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Laser scabbling of mortars

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HIGHLIGHTS

- This is the third study in a series on laser scabbling.
- The present study investigates the factors of laser scabbling of mortars.
- Degree of saturation affects volume removal; however, the relationship is non-linear.
- The use of PFA, probably due to its effect on permeability, increases volume removal.
- A higher fine aggregate content also increases volume removal.

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ABSTRACT

Laser scabbling of concrete is the process by which the surface layer of concrete may be removed through the use of a low power density laser beam. Previous research has suggested that the driving force responsible for laser scabbling is developed within the mortar. The aim of this investigation was to establish the key parameters that influence laser scabbling of mortars. The results show that the removal of free water from mortars prohibits scabbling, but resaturation allows mortar to scabble. A reduced permeability, either due to a reduction in the water/binder ratio or the use of 25% PFA replacement, enhances the scabbling. A higher fine aggregate content increases volume removal and fragment sizes during laser scabbling.

1. Introduction

This paper describes the third part of an investigation into the mechanisms responsible for laser scabbling; a technique used for the removal of the surface layer of concrete which can be used for decontamination in nuclear decommissioning. Radioactive contamination in concrete is generally limited to a depth of around 10 mm [1]. Application of a high power laser (of low power density), perpendicular to the concrete surface, causes concrete fragments to be ejected, thus reducing the volume of radioactive waste sent for disposal. This technique is preferable to alternative methods, such as mechanical scabbling or high pressure water jetting, as no reaction forces or secondary wastes are created.

In the first part of this study [2], a wide range of materials were investigated to identify key factors that affect the laser scabbling process with the aim of establishing an experimental procedure for the quantification of relationships between laser interaction time, surface temperature, volume removal and size of fragments.

The second part of the study [3] investigated the relationships between laser interaction time, volume removal and surface temperatures for different compositions, in order to identify the effect of concrete composition on laser scabbling behaviour. Specimens tested included cement pastes, mortars and concretes, with and without 25% PFA; hardened cement pastes with different water-binder (w/b) ratios; and concretes using basalt and limestone aggregates of different aggregate sizes.

The results of the first two test series showed that:

1. Volume removal of mortars was higher than that of concretes [2,3].

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2. The primary driving force for laser scabbling of concretes developed in the mortar and not in the coarse aggregates [2,3].
3. The dominant mechanism for scabbling of mortars was a combination of thermal stress spalling and pore pressure spalling (which is reduced due to the reduction of available water in the mortars compared to the cement pastes) [3].
4. The use of PFA as a cement replacement material (75%OPC + 25%PFA) [2,3] and/or reducing the w/b ratio [3] enhanced volume removal during laser scabbling of hardened cement pastes (this was attributed to reduced permeability of the material).
5. Reducing the degree of saturation of specimens (saturated vs. air-dried) did not reduce scabbling [2].
6. There was no evidence of stochastic tendencies [2,3], as reported in previous studies [4–7].
7. Mortars and cement pastes using the same binder compositions exhibited different scabbling behaviour [2,3].

2. Scope and aim of the research

The first two test series suggested that the mortar is responsible for the primary driving force in laser scabbling of concretes. This paper aims to determine the relationship between laser interaction time, volume removal and surface temperatures for different mortar compositions, in order to identify the parameters affecting the laser scabbling of mortars.

The compositions selected for investigation in this study were designed to isolate the following factors that were highlighted from the previous two test series [2,3]:

1. Mortars of the same composition with different free moisture contents, to determine the effect of free water content, and potential operational uses, on laser scabbling.
2. Mortars with different w/b ratios, to determine the effects of permeability and strength on laser scabbling of mortars.
3. Mortars with and without 25% PFA replacement, to add to previous work on the effect of PFA replacement on laser scabbling.
4. Mortars with different fine aggregate contents, to gain an understanding of the effect of fine aggregate content on laser scabbling.

