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MOLAB User Report

Project Title: MacSTONE: Effects of fire on building stone at the Mackintosh School of Art, Glasgow, Scotland

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Venue: The Library of the The Mackintosh Building of the Glasgow School of Art, Scotland, June 20th to 24th 2016.

The Glasgow School of Art (GSA, 1897-1909) is considered the masterwork of Charles Rennie Mackintosh (1868-1928) and remains the functional core of one of Europe's leading Art and Architecture Schools [1]. On the 23rd May 2014 fire burnt through the west end of the GSA [2,3,4]. Starting in the basement the fire engulfed several studio spaces, and the School's library; perhaps the finest example of Art Nouveau interior design in the world [1,5]. The public and expert reaction to the disaster [5] has contextualised recovery; research seminars developed collaborative projects around the impact of the fire, from which this project grew.

In the devastated library space, damage is evident on the sandstone walls, notably the piers between the windows and the walls either side of the tall windows. Surface spalling and cracking of the stone will require significant intervention as part of the restoration effort. The loss of cultural, historic and artistic value, due to the fire, is indeed tragic, but the damage to the structural fabric of the building also behoves us to understand the material impact of the disaster to assist in the restoration and recovery activities. The purpose of the MOLAB visit was to perform analysis on the affected walls to understand the effects of the fire on the stone and to evaluate the degree of damage. It is hoped this will contribute to decision-support for the repair works.

Access to the library for MOLAB was under conditions of a construction site, with appropriate health and safety measures with regard to working practice and personal protection. Structural assessment of the walls of the Macintosh school necessitated the construction of a bracing scaffold. Access was required from floor level up to approximately 4-5m height. Two movable scaffold towers were erected against the fixed scaffold, and permission obtained to place measuring equipment onto the fixed scaffold.

Four MOLAB teams attended:

MOLAB 1 - reflection Mid –FTIR

MOLAB 2 – Stimulated infra-red thermography (SIRT)

MOLAB4 – Digital Holographic Speckle Pattern Interferometry (DHSPI)

MOLAB5 – Nuclear Magnetic Resonance (NMR)

(UWS- also applied Leeb Surface Hardness and Ultrasonic Pulse Velocity measurements.)

Analysis was performed in 17 locations on the wall (Fig. 1), and on specimens of fallen fire-damaged and also taken-down stone, with known locations. For most of these locations analysis was performed using all methods. The stone is from the Giffnock quarries in Glasgow (quartz arenite, secondary



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kaolinite, Fe-oxyhydroxides and ankerite [$\text{Ca}(\text{Fe},\text{Mg},\text{Mn})(\text{CO}_3)_2$], medium grained, well sorted, 20-25% porosity, similar to [6]).



Figure 1: overview of the damaged sandstone piers in the Library of the Mackintosh Building. View is facing west, and the red dots indicate the location of analysis points, including of taken-down stone (i.e. not an in-situ measurement) for the highest located point.

Reflection Mid –FTIR

Seven areas were analysed and 46 measurements made. The highlights from the measurements include the confirmation of the main constituents of the stone; kaolinite, quartz (no surprise) and Fe-oxides and a signature of an Fe-carbonate, probably the ankerite cement. On surfaces where fresh stone had been exposed, there are indications of the formation of gypsum and also oxalates, suggesting weathering of the stone since its exposure during the fire, next to a glassless window. The gypsum may be earlier evidence of surface soiling, or a reaction product from the fire, however other instances of Calcium-sulphates show variation in hydration state, that probably is related to temperature related effects from the fire. Kaolinite may be expected to show a transition to dehydroxylated meta-kaolinite at temperatures around 600° C, and indeed the IR results do show evidence of this taking place particularly on the outer blackened portions of stone, and less so on areas of spalling.

Stimulated infra-red thermography (SIRT)

Thirteen areas were examined using stimulated thermography. At each location the surface of the wall was warmed using lamps and an infra-red thermal image movie captured over a period of up to eight minutes. The variety of surfaces analysed ensured differences in behaviour were captured. Soiled surfaces obviously increase in temperature more than lighter unsoiled or spalled surfaces (which expose fresher, lighter coloured stone). Detachments also retain heat more and become very clearly delineated in the images. There is increased heterogeneity of the surfaces in un-spalled areas and in areas interpreted as having experienced higher fire temperatures.



