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Deterioration of Cement-Rendered Brick Masonry Buildings: Case Study of a World War II Airfield in East Lothian, Scotland

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Abstract This paper investigates the deterioration of cementitious renders, with reference to the buildings on a World War II Airfield, now the Museum of Flight, in East Lothian, Scotland. Most of the buildings are brick masonry with a thin cementitious render, and on several of them the surface of the render is blistering, flaking and eventually being lost altogether. The blistering was investigated using non-destructive techniques such as infrared thermography, electrical resistivity measurements and rebound hardness testing; and with analytical methods such as X-ray diffraction, scanning electron microscopy and ions analysis of aqueous extracts. The results show that the deterioration is active and ongoing, and suggest that it may involve the movement of moisture, may be linked to the presence of certain aggregates within the render and may be salt-related.

1 Introduction

1.1 The deterioration and conservation of concrete and cement

Buildings and structures constructed using concrete and cement constitute an important part of our tangible cultural heritage from the late nineteenth and twentieth centuries. However, the significance of these buildings has only recently begun to be recognised, and so less research has been undertaken to understand how and why they deteriorate than for traditional buildings. The development of conservation methods and techniques is also at a less advanced stage than for traditional buildings, and most of the literature relating to concrete repair is directed towards modern reinforced concrete, rather than historic concrete and cement. A further issue is the difficulty of applying the usual principles of building conservation to concrete and cement, 'particularly in relation to the aims of minimum intervention, retention of authenticity and reversibility' [1].

1.2 The museum of flight, East Fortune

A Royal Naval Air Station was built at East Fortune, in East Lothian, Scotland, in 1915, to house both airships and aircraft. It was and still is a rural location, approximately 5 miles from the North Sea. The station was used for military purposes again during the Second World War, and many new buildings were constructed very quickly. After the war finished the station was gradually wound down, until 1975 when the Second World War buildings were opened as a Museum of Flight by National Museums Scotland. In 1990 the site was designated as a Scheduled Ancient Monument and 8 of the most significant buildings were given a category B listing.

The Museum of Flight includes around 23 brick buildings with cementitious renders. They are simple rectangular structures, with protruding piers on the outsides for extra structural stability, and although they may appear to have little architectural merit in themselves, they are significant because they help to make the site 'probably the most complete Second World War temporary airfield in Britain' [2]. In order to preserve this completeness, the original fabric of the buildings needs to be preserved as far as is possible.

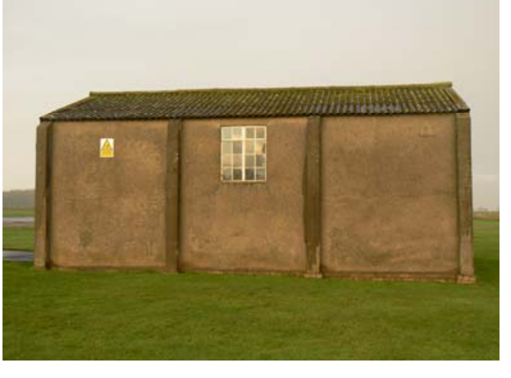


Fig. 1 The Crash Tender (Building 38), an example of the cement-rendered brick masonry buildings

1.3 Types of deterioration

Considering their age and the circumstances of their construction, the buildings are in fair condition. Many still have their original asbestos roofs, still functioning, and most of the cementitious render is original. Only a few of the most severely deteriorated bricks have been replaced. However, some deterioration has occurred, due to a combination of the way the buildings were designed and constructed, and the environmental conditions at the site. The deterioration includes breaking and crumbling of the unrendered bricks just above the ground; salt efflorescences forming on the inside walls of the buildings; cracking and delamination of the render; and blistering and flaking of the render. This paper will focus upon the work that has been undertaken to investigate the blistering render and identify possible causes for it.

Fig. 2 The blistering render on Building 47 (Spare Parts Store)

2 Method

2.1 Surveys to investigate the patterns of deterioration

A condition survey found blistering and flaking on only 3 of the brick masonry buildings with a cementitious render: the Main Stores Office (Building 26), a small Latrine block (Building 46) and the Spare Parts Store (Building 47). Infrared thermography was employed as an additional method for mapping the areas of blistering render, in the hopes that it might identify areas where the blistering was at a very early stage. The Flir B400 camera that was used was able to measure the temperature of all the surfaces in the field of view and produce a false coloured image to facilitate the interpretation of the thermal patterns.

2.2 Moisture movement through the render

In order to understand the movement of moisture through the render, the sorptivity of the render was measured and compared to the values obtained for the bricks used at the site. Sorptivity characterises the ability of materials to absorb and transmit water by capillarity and was measured using a standard procedure [3].