3. Materials, specimens, test set-up and experimental programme

The material compositions used in this study are given in Table 1. The materials used for preparing the test specimens were: Lafarge CEM 1 OPC (BS EN 197-1:2000 strength class 52.5 N); CEMEX PFA (LOI-B and fineness-s); and fully graded marine dredged quartzitic sand from Hoyle Bank, Morecombe Bay, UK. It should be noted that the CEM 1 used in this study was of a different brand to that used in the two previous studies [2,3].

All mixes underwent 30–60 s dry mixing followed by 3–5 min wet mixing. The slurry was transferred to 100 mm cube moulds which were 3/4 filled and vibrated for approximately 10 s before being filled and vibrated again for approximately 10 s, and the cast face trowelled smooth. All specimens underwent a ten day temperature matched curing regime reaching a peak temperature of 65 °C after 36 h, gradually returning to 20 °C after 240 h. After curing, the 100 mm cubes were cut in half using a diamond saw, creating 100 mm × 100 mm × 49 mm (±1 mm) cuboid specimens, which were stored in a mist room at 100% relative humidity until testing, or preconditioning.

The mix composition of the mortar used in the free water investigation (Mp) is detailed in Table 1. It is the same mix composition as the mortar (M) used in the first test series [2] and the PFA + OPC mortar (Mp) used in the second test series [3]. Specimens tested in the free water investigation were exposed to the preconditioning methods detailed in Table 2 until constant mass was achieved (a loss of <2 g/day for oven dried and <0.1 g/day for dessicated and air dried specimens). The moisture content and degree of saturation of specimens exposed to the different preconditioning methods are also given in Table 2.

The laser interaction times and age of specimens at the time of testing are given in Tables 3–5; each test was repeated three times unless stated otherwise. All scabbling tests were carried out using an IPG Photonics YLS-5000 (5 kW) Yb-fibre laser. The specimens were subjected to a static, continuous, diverging laser beam with a stand off distance of 340 mm from the focal point which gave a nominal beam diameter of 60 mm. Tests were conducted with the laser beam applied to a vertical concrete surface to avoid debris falling back onto the specimen during testing.

The change in mass due to laser application was determined as the difference in mass of the specimen measured before and after testing. The mass change was converted to volume by dividing the mass by the density determined in accordance with BS EN12390-7:2009 [8]. The volume removal graphs show the mean of the repeats with standard deviation error bars. Porosity, moisture content and degree of saturation were subsequently determined using values found in the density tests.

Porosity = $100 * ((m_{sat} - m_{od})/(m_{sat} - m_{sub}))$,
Moisture content = $100 * ((m_t - m_{od})/m_t)$,
Degree of saturation = $100 * ((m_t - m_{od})/(m_{sat} - m_{od}))$; where m_{sat}, m_{od}, m_{sub} and m_t are saturated, oven-dried, submerged and as received masses respectively.

An infrared camera (FLIR SC 640) was used to monitor the surface temperatures. The average surface temperature was taken over the surface area that exceeded 100 °C after 1.0 s of interaction time. The time histories of average surface temperature, showing the temperature fluctuations due to ejection of fragments (their amplitudes corresponding to size of fragments), were used as key data in characterisation of the scabbling behaviour of each material (Fig. 1).

The infrared camera can operate within temperature ranges of 0–550 °C or 200–2000 °C. In most cases surface temperature data was recorded for six tests per composition (three in each temper-

Table 1
Mix compositions of specimens in the three investigations: (i) effects of free water content, (ii) effects of w/b ratio (and binder composition) and (iii) effects of fine aggregate content. All values are mass/binder ratios unless otherwise stated.

	(i) Free Water	(ii) Effect of w/b ratio				(iii) Effect of fine aggregate content			
	*Mp	Mp37	Mp47	Mo37	Mo47	Mp0%	Mp20%	Mp40%	Mp60%
Water	0.42	0.37	0.47	0.37	0.47	0.42	0.42	0.42	0.42
OPC	0.75	0.75	0.75	1	1	0.75	0.75	0.75	0.75
PFA	0.25	0.25	0.25	0	0	0.25	0.25	0.25	0.25
Fine agg.	1.84	1.84	1.84	1.84	1.84	0	0.36	0.95	2.13
$\%_{(m)}$ sand	56	57	56	57	56	0	20	40	60