite inconspicuous. One particular characteristic of the limestone that requires strong emphasis is the presence of numerous, squiggly, filamentous partings of conspicuously darker colour that surround the numerous ragged fragments that comprise this rock. It appears that the rock is a pseudo-breccia probably formed by intraformational slumping of limestone that was accumulating in shallow water. Variation in the number of shelly fossils and in their distribution, together with infinite variation in the size of the pseudo-breccia fragments reflects the mode of formation. It follows that in most instances there is a direct correlation between the number, and the size, of the pseudo-breccia fragments and the fine, hairline partings that define each fragment and separate each from the adjoining one. The partings are filled with material that is different from the bulk of the rock. It is darker in colour and consists mostly of clay and/or hydrated oxide. Because the filling is weak the general bonding of any limestone tiles or slabs containing a high proportion of these partings is diminished, i.e. these partings are clearly a source of structural weakness. Additionally, these partings are usually incompletely filled and therefore they are significantly more porous than the calcareous part of the rock.

STRUCTURE

Because the partings are weak it only requires a small amount of force by an expansive or crystallizing substance to fracture an area of the limestone where partings are particularly abundant, where they meet, where they occur just below the surface, or where they intersect at a shallow angle. Due to their mineral composition (mostly carbonate) limestones and marbles have very little "give". They are unable to easily accommodate and redistribute stresses so, in effect, they are quite brittle. This means that even a small amount of stress exerting some pressure within the rock will lead to a fracture and generally some dislocation. The presence of numerous lines of weakness (as little as 2mm apart) makes the fracturing much easier.

COMPOSITION OF PARTINGS

It has been noted above that the limestone contains numerous partings which are distinctly more brownish than the calcareous part. When a parting is exposed there is usually one dominant colour - a deep orange-tan but there are occasionally some black specks. The black is a manganese mineral, the other a combination of clay and hydrated iron oxide (Photograph 3). Representatives of these mineral groups could easily have been precipitated and/or deposited concurrently with the calcium carbonate because the association between the carbonate and the other mineral groups in their reef settings is often close and quite common. As the carbonate reef crumbled and brecciated the thin clay and hydrated iron and manganese oxide beds would also have been disrupted and would have been mixed with the carbonate fragments. The hydrated oxide is usually fairly stable chemically and provides a structurally weak cementitious infilling. On the other hand one of the main clay varieties is smectite. Because this is an expanding clay the expansive forces resulting from repetitious wetting and drying could be sufficient to rupture the limestone along the partings that contain it.

QUALITY CONSIDERATIONS

Several varieties of Jerusalem stone have been quarried in Israel for at least two millenia. Most of these varieties are generally quite sound but few appear to have the abundance of partings exhibited in the Ramon limestone used in this residence. Many features and structures constructed using Jerusalem stone have survived for centuries. This suggests that it is generally of at least reasonable quality and the amount quarried, processed and sold throughout the world should be testimony to its quality. This brings into question the quality of the limestone tiles used in the residence. There is no doubt that there is some variation in the quality of the stone based simply on the abundance of the partings. A high number of partings will give a higher porosity and allow more fluid to be exchanged. It also weakens the stone physically and diminishes the quality of the surface. Published research on the technical characteristics of this group of stone indicate values that are only likely to be achieved where the incidence of these partings is low. It is considered unlikely that the majority of limestone tiles in this residence would meet the published values for many of the tests. In the absence of reliable information regarding the range of materials being extracted from the quarry, the quality control selection procedures during slab and billet production, and the final quality selection criteria of the limestone tiles, and without being able to undertake the relevant physical tests, it is difficult to compare the quality of the tiles at this residence with what is typically produced in Israel and sold into Australia.

THERMAL EFFECTS

One more factor that could be playing a small role in the spalling process is the effect of temperature. Closer to the windows facing north there is a greater degree of spalling. Occasionally, elevated floor temperatures resulting from opened blinds and/or doors will inevitably lead to an acceleration of all the reactions and processes outlined above. Elevated temperatures are a principal driving mechanism for fluids.

EFFECTS OF ACID WASHING

Acid-washing of masonry materials is quite a common practice to remove cementitious substances and assist in the final clean-up in construction. Weak hydrochloric acid or (industrial grade) muriatic acid is commonly the acid used. The application of other types of acids to stone and other forms of masonry are specialist procedures carried out for specific purposes. For example, phosphoric acids are commonly used to remove stains and precipitates involving iron, and hydrofluoric acid can be used for removing stubborn stains that cannot be removed by other acids. Hydrofluoric acid can also be used to lighten dark-coloured granites.