The pattern of moisture movement through the render was initially investigated simply through visual observation of the buildings in different weather conditions, since the render appears darker when it is wet. The moisture contents of the bricks and the render were then investigated non-destructively using infrared thermography and moisture resistivity measurements, and direct analysis of the moisture content of the bricks and the render was also undertaken where possible, by sampling small pieces of delaminating material still in contact with sound material. The results were compared to values for the moisture content at saturation for the material type, obtained during experiments to measure the porosity of samples.

2.3 Surface properties of the render

The surface properties of the blistering render were investigated non-destructively using a rebound hammer, also known as a Schmidt hammer, which measures the rebound hardness of a material. Hardness testing may be considered equivalent to performing a compression test on a small volume of the material's surface, and a correlation between hardness and yield stress may therefore be expected, and has been demonstrated experimentally [4].

In order to compare the appearance of the render at the surface and in-depth, core samples were taken in a blistering area and a non-blistering area on Building 46, and examined with the naked eye and at low magnification.

2.4 Analysis of the cementitious component of the render

X-ray diffraction was carried out on finely ground samples of the cementitious part of the render, from which as much aggregate as possible had been separated either manually or by sieving. Aqueous extractions were then prepared from the bricks and from the cementitious parts of the mortars and renders, and were analysed using Ion Chromatography to obtain concentrations of chloride, nitrate, phosphate and sulphate; and with ICP-OES to obtain concentrations of calcium, magnesium, sodium, potassium and aluminium. The percentage by weight of each ion extracted from the sample was calculated.

2.5 Analysis of the aggregate component of the render

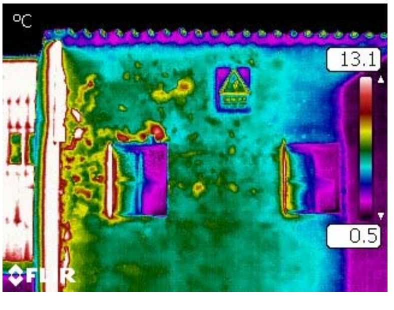
The render composition varies from building to building: some render contains almost no aggregate except fine sand and some is very rich in pebbly aggregate. The blistering only occurs in the latter type of render, suggesting that the pebbly aggregate may be a relevant factor. Blistering pieces of render were sampled and inspected, and specific aggregate particles were then examined using an optical microscope and a Scanning Electron Microscope (SEM), and were analysed with the SEM and with X-ray diffraction.

3 Results and discussion

3.1 Surveys to investigate the patterns of deterioration

The visual survey demonstrated that for the 3 affected buildings, the blistering occurred more frequently on south-facing walls, but also on north-facing walls. It was found in patches all over, but seemed to be concentrated on the piers and on the flat areas of wall just adjacent to the piers. On Buildings 46 and 47 it was found immediately to the right of the piers, on the south east side.

The infrared thermography survey was undertaken on a day when the walls of Building 46 were heated up by the sun, and the blistering areas appeared warmer. This was because there are air pockets within the blistered render, creating a thermal break and resulting in the render heating up more readily than elsewhere. Furthermore, the infrared thermography showed large areas adjacent to the visible blistering which looked sound to the naked eye, but where hollow patches had begun to form below the surface. This was confirmed by tapping. For example, the area between the 2 windows on the NW side of the SW wall on Building 46 looked fine, but the infrared thermogram showed that it was beginning to blister.



Figs. 3, 4 Infrared thermogram of the SW wall of Building 46, with a digital image for comparison (Images: Maureen Young)

3.2 Moisture movement through the render

Table 1 Sorptivity of the cementitious render and bricks from the Museum of Flight

	Render from Building 24	bricks type 1 (Niddrie)	bricks type 2 (Edinburgh)	bricks type 3 (White Hill)	bricks type 4 (Prestongrange)
Sorptivity in $mm/min^{1/2}$	0.10	0.51	0.58	0.67	1.79

The render was found to have low sorptivity in comparison to the bricks, meaning that the absorption and desorption of moisture by the render occur fairly slowly.

It was observed that many buildings appear to have a zone of rising damp at the base of the walls, extending up to 1 m from the ground. When it rains the entire wall surface is wetted, and because the piers are the most exposed parts of the walls, they become wet most quickly, and take longest to dry out. These observations were substantiated by the moisture content data in combination with the non-destructive testing, which showed that the bricks and mortar close to the ground are very wet, and that the render at this level is also wet or at least damp. The driest areas of render are found at heights above 1 m on the flat walls, and the render on the piers tends to be slightly damp even on dry days.

