PAPERS

The Use of Fluorescent Dyes in Highlighting Some Construction Problems

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Introduction

There are a number of ways in which fluorescent dyes have been used to investigate different construction problems. Importantly, most methods of use can be non-destructive and the dyes used biodegradable, leaving no traces after a short period. Care must be taken to employ good observation coupled with careful consideration of the problems in hand to ensure that the most appropriate methods are used and the right conclusions drawn. Thus far, fluorescent dye techniques have been used with considerable success to investigate problems with moisture penetration to building interiors and to look for cracking in a variety of materials.

Moisture problems in construction were an obvious target for dye techniques owing to the commonly porous and/or permeable nature of most construction materials. By looking carefully at a moisture problem, dyes could be introduced into the moisture at an appropriate point and then where they travelled to could be observed. Conclusions could then be drawn as to the migration of moisture.

Fluorescent dye penetrants had been developed for the aeronautics industry in the quest to identify hairline cracks in aircraft at the earliest opportunity. The methods were taken up for the inspection of steel and other metals used in construction, also for the identification of cracks. The techniques were found to be very easily applied to polished natural stone materials.

The field is young and has endless possibilities, having already come a long way from being a simple guide to the flow of water down drains.

This article will concentrate on the usefulness of fluorescent dyes in the areas of stone cladding cracking, moisture penetration in cavity walls and microscopical and reconstructed stone testing.

The Cracking of Stone Cladding

The 1980s boom in construction saw a huge increase in the use of natural stone cladding. With improved technology, the use of thin stone panels became *de rigueur*, particularly for external façades. Numerous fixing systems were designed to accommodate the panels, many involving either pins or brackets (corbels) inserted into the panels. Owing to the panel thinness, the fixings were the most critical points around which any failure was likely to occur.

Many stone façades comprise marble, granite or hard igneous materials similar to granite. Most commonly, these materials are given a high polish but may also be given a variety of textures. The dye penetrant is painted on to the stone surface and allowed to soak in for several minutes. The excess dye on the surface is removed leaving only the dye that has penetrated the stone. The subject is viewed under ultraviolet (or black) light, which excites the dye that has penetrated the subject. The method works best when the surface excess can be almost completely removed, which is why the method works so well with flat, polished stone surfaces.

The recent bomb blasts in London put stone cladding systems to an extreme test. Moving away from a blast centre and obviously shattered materials, a mixture of variously damaged panels on examination were found next to apparently unaffected

