Barry Hunt & Bruno Miglio[1]

DETERIORATION OF STONE FLOORS

The authors look at some of the reasons why stone floors may deteriorate and suggest ways in which the problems may be avoided.

Thorough assessment of the material combined with good design installation and maintenance should preclude many of the problems that are sometimes encountered with natural stone flooring.

Any problems can usually be related to factors ranging from the quarrying processes through to inadequate design details. Although deterioration may not progress sufficiently to seriously affect performance during design life, under certain environmental conditions (including those induced during maintenance) deterioration may be accelerated, occurring even before the practical completion of construction.

This article describes several different occurrences of stone floor deterioration that the authors have encountered, in particular a variety of mechanisms which have led to the discoloration or staining of the stone surface.

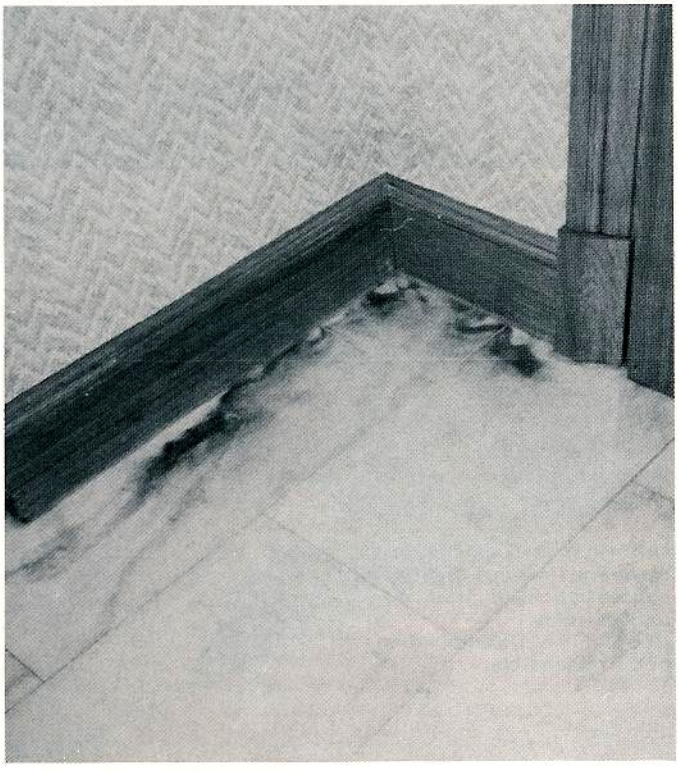


Fig 1: Spread of organic materials from wooden skirting due to attack by cleaning fluids.

STONE FLOOR FINISHES

The range of stone finishes includes flame-textured, bush-hammered, riven, sawn, polished and honed. The choice of finish will depend mainly on the location and purpose of the stone and the desired visual effect, problems that may be encountered with some of these finishes are described below.

Rough finishes

In areas with heavy traffic such as pavements, resistance to abrasion and to polishing in order to maintain slip resistance will be of importance. The American Society for Testing and Materials (ASTM) gives minimum limits for resistance to abrasion and in addition suggests that there should not be a hardness difference of greater than 5 between adjacent stone types. There are certain commonly used weaker stones (some York stones are good examples) which fail these limits but may still be used successfully, although increased slab thickness will need to be considered to counter any abrasion loss.

One of the most favoured rough finishes for stone is flame-texturing, which involves applying high heat to the surface of the stone and then rapidly chilling it. The resultant rapid expansion and contraction cracks the surface which breaks away to leave an uneven texture. Stone slabs subjected to this treatment may be damaged beyond any visible surface spalling thereby leading to a possible loss in strength. This may become more critical with decreasing slab thickness. Under heavy foot traffic the affected surface zone may more rapidly deteriorate with a general loss of surface roughness.

Polished finishes

With polished stone floors poor workmanship may result in adjacent slabs being out of level. This may lead to uneven wear characteristics, a typical example being loss of polish at slab edges which are raised relative to the surrounding slabs. A finished floor exhibiting such a problem may have to be re-polished.

Even lightly trafficked polished floors may lose their finish to some extent, being scratched by hard objects such as dirt particles and metal shoe heels. Heavy localised impacts can cause compaction marks, a type of local cracking in the stone which occurs more frequently in the softer stone types.

