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The effect of ageing and drying on laser scabbling of concrete

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HIGHLIGHTS

- This is the fourth study in a series on laser scabbling.
- Results suggest that drying reduces laser scabbling in concretes.
- Results suggest an optimum degree of saturation exists.
- The effect of ageing on saturated specimens is generally small.
- An increase in stochastic scabbling behaviour may exist with age.

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ABSTRACT

Laser scabbling of concrete is a process by which the surface layer of concrete is removed through the use of a high power (low power density) laser beam. In order to understand how the age and treatment of structures may affect the laser scabbling process, the aim of the research presented in this paper was to establish a relationship between laser interaction time, surface temperature and volume removal for cementitious materials of different ages and different degrees of saturation. The investigation focussed on (i) the effect of age on saturated specimens and (ii) the effect of prolonged drying. The results show that drying of specimens had the largest effect on scabbling. The effect of age on saturated specimens was small for PFA + OPC pastes, mortars and concretes, but significant for OPC pastes, where the volume of scabbling dramatically reduced with age.

1. Introduction

Laser scabbling of concrete is a technique which can be used for removal of the contaminated surface layers in decommissioning of nuclear structures. Significant advantages over alternative methods are that it does not create large reactive forces (typical for mechanical removal) and does not produce additional waste material (water jetting) [1]. Presented here is the fourth part of a study [1–3] of the key factors and mechanisms that control the efficiency of laser scabbling.

The design life of a nuclear power plant is generally 60 years, which is often extended to improve the economic rewards of the station. Furthermore, the first stage of decommissioning is usually to remove the fuel and leave the structure in a state of passive safety for around 20 years to allow the majority of the short lived radionuclides to decay. As a result, structures undergoing decommissioning will be of the age of around 80–100 years.

Concrete age is an important factor affecting its properties, from cement hydration in the early stages to environmental effects, such as drying and weathering, in the later stages.

Extra specimens were saved from the first two test series [1,2] to be tested at a later date, in order to determine the effects of ageing and drying on laser scabbling. These specimens continued to be exposed to the same conditions as those that were originally tested (i.e. air dried or saturated). The results of this study are important to validate the results and conclusions made in the earlier stages of this investigation [1,2].

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2. Scope and aim of the research

This investigation focuses on understanding the effects of ageing and drying of concrete on the effectiveness of laser scabbling. The aim of the research was to determine the relationship between laser interaction time, average surface temperature and volume removal for material compositions of different ages and drying exposure times in order to analyse the effects of concrete age and degree of saturation on laser scabbling behaviour, characterised by temperature at the onset of scabbling, surface temperature changes during scabbling, rates of volume removal, fragment ejection frequency and fragment sizes. The compositions reported in this study (presented in Table 1) were selected for the earlier test series [1,2] to isolate factors that have a significant effect on the process. The notation in Table 1 is the same as that in the second study [2], but different from the notation used in the first study [1], where PFA + OPC binder was used for all limestone concrete (LC), basalt concrete (BC) and mortar (M) specimens. In this study (as well as in [2]) the investigation was extended to concrete and mortar specimens with OPC binder (Lo, Bo and Mo), in addition to those cast with OPC + PFA binder (now denoted as Lp, Bp and Mp). The results reported here are grouped into two investigations looking at (i) the effect of age on saturated specimens and (ii) the effect of prolonged drying.

3. Materials and test methodology

The material compositions of the specimens tested in this investigation are detailed in Table 1. The experimental methodology was the same as the one used in the first two test series [1,2]. The scabbling was induced by using an IPG Photonics YLS-5000 (5 kW) Yb-fibre laser to fire a static, continuous, diverging laser beam with a stand off distance of 340 mm from the focal point (giving a nominal beam diameter of 60 mm) on 100x100mm surface[1] of rectangular specimens (49 mm thickness), for exposure (interaction) periods of 10 s, 20 s, 30 s, 40 s (for all specimens), and 70 s (for selected specimens).