Table 2 Moisture content of the cementitious render and bricks from the Museum of Flight

	Unrendered bricks just above the ground	Mortar from joint in bricks close to ground	Render from close to the ground	Render on piers at various heights, on wet and dry days	Render from above 1.5 m on flat walls on dry days
Moisture content (% weight)	10.3 - 14.8	13.4	7.6 – 13.1	4.4 – 6.8	1.3 – 2.1
Moisture content at saturation for similar material (% weight)	12.9 - 16.4	14.9	17.3	17.3	17.3

3.3 Surface properties of the render

The rebound hammer testing on Building 47 showed that the reading in blistering areas was usually the same as in adjacent sound areas, suggesting that the blistering is not indicative of significantly weakened render. Additionally, although the surface of the core from the blistering area broke off in a thin sheet approximately 2 mm thick, the samples were otherwise visually very similar. The core from the blistering area did not appear to be disintegrating throughout.

3.4 Analysis of the cementitious component of the render

The most useful results to date have been obtained from the analysis of aqueous extracts.

Table 3 Percentage of selected anions and cations extracted from render samples

	% Cl^-	% SO_4^{2-}	% Ca^{2+}	% Na^+	% Al^{3+}
Building 23	0.0006	0.0154	0.1158	0.0082	0.0002
Building 24	0.0015	0.1831	0.1433	0.0118	0.0002
Building 23 (1992 render)	0.0012	0.1106	0.0409	0.0046	0.0001
Building 26: blistering area	0.0039	0.0245	0.1580	0.0135	0.0593
Building 26: no visible blistering	0.0009	0.0341	0.0559	0.0087	0.0219
Building 46: blistering area	0.0158	0.4876	0.2106	0.0187	0.0179
Building 46: no visible blistering	0.0045	0.0916	0.1373	0.0092	0.0103

The results have been given for the historic render and a more modern render on 2 buildings where there is no sign of blistering (Buildings 23 and 24), and for the blistering and non-blistering areas on Buildings 26 and 46. Figures have only been quoted for those ions which were detected in reasonably high concentrations. More comprehensive ions analysis is required, but these initial results show that the 3 highest concentrations of chloride ions and the highest concentration of sulfate ions came from buildings where the render is blistering. Also, the concentrations of aluminium ions, although low, were over 10 times greater for the buildings with blistering render than for the buildings with no blistering.

3.5 Analysis of the aggregate component of the render

It was found that blisters often seem to form above certain types of aggregate, including a greyish flaky material, a soft orange-yellow material, and little pods of fibrous material, which may be of plant origin. Examination with the SEM showed that the small pods are composed of long tangled fibres. The greyish material has a fairly smooth appearance, and the soft yellow material is rough and granular. Preliminary X-ray diffraction results have identified lots of carbon in the greyish material, suggesting it may be charcoal, and quartz in the yellow material, suggesting it may be sandstone. These aggregates are all very soft, and are probably quite porous.

Fig. 5 A blistering piece of render on Building 47, with a large grey particle underneath

4 Conclusions

The blistering of the render on some of the buildings at the Museum of Flight is concerning because original render is being irreversibly lost, and the deterioration is active and ongoing. Condition surveys show that the blistering seems to be concentrated on and around the piers, which are the parts of the buildings undergoing frequent cycles of wetting and drying. This suggests that moisture may play a part in the deterioration mechanism.

Examination of core samples and rebound hardness readings indicate that the blistering is largely a surface effect which does not occur through the depth of the render, and that the blistering areas are not significantly weakened.

The ions analysis results are not fully comprehensive, but suggest that the blistering may be linked to higher concentrations of chlorides, sulfates and aluminium than those found elsewhere. It is possible that gypsum ($CaSO_4.H_2O$) and/or ettringite ($[Ca_3Al(OH)_6.12H_2O]_2.(SO_4)_3.2H_2O$) is crystallising within the render, but this requires further investigation.

Finally, the blistering seems to be related to the presence of pebbly aggregate. The presence of plant material shows that the aggregate was not particularly clean, so it is possible that it was contaminated with soluble salts. It may also be that the chemistry of individual particles is relevant, as the blisters often seem to form above certain types of aggregate. There may be some physical effect connected to the absorption and desorption of moisture from the aggregate particles, with associated dimensional changes, or even a chemical effect due to concentrated areas of soluble salts forming around the aggregate particles, and subsequently crystallising, perhaps as less soluble compounds.

If the blistering is related to the chemical composition of the render, there is little that can be done to prevent it. The buildings where blistering is occurring need to be recorded thoroughly before the render is lost, and techniques to conserve the render need to be investigated. If replacement of areas of the render becomes unavoidable, this should be undertaken as sympathetically as possible.

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