This type of damage may produce a lightening in colour at the point of impact due to the amount of light being reflected and scattered from the surface of the stone rather than from within the stone. The stone will appear to lose its natural colour and become lighter. Where white stones are used this may not be significant but as original colour intensity increases so does the potential for loss of colour. Black stones commonly suffer from the problem of matting to a light grey colour, sometimes within a matter of weeks of installation.

OTHER FINISHES

Some stone types do not fit easily into either of the above categories. Travertine is one example considered here.

Travertine

Travertine for flooring may be filled or unfilled but either

1. Sandberg Laboratories Group, London, UK.

Below: Fig 2. Discolouration from white to orange of feldspar crystals at the polished surface of a granite. Magnification: x 2.

Right: Fig 3. Discolouration of Carrara-type marble floor.

Left: Fig 4. Dark patches in a travertine floor due to different concentrations of dirt in unfilled voids.
Above. Fig 5. Discolouration of Carrara marble.

choice leads to other considerations. Individual travertine panels may vary in character from solid to honeycombed and if an even wear is to be achieved across the whole floor a clearly defined range of acceptable voidage should be specified. This will also avoid patchiness caused by different concentrations of dirt infilling the voids (see fig 4).

Any voids in travertine which are large enough to trap heels must be filled, but unfortunately, some large voids may be hidden beneath the surface and could appear during normal use. Any maintenance programme should quickly identify such deterioration so that prompt remedial action is taken.

If choosing filled travertine, panels with as few voids as possible should be selected. In addition to a colour match and weather resistance the filler material should also exhibit similar wear characteristics and must be able to expand and contract with the travertine if it is not to debond and become loose.

Floor treatments

The process of crystallisation or vitrification reputedly creates a glass-like layer within the surface of the stone flooring material. The contractors offering these treatments claim that this results in a completely sealed floor which should resist soiling or discoloration. Further properties claimed include hardening of the surface, increased slip resistance and a reduction in the required maintenance.

The process can be carriedout on different floor types using different chemicals, however, its use is more often limited to softer stones, chiefly marbles.

Used on marble the process appears to involve a reaction between the mineral calcite (the major marble constituent), an acid in the crystallisation chemical (containing fluorine) and metallic ions. A wire wool pad fitted to a rotary maintenance machine apparently generates enough heat by friction to include the necessary reaction which produces the mineral fluorite (calcium fluoride). Fluorite has a slightly greater hardness than calcite, and the new surface should therefore be more resistant to wear. In calcite based stones such as travertine and limestone the presence of voids and other features may result in a greater absorption of the crystallisation chemicals which has led to claims of increased strength.

Marble floors where there is heavy traffic may require retreating, and the constant ingress of acidic crystallisation chemicals into the stone could lead to premature distintegration. There is another potential problem in that even the purest marbles contain a variety of minerals which might react unfavourably with the crystallisation chemicals. Certain iron sulphide minerals commonly present in marbles and limestones are known to release discoloring iron compounds when subjected to oxidising or acidic conditions.

Stone impregnators are designed to fill the surface pores of stone to prevent the ingress of water and dirt. Unlike sealers, which are not penetrants, nothing should remain upon the surface of the stone to affect its appearance. The use of sealers may require stripping and recoating with possible ultimate damage for the stone surface. Care should be taken when restricting the natural progression of moisture through the stone as unexpected side effects may be experienced.

Commonly used sealers/impregnators include silicones and acrylics, which are organic materials, with either a water or organic solvent base. The water based silicones can exhibit very high alkalinity (up to pH 13), which may be excessive for some stone surfaces. Any treatment applied to the floor surface should be resistant to discoloration or decomposition.

TABLE 1

Some types of staining and their possible cause

STAIN OCCURRENCE	CAUSE	FORM (see key)	POSSIBLE ORIGIN (see key)
Eratic spotting	Welding spatter, cutting	N	CQ
	Shards from angle grinding	N	C
	Decay of certain constituents	P/N	I(D)
	Alteration of certain constituents by flame texturing, then decay	P/N	IQ
Overall discoloration	Bleaching by the sun	N	P
	Abrasion (surface scattering effects)	N	CP
	Even breakdown of constituents	P	I
	Surface attack - bleaches etc	P/N	IP
	Decay of applied finishes	N	IP
	General usage - aging	N	P
Patchy discoloration	Moisture darkening	P	D
	Stone deterioration in moisture affected zone	P/N	DI
	Migration of materials from bedding etc.	P/N	DI
	Deterioration of surface materials silicones and mastics in joints	N	DI
	Presence of oils, inks etc.	P	Q(C)
	General usage - spillages	N	P
Related to stone features	Concentration of materials in areas of high porosity and permeability	P	D(I)
	Deleterious constituents in veins and other discontinuities	P	I(D)
Related to construction features	Joints (migration from below), filler materials deteriorting	P/N	DI
	Fixings - rusting iron etc.	P	DI
	Epoxy fillers/repairs (aging by sun)	N	DI
	Construction Dirt (in voids, joints etc)	P	C
	Packing and storage - strips	P/N	I(C)
Biological action	Organisms feeding off organics in stone	P/N	I
	Growth of organics in moisture zone	N	D
Others - variable form	Fire damage - soot	N	CP
	Pollution	N	P
	Efflorescences	N	CP