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Digital Holographic Speckle Pattern Interferometry (DHSPI)

The areas examined using SIRT were mostly also examined using DHSPI. Similarly to SIRT, the surface under study is heated for a short time using a lamp, and the 3-dimensional movement response is recorded using the laser scanner detector and also with a thermal imaging camera. Variable responses of the surfaces are captured in images exhibiting interference fringes; in general curved fringes indicate movement in the z-axis, to and from the viewer, and straight fringes indicate in-plane movement on the surface being investigated. In the areas considered to be least damaged (lower North window surround), the level of damage (dislocations essentially) are not significant where obvious dislocation is not seen, and movement of the surface is mostly in-plane with the surface orientation. Areas with surfaces exposed by spalling (presumably by a fire damage leading to loss of surface) show low indications of damage, with linear, widely spaced fringe patterns. In contrast surfaces that retained their original surface profile, mostly show curved and relatively more dense fringe patterns indicating surface damage. This appears to correlate roughly with the expected areas of highest temperature during the fire.

Nuclear Magnetic Resonance

Four areas were studied in-situ in addition to measurement on a fragment of stone taken down from a known location and height on the south stone pillar. Relaxation time (T_2) measurements show a systematic variation of value with location. T_2 increases with height above the floor and from least to most damaged areas. NMR measurement of similar stone that has been heated in the laboratory showed a very strong apparent correlation of T_2 with increasing temperature. This enables us to suggest temperatures reached on the walls, up to 900° C. Depth profile analysis also reveals patterns in water absorption. For most specimens areas absorption is detectable up to 10 mm from the surface, but mostly less. For the sample from the highest location on the walls, that is considered to have suffered the highest temperature during the fire, the water absorption is still appreciably high beyond 10mm. This suggests an increased porosity and permeability of the stone, something consistent with laboratory measurements of similar properties on experimentally heated stone (performed by the authors of this report).

Conclusion and Further Work

There has certainly been visible damage to the walls of the library of the Macintosh Building at the Glasgow School of Art, and MOLAB's non-destructive methods, applied in this project, appear, at a preliminary level of interpretation, to provide measurements of physical, mechanical and compositional properties that rationally vary with our estimates of the degree and intensity of damage done. The intensity of damage appears to vary from the north and lower portion of the interior of the west façade to the higher parts of the two central stone pillars, with an indication that the temperature at the highest point may have reached 900° C. However, lower down the level of damage, apart from discolouration in some parts is possibly not, in comparison, very great. Temperatures may have reached 300-500° C in these areas. Detachments and small areas of spalled stone are still common in these lower zones. Where stone has suffered significant surface loss through spalling, the new surviving *recessed* stone surface, though representing a much reduced cross sectional thickness in the wall, exhibits properties that indicate that it has not suffered damage during the fire. However, and rather obviously, the stone is of course damaged due to spalling caused by elevated temperatures, but the surviving stone represents that beyond some lower threshold for the temperature effects.



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Further work is planned to investigate, and corroborate the composition of the phases that show change from FTIR analysis. This will be by XRD at UWS, on surface scrape samples from the walls of the library. In addition to this, a representative set of specimens was obtained from the GSA from the taken-down stone (with numbered locations attributed by Nic Boyes Conservation), from various heights across the damaged stone piers. Additional lab-based FTIR is also planned to compliment the analysis done in-situ, mainly as it was not possible to apply the method at higher levels of the wall. These specimens could also allow us to better calibrate the DHSPI results, alongside experimentally burned materials, so that the variation in response can be better tied to the temperatures of exposure suffered by the stone. The results obtained from the NMR results also suggest further work to improve the calibration of our understanding of the variation in properties measured in-situ. Combined studies with additional microstructural and compositional characterisation on the taken-down specimens by a variety of laboratory based methods should provide a much better understanding of the effects of fire on this variety of sandstone.

References

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