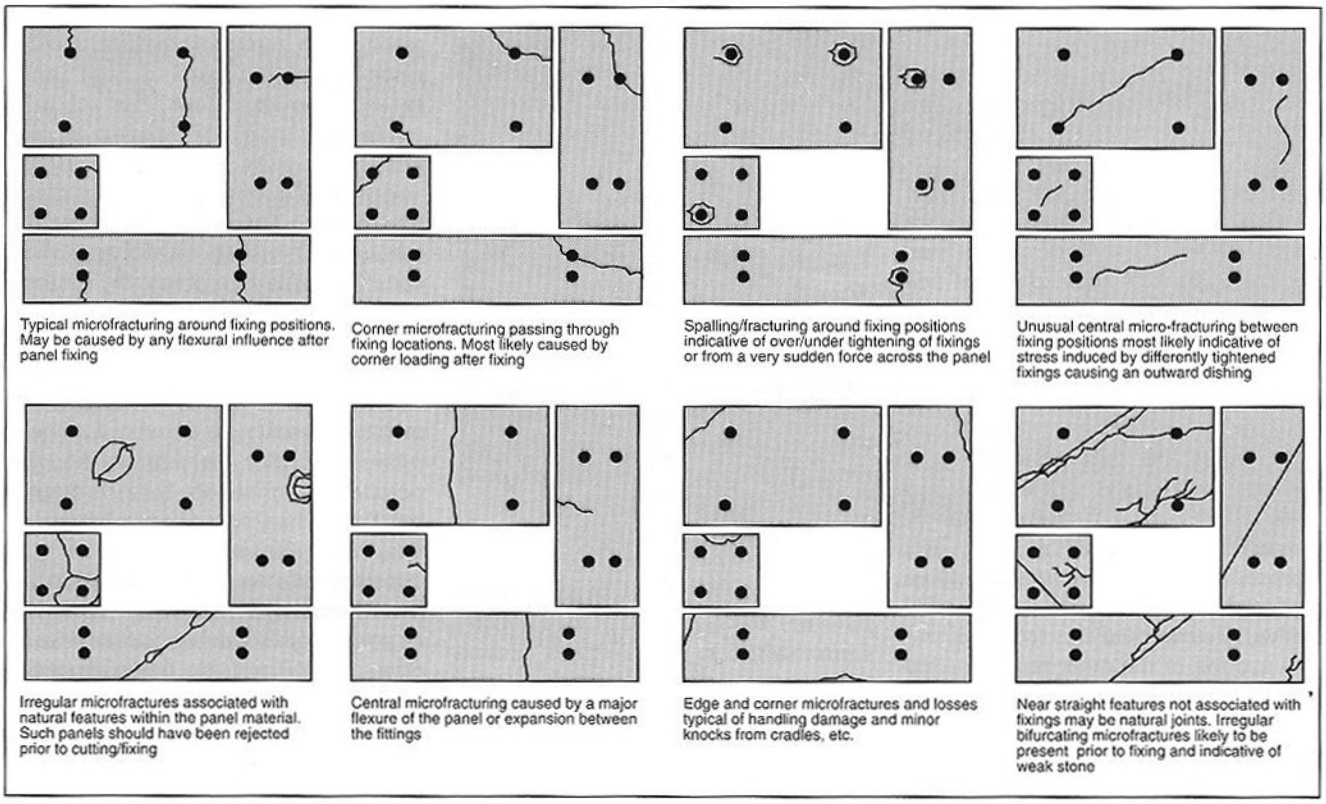

Figure 1. Different Crack Styles for Thin Stone Panels Which Have Been either Face-fixed or Invisibly Bolted. Typical Fixing Locations Are Indicated by the Four Dots. Crack Styles for Other Fixing Systems May Be Considerably Different

panels. It was assumed that a level of damage causing microfractures not visible to the naked eye must have been introduced into many panels. Dye testing was seen as the most effective way to classify non-destructively the degree of microfracturing and determine the longer-term potential panel durability.

Microfractures were found to be associated with fixing positions but closer examination suggested that some of the microfractures were present prior to blast effects. A summary of idealized crack styles is given in Figure 1. Where microfractures are identified, they should undergo careful visual inspection in good light to identify whether the cracks contain dirt (indicative of old age) or are chibbled, a term coined to describe the smoothing and/or loss of crack edges. Chibbling is indicative of an old crack that has had time to deteriorate by any combination of heating/cooling, wetting/drying and freezing/thawing cycles. Fresh cracks still exhibit partially attached chips at crack edges.

Natural stone contains numerous natural microfractures owing to cleavage traces, crystal grain boundaries, veinlets, tight joints and other similar structures. Such features are in the order of a fraction of a micron in width. By penetrating these features, it is demonstrated that the dyes are able to enter any significant microfracture. Introduced microfractures tend to be roughly linear against the background "noise" of the natural microfractures. Veinlets and joints, however, can appear strikingly similar to induced microfractures, re-emphasizing the need for good geological appraisal. One further problem with assessing stones using dye techniques is the presence of weathering, which can make stones more porous/microporous so that they accept a quantity of dye that can obscure the microfracture detail; only the best viewing conditions will allow easy distinction of features. The apparent degree of weathering should be assessed by a geologist.

From my own investigations of blast-affected stone panels, it was evident that some panels were cracked prior to the blast, as a result of either general handling during construction, original use of poor quality materials, uneven tightening of fixings across a panel or any combination of these factors. The features identified may have been insignificant prior to the blast, possibly being exploited by it to produce further damage. Some of the pre-blast damage identified highlighted problems of quality control with the original construction. Furthermore, some of these stones may have been in an extremely dangerous condition.

Dye testing can be used quickly on panels prior to fixing or even cutting in the stone yard to determine the presence of cracking or natural features that may indicate lines of weakness. Considering that uncut stone slabs may be worth in the region of several thousands of pounds, rejection of inferior materials at this stage becomes highly cost-effective for the purchaser. A second check can be carried out once the stones have been fixed to guarantee the workmanship and prevent the creation of potentially lethal situations.

Rough stone surfaces can be dye-tested, provided that the surface is relatively non-porous, but additional care with removing the excess surface dye must be taken. Developing compounds which suck dye concentrations from cracks can be used but are expensive and slow.

Moisture Penetration of a Cavity Wall

A cheap alternative to natural stone is reconstructed stone comprising fine aggregate material within a cementitious binder made to look like and be employed in the same way as natural stone. Its main drawback is a microporous structure which can lead to high water absorption and potential for moisture flow through its fabric. Consequently, its use should be as part of a cavity wall system or any other system including correctly placed damp-proofing membranes.

A new-build project in West Yorkshire with moderate exposure (using the local spell index) consisted of a reconstructed stone outer leaf tied to a blockwork inner leaf using reverse angle ties with a central kink. The internally plastered faces of the blockwork sometimes exhibited well-developed damp patches related to the location of the reverse angle ties. Moisture bridging across the ties was due to the presence of mortar on them. The mortar was cleaned off but, before a practical completion certificate could be issued, a guarantee that the remedial methods had worked was required.