KEY

Form P = Penetrative; N = Non-Penetrative; P/N = Both P and N.

Origin: C = During Construction; D = Possible Design Fault (Poor detailing - often allied to inferior materials); I = Inferior Materials (may occur at any time); P = Post Construction; Q = Quarrying and Finishing Processes.

OTHER SPECIAL PROBLEMS

Modern finishing techniques and cutting technology now allow stone to be cut into very

thin panels, or tiles perhaps 10mm (or less) which may be applied directly to bedding mortars and screeds. If there are any dificiencies in the bedding materials such as large voids, surface fluctuations from inconsistent mixing, or low cement content (low strength), the stone may not be supported sufficiently and high localised stresses may induce cracking.

Expoxy resins and other similar materials are sometimes bonded to the underside of tiles to increase their thickness and strength. Such materials in combination with stone should be chosen with care as backing materials should exhibit similar properties to the adjoining stone. The coefficients of thermal expansion, for example, are important and any incompatibility between the bonded materials can result in bowing, dishing or cracking when subjected to changes in temperature of humidity.

Limestones, sandstones and any similar rock types with a pore structure may be susceptible to the action of frost in exposed locations causing surface delamination of the stone. Cracking through the stone may be indicative of structural fault but could also be due to a vertical orientation of any bedding.

Granites in their unweathered state are normally resistant to frost processes, however, flame-texturing may impart numerous small surface defects increasing the susceptibility of the surface zone to the affects of frost.

STAINING & DISCOLORATION

Of all the problems that may be encountered with a stone floor, staining or discoloration can be the least predictable and one of the more costly ro remedy, sometimes leading to complete floor renewal. Unfortunately, due to the lack of guidance available when such situations arise, the problem is often written off as something that will disappear naturally or can be removed easily using a poultice or other proprietary product. However, in many situations this may not be the case and permanent damage to the stone may have occurred.

Staining and discoloration are terms which are commonly used synonymously, however they describe distinctly different problems. The term staining should be used when materials foreign to the floor are entirely responsible for the colour change to the stone. Discoloration is taken to mean a change of part or all of the natural constituent materials of the stone, although foreign materials may be required to act as catalysts for the discoloring reaction.

Once laid, all stone floors are open to the processes of weathering, even inside buildings, which frequently involves degrees of discoloration. Some recent occurrences of stone discoloration have developed usually rapidly, sometimes before completion of construction, and such incidents appear to be increasing; this in part may be related to changing construction methods, including the associated use of a variety of modern materials.

Careful consideration of stone type, its source, finishing process, packing and transportation methods, storage procedures, design detailing, final usage and maintenance will minimise the potential for discoloration.

Stone type

Some rocks contain certain minerals which are either slightly unstable or may be susceptible to some types of chemical reaction. The products of such breakdown or reaction include a number of essentially amorphous (non-crystalline) solids which are characteristically opaque and do not exhibit the reflective qualities of minerals. The presence of even trace amounts of these materials can affect the optical qualities of minerals and ultimately the stone to which they belong.

Petrographical examination of proposed stone materials, based on the microscopical examination of thin-sections of the stone, is a simple yet comprehensive technique that can give much information on the presence of unstable materials or any other potentially deleterious constituents.

In addition a great deal of information about particular types of stone can also be obtained by inspection of the quarry source.