Carbonate marbles and limestones are a special class of rocks because of their composition, particularly in their elevated reactivity to acidic solutions. Reaction with certain acidic solutions can be rapid and many chemical processes make use of this property. Reaction can also be slow but nevertheless spectacularly damaging (for example, the effect of acid rain and polluted urban atmospheres on limestone buildings and European marble statues). Much of the resultant impact on carbonate stone depends on the type and strength of any applied acid as well as the length of time of application.

The 400x400 Jerusalem limestone tiles were received from the importer/distributor with a polished upper surface. Because this was not the specified honed finish, the tiles were subjected to an acid wash. Exactly how this was done and what controls there were over this procedure is unknown. Furthermore, it is presumed that muriatic (hydrochloric) acid was used for this purpose mainly because of its rapid rate of reaction on such a rock type.

Because this particular limestone contains many stylolites (pressure solution features) with natural voids (holes) along most or all of these structures there is a high probability that many of these holes were enlarged by the entry of acid during the acid-wash treatment. Any acid that entered the holes along the stylolites would have been very difficult to remove by subsequent washing (with water). Chemical reactions would have continued until the acid was neutralized. One important product of the reaction between limestone and muriatic acid is gas - carbon dioxide. The unavoidable production of this gas within the numerous tiny voids could well have exerted considerable pressures on many small sections of limestone between stylolites. An additional and very important biproduct of the reaction between muriatic acid and limestone is the production of calcium chloride. Calcium chloride is a salt that is rapidly produced when the acid comes into contact with the limestone. As the acid is sponged or otherwise distributed over the surface of the tile there is a strong likelihood that some of the salt (produced from the surface of the tile) could find its way into the voids or be formed in situ (within the void) by reaction with the acid. Fairly high concentrations of salt could result and even after neutralization the salt would remain in the voids and be subject to episodes of wetting and drying. A particularly interesting characteristic of this salt is that it can dry out and then reabsorb a considerable amount of moisture when available (i.e. it is deliquescent). This could lead to a situation of cyclical wetting and drying - one that can exert considerable local pressures within planar structures such as stylolites, especially in the presence of swelling clays.

SEALING - general

It seems to be customary practice in Australia and the US that when a stone that is perceived to be porous is laid a "sealer" is applied to the finished surface. This is usually done to allay the clients' fears of staining or soiling and the majority of sealers would appear to be suitable for the protection of the stone surface from solid particles such as dust. Unfortunately, there are sealers and sealers and there is a plethora of stone types each with their own distinctive compositions and intrinsic physical characteristics. This is compounded by the lack of understanding by chemical companies of the use of their chemicals to the end products (i.e stone), the disparate knowledge of the chemical applicators and the stone types, and in general the vast misinformation that has been distributed throughout the world in relation to the practice of sealing stone. Combine this with the knowledge that this section of the industry is totally unregulated and that there are scores of backyard laboratories mixing the various base chemicals, active ingredients, and proprietary additives in any number of combinations.

SEALING - the science

The science behind "sealing" certain varieties of granite, and to a degree sandstone, is reasonably well-founded; however, the science behind "sealing" **calcareous rocks** remains dodgy. Irrespective of the type of "sealer" it is a widely accepted fact in the stone industry (by honest and experienced persons) that such products **cannot** prevent certain soiling agents from penetrating into the rock. All the more so when there are visible physical partings and voids in the stone. Even though the carrier (frequently a low-viscosity hydrocarbon) may penetrate the stone quite well (but only where there really is some porosity), and carries the "active ingredients" into the pores and spaces, it is a highly contentious scientific issue as to what happens to the "active ingredient" within the pores and spaces of calcareous rocks when the hydrocarbon carrier evaporates. It is extremely unlikely that all the pore spaces and partings become totally sealed. Indeed, effective (total) sealing of the surface of any porous stone such as this limestone, any sandstone, and even granite can also be detrimental. This is because there is a continuous exchange of fluid (mainly water vapour) between the tile (and its substrate) and the environment. If this exchange is prevented physically (i.e. by applying a barrier) fluid pressures will rise dramatically, small amounts of dissolved substances (e.g. salts) will accumulate beneath the sealed surface, and spalling will inevitably ensue. Under controlled circumstances stone that has been sealed on the upper surface can be induced to spall within 2-3 weeks. Interestingly, much of the limestone used as tiles in the Middle-East is not sealed.