The results are presented as time histories of:

1. *Volume Removal*: The volume removal histories were constructed by connecting discrete values of volume loss calculated at the end of the interaction periods for each specimen (at 10 s, 20 s ...etc.), from measurements of mass loss of the specimens before and after scabbling, and converting to volume by dividing the mass by the density determined in accordance with BS EN12390-7:2009 [4]. This approach was validated by direct measurements of volume loss using a 3D scanner (see [1]).
2. *Average Surface Temperature*: The average surface temperature of the heat affected zone (HAZ[2]) was monitored by using an infrared camera (FLIR SC 640) recording thermal images of the surface at time steps of 1/30 s. The average surface temperature changes as a result of scabbling: it rises when there is no scabbling, and drops when material is ejected and cooler surfaces underneath the ejected fragments are exposed. Hence, the temperature histories give a detailed picture of the scabbling process, that complements the discrete volume removal data: continuous rise in temperature indicates that there is no scabbling, small and frequent fluctuations show frequent ejection of small fragments, whereas a monotonic temperature increase followed by a large drop in average temperature indicates a less frequent ejection of larger fragments. The slope of the baseline around which the temperature oscillates is a good measure of scabbling efficiency, with most effective scabbling resulting in zero gradient. The stages of scabbling behaviour are illustrated in Fig. 1: (1) initial steep increase in surface temperature until the onset of scabbling, (2) a period of intense scabbling at nearly constant baseline temperature, characterised by either very frequent, small amplitude or larger, but less frequent temperature oscillations (resulting in a high rate of volume removal), followed by (3) a period of reduced scabbling (smaller fragments and/or reduced frequency of ejection), increase in baseline temperature and reduced rate of volume removal) and finally (4) a period of monotonic increase of surface temperature (no further volume removal).

4. The effect of age on saturated specimens

4.1. Test programme for saturated specimens

In order to test the effect of age on laser scabbling, extra specimens were made during casting for the investigation into the effect of concrete composition on laser scabbling [2]. The first series of tests were performed at the ages of 3 months for the cement paste specimens and 8 months for the concrete specimens. The remaining specimens were then stored in a saturated state in a mist room ($\approx 20\,^{\circ}$C, $\approx 95\%$ relative humidity) until they were tested 14 months later.

The experimental programme of this study is presented in Table 2, showing the material composition of the specimens, laser interaction times (duration of exposure), ages of specimens at the time of testing and number of repeats of each test. The test results, presented as time histories of volume removal and average surface temperature (e.g. Fig. 2), were obtained by using an experimental procedure described in detail in the first report of this investigation [1].

4.2. Test results for saturated specimens

The time histories of volume removal and average surface temperature of saturated hardened OPC paste specimens, tested at the age of 3 months (71–77 days) and 17 months (479 days) are presented in Fig. 2.

Fig. 2a shows that both OPC pastes (with w/b ratios of 0.32 and 0.42) experienced reduced volume removals when tested at 17 months compared to those tested at 3 months (up to around 40% drop for O_{32}, and 30% for O_{42}). At interaction times below 40 s, the younger O_{42} paste experienced a higher rate of volume removal (around 0.9 cm^3/s) than the older O_{42} paste (around 0.4 cm^3/s), but between 40 s and 70 s both ages showed similar rates of volume removal (around 0.2 cm^3/s). The younger O_{32} paste shows a much higher rate of volume removal throughout the interaction times tested (1.6 cm^3/s), compared to the older O_{32} paste (1.1 cm^3/s initially, reducing to 0.4 cm^3/s). OPC pastes with lower volume removals exhibit higher average surface temperatures (Fig. 2, b and c); as material is removed less frequently, the surface is exposed to prolonged laser interaction and heated to a greater extent, inducing more extensive vitrification (Fig. 3).

The results for the saturated PFA + OPC pastes (Fig. 4) show that the age difference of the specimens had little effect on their scabbling behaviour. The rate of volume removal of the two P_{32} pastes is practically identical (Fig. 4a). The temperature at the onset of scabbling is higher for the aged P32 specimen (Fig. 4b), but once the process started the rates of temperature increase were the same. The surface temperature histories of the two P_{42} specimens (Fig. 4c) are very close, resulting in very similar volume removal rates (Fig. 4a).

[1] horizontal in [1], vertical in [2] and in this study

[2] HAZ was defined as the surface area that exceeded 100 °C after 1s of interaction time