A section of the outer reconstructed stone wall was kept dry for a few days and then painted with fluorescent dye penetrant, which was allowed to soak into the reconstructed stone for about 15 minutes. A mains pressure hose was then turned on to the area and a constant rain of moisture across the test surface maintained. The cavity behind the test area was viewed from an opened corner using black light.

After about 45 minutes, the first moisture appeared on the inner face of the outer leaf. This appeared at the junction of mortar on top of the reconstructed stone blocks, spreading into the mortar more completely after 80 to 90 minutes. The mortar joints became almost completely saturated after about 130 minutes. At this time, moisture started to emanate from the reconstructed stone units. Eventually, numerous drips down the inside of the cavity developed, some of these running on to the reverse angle ties but dripping from the central kinks and not bridging the cavity.

The test demonstrated how important the contacts between different materials are, although, under a constant barrage of water, moisture flow can develop through a whole surface and not just well-defined channels. If the flow on to the inside of the cavity is well developed, taking into account wind pressure effects during a heavy downpour, it is thought possible that water can jet across the cavity from junctions. Whether or not water jetting can be proven, it might be prudent to give the mortar on the inside of the outer leaf slight lips to help direct the water across the inner face of the outer leaf rather than the cavity.

Finally, the extremely simple test method gave the seemingly impossible assurance that further moisture ingress into inner leaf materials was extremely unlikely to occur.

Demonstration of Moisture Uptake by Reconstructed Stone

Reconstructed stone units used variously on a large construction exhibited good performance except for the occurrence of damp on the internal faces of mullion units. The mullions ran through to the outside, with three faces available for moisture absorption. The mullion units were the only units used without either a cavity or a damp-proofing membrane. It was obvious that moisture was being transmitted directly from external to internal faces through the porous/microporous reconstructed stone unit, but a demonstration of how this transmission was occurring was required.

A section of a mullion unit was sealed at each cut end with a silane-type material. The exposed faces of the mullion and those internal faces which would normally be plastered were left free. The central areas of the mullion where it would normally have been held by the window frame were sealed using a silicone. A simple diagram of the preparation is given in Figure 2. The exposed faces were coated with fluorescent dye which was allowed to penetrate for about ten minutes. The mullion was turned upside-down and the exposed faces immersed in water. The sample was then viewed in black light.

After ten minutes' partial immersion, the dye was visible at the bases of the untreated internal side faces; 45 minutes into the test, the dye had reached the innermost surface, having risen up the majority of both inner faces. The moisture rise clearly exploited zones of higher micro-porosity owing to very localized variations in compaction. Thin crack features also became visible during the test, the dye also exploiting such conduits. After two hours, the mullion unit was almost completely saturated.

The test relied solely on the capillary absorption of the reconstructed stone, working against gravity effects which might normally be expected to be a positive factor in increasing the potential for moisture flow through a material. The partial immersion in water of the exposed faces was considered to equate to the continued introduction of fresh water on to the exposed faces during a continuous downpour of rain. No dye entered the sealed cut ends, indicating that these had not biased the result in any way.

The simple test demonstrated how rapidly moisture could be transmitted through reconstructed stone, damp occurring internally where the design was inappropriate rather than the material itself failing. Reconstructed stone products are notoriously difficult to test, with great variability in the results often having been found. The test highlighted the manufacturing variability, particularly differences in compaction which would explain such results.

Microscopical Techniques

Petrographic examination is one of the most invaluable tools available for many materials investigations. Visual and low-power microscopical examination may be combined with

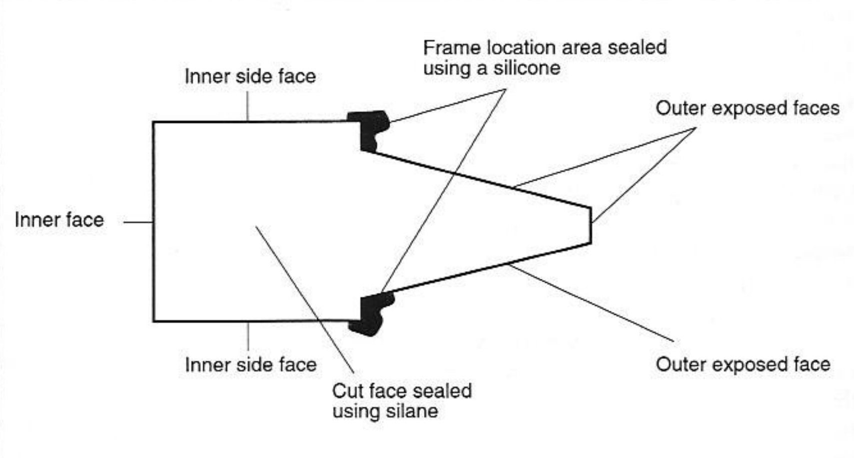

Figure 2. Cross-section of a Mullion Unit Used for Testing to Determine the Capillary Uptake of Moisture Incident on the Exposed Outer Faces through to the Unexposed Inner Faces