Quarry inspection

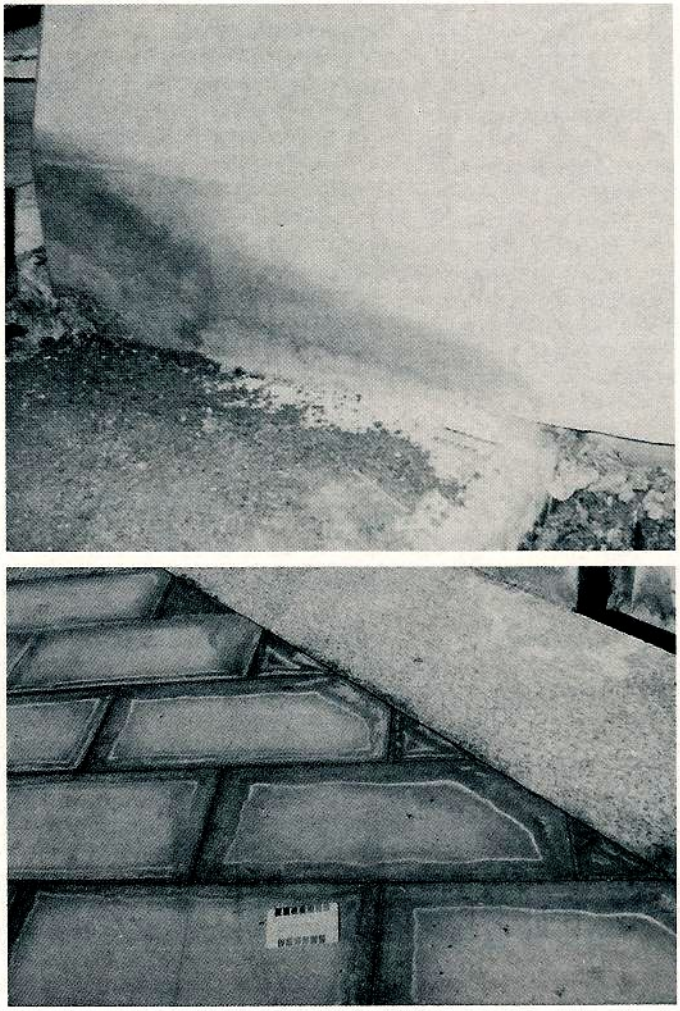
Inspection of the quarry workings can give a reasonable indication of available reserves for a project, variations in the stone and also how well a stone will retain its colour. For large projects it is always advisable that the quarry is inspected by a geologist experienced in the selection of stone. However, in cases where this is not practical, testing should be carried out as an aid to the prediction of discoloration.

Decaying plant products and the natural weathering of the rock may release a variety of materials which can be washed downward into the underlying rock by percolating groundwater. Stone slabs cut from rock into which foreign materials have ingressed may appear fresh, but can be stained rapidly by the retransmission of the trapped materials onto stone surfaces. Some of the materials may stain only as a result of being able to oxidise in their new environments. It is therefore essential that stone is not chosen from areas affected in this way, and again predictive tests can be used to detect potential discoloration.

Cutting and finishing

Some stone cutting procession still employ iron shot as an

Bottom: Fig 7. Efflorescence associated with moisture release at joints.



abrasive. However, if the cut stone is inadequately washed, sawn surfaces can retain remains of the iron which may oxidise to spread various staining iron compounds into the stone. Dressing the stone may not necessarily remove all this material which may be forced deeper into the stone through the pores or along crystal grain boundaries, cleavages and other natural features.

If the remains of the iron shot is trapped in small pits in the stone surface and is not completely removed by finishing; staining may then be able to spread across the finished surface. It is advisable that the iron shot be removed from all surfaces as stacking of the stones may allow the passage of iron compounds from affected to unaffected surfaces (especially sawn to dressed surfaces), particularly if moisture is available.

Chemicals containing waxes, oils, fats and similar organic materials may all be used upon stone surfaces to enhance the depth of colour and the apparent degree of finish. Improper use of such organic materials may, in certain cases, provide problems for future maintenance.

Care must be taken not to spill oils, etc, upon stone surfaces, especially when rough. They may penetrate to a considerable depth and be largely invisible until polishing occurs when they can reappear as staining patches.

In a specific case investigated by the authors an indelible marker pen had been used to mark the stone in the cutting works. Although the stone had subsequently been ground and polished, the ink had penetrated the stone sufficiently for it still to be visible. Needless to say the writing was not noticed until the stone had been used in the construction and subjected to particular lighting conditions.

Packing, transport and storage

Stone is often stacked in wooden crates for transportation. If wet or damp, the wood may transfer a variety of organic materials which commonly impart yellow to brown colours to the stone. Often such materials will remain upon the stone surface and can be easily cleaned off, but particularly in the case of porous stones they may be absorbed into the stone and be transmitted back to the surface at a later time.