TESTING

(a) Petrographic analysis

A separate petrographic investigation on three portions of tile highlighted the abundance of the brownish clay and hydrated oxide throughout the rock. Mostly the composite brownish material occurs between the brecciated clasts but there is also usually some brown material along the boundaries between sections of coarsely crystalline limestone and the typical fine-grained material. Whether the presence of this brownish material at this particular location will influence the mechanical behaviour of the already contrasting physical characteristics (fine and coarse grainsize) is unknown. What is clear is that the filling of the stylolites and other filamentous, squiggly lines is not continuous, i.e. there are voids (empty spaces) along the uneven planes of these partings. This means that there is a high likelihood that moisture will penetrate into these partings and that there will be continuous shrinkage and expansion of the brown material along these partings depending on the amount of moisture that is present. Irrespective of the variety or composition of the sealer used these products will not adhere to this type of dimensionally unstable material. Sealers will therefore provide little or no protection against the ingress of fluids into this limestone from above, underneath, or the sides.

CONCLUSIONS

It has been demonstrated that the Ramon Gold limestone floor tiles at this residence contain an abundance of naturally occurring partings and that the processes of pitting and spalling that are in progress are directly linked to these partings. Not only are these partings structural weaknesses but they contain many voids and one or more naturally occurring minerals that influence the technical characteristics of the stone. Because of the voids these partings allow the penetration of moisture into the rock from above, from the side (along joints) and from the cementitious substrate below. They also allow the penetration of any salts which might have originated from acid-washing and any that accumulates on the floors, windows and walls. Normal floor cleaning procedures are likely to contribute significantly to the ingress of fluids and dissolved salts. Prevention of fluid ingress (along with dissolved substances) into these limestone tiles in this seaside location is extremely difficult because of the voids and because of the dimensionally unstable minerals that occupy these partings. "Sealers" cannot effectively prevent the ingress of moisture into this rock type irrespective of whether they are termed penetrating or not. Sealers are usually meant to retard the rapid ingress of fluids into stone, to exclude certain chemicals, and, in general, to preserve the original appearance of the stone tiles. However, they can equally prevent the exit of fluids and chemicals from within the stone. Indeed, there is a strong suggestion that the application of a sealer could be playing a major role in the spalling of the limestone tiles due to the "entrapment" of calcium chloride salt that was produced by the application of acid on the original tile surface to remove the polished finish.

Proximity to the large windows facing north would have resulted in frequent elevations in the floor temperatures the effect of which would have been to promote a greater degree of fluid activity, induce more dimensional instability, accelerate wetting and drying, and accelerate the precipitation and crystallization of chemicals such as salts. Because of its seaside location there is an inevitability that some wind-borne salt (plus moisture) will make a gradual entry in very small amounts into the residence.

Because of the incidence of serious pitting along the northern side of the downstairs entertainment room and clear evidence that many other tiles are also but as yet less affected there is little cause for optimism to believe that the process has halted. In fact, it is extremely unlikely that the process can be arrested. As long as there is available moisture, salts, expansive clays in the numerous partings, and structural weaknesses in the stone, the pitting will continue in the downstairs areas and there is a strong likelihood that pitting will gradually commence in the more exposed upstairs sections. The onset of the pitting will be sporadic because as noted above there is conspicuous variation in the quality of the tiles. Indeed, not all the tiles will be affected because in some the abundance of the partings and their spacing is quite low.

The problems experienced in this location have been duplicated in a number of other Australian locations and the problems associated with this variety of limestone are well known overseas. It is clear that there is a considerable variation in the quality of the limestone tiles based simply on the occurrence and abundance of the natural partings as described. Of interest is the fact that the importer of any stone into Australia is not required to provide any accurate and reliable information on its suitability irrespective of whether there are inherent problems with the material in certain situations in other countries. Decisions of whether or not a certain stone is suitable in its intended application is generally left to the architect or specifier. It is unfortunate that advice on the composition and suitability of stone in certain applications is rarely sought by architects or builders in Australia and the US.

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Dr. Hans-Dieter Hensel is an authority on the composition of stone, its uses, benefits and problems. Now QLD-based, he has 27 years of experience in the science of stone, its testing, assessment, quarrying, processing, and supply for domestic use and export.