Wrapping stone for delivery in clear plastic materials has become popular as this helps to keep dirt, water and other contaminants from entering the stone, but it has been found that the polished surfaces on some stone types can be affected under certain conditions. A similar loss of polish may also occur when completed stone floors are protected by plastic sheeting.

Stone should be kept dry at all times and if wetted must be allowed ample time to dry prior to packing and/or storage. Storage itself preferably should be in a dry environment.

Construction design

Apart from dirt, which can be blown onto and ingrained into the stone surface, almost all staining and discoloration mechanisms require the presence of some form of moisture.

Many limestones naturally contain a proportion of organic material which may have derived from the decay of former living organisms. This material may be insoluble, soluble only in alkaline solutions, or soluble in water.

For many years the incidence of limestone discoloration was restricted to just a few stone types but, with the advent of Portland cements, the number of such cases has increased. This is due to the presence of sodium and potassium in the Portland cement which allows alkaline waters derived from it to act as solvents to some organic materials. Unfortunately as this phenomenon has received little attention there are continuing problems with the brown discoloration of certain porous limestones including, for example, the US Indiana limestone (similar to Portland stone in appearance) and Portland stone itself in some restoration projects.

Many stones, including marbles, granites, limestones and sandstones, contain iron sulphides (pyrite), but usually in low concentrations. In some stone types, including Carrara marble its presence can be particularly discolouring. The highest quality Carrara marbles are pure white grading down to shades of grey. Close examination of the veins and spots, and the body of the greyer marbles reveals the presence of an increasing proportion of iron sulphide minerals, usually as grains below a thousandth of a millimetre (one micron) in size. It appears that alkaline solutions (possibly drawn from underlying cementitious bedding materials) and strongly oxidising agents such as bleach and some other floor cleaners may be able to react with the iron sulphides. Due to the light colour of the marble even the smallest release of iron in the form of ferrous oxides can cause a dramatic change in colour. The form of the ensuing discoloration can be highly variable due to changes in crystal density, size, permeability, and content of discoloring material. Often the veins contain the highest content of deleterious constituents and appear to be the most stained areas of the stone. (see fig. 3)

The pattern of such discoloration can be highly variable, and may be due to differences in the quality of the underlying bedding materials and their ability to absorb and release water, particularly that derived from cleaning. Bedding materials should be allowed to dry sufficiently before the final stone laying-constituents should not be used within the bedding materials which themselves may be liable to release discoloring compounds.

Care must be taken when employing any combination of materials with cements. This was highlighted by an interesting case of staining that occurred recently in a large structure in Bahrain. An external stone floor developed brown staining shortly after completion of the construction. The staining was found to affect several types of marble and was associated with the major joints which had been filled by an elastomeric material. Alkalies from the underlying bedding materials had attacked the elastomer, dissolving out a coloured organic material which was then deposited upon the stone surface. Successive cycles of alkaline solution attack allowed the stain to spread with a 'chromatographic' appearance.

Some sillicone-based materials may also be attacked by alkaline solution and sillicones have also been found to release oils which can lead to staining.

Construction contamination

Welding and grinding of ferrous metals will inevitably be carried out on site for fixing and other purposes and modern construction may be carried out while other trades such as stone fixers are also working in the same area. Such activities can release iron in a molten form which may adhere to stone surfaces. If this spatter is not removed it can potentially oxidise releasing staining iron compounds.

STONE FLOOR MAINTENANCE

A thorough and well considered programme of maintenance must be carried out on stone floors to ensure an adequate service life. Such maintenance will generally involve sweeping (dry dust mopping) followed by damp mopping. Any damp mopping should be done without excessive rinsing which may drive materials into the stone or dampen the underlying bedding materials. If any chemical treatments are to be applied to the floor it is imperative that their compatibility with the stone has been evaluated beforehand.

One material in particular that should not be used on stone floors is bleach. Most bleaches are oxidants and as such can attack a wide range of materials and minerals in a variety of ways, so that any discoloration with bleach may only accelerate the problem.

Similar reactions can occur with the use of acidic masonry cleaners which are sometimes used on certain types of stone. Obviously acids should never be used on marbles or limestones for cleaning purposes but even granites may be attacked with a resultant green/brown discoloration caused by the breakdown of some of its constituent minerals.