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Studies of hair for use in lime plaster: Implications for conservation and new work

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ABSTRACT

Historic buildings constructed with lime plasters often require repairs and re-plastering of areas as part of a maintenance and conservation regime. Hair is commercially available for use in lime plaster and mortar, as it is still used today to provide additional strength and crack resistance to fresh plaster. In this study we examine commercially available imported hair from a number of species as well as fresh, untreated horse hair. Small angle X-ray scattering (SAXS) demonstrates a loss of keratin structure in most of the imported, treated hair samples, including horse hair compared to untreated indigenous horse hair samples. Fourier transform infrared spectroscopy (FT-IR) shows that the imported horse hair has high levels of cysteic acid present which is not shown in the fresh, untreated hair. The results obtained suggest that imported hairs are treated with an oxidising agent such as bleach or acid prior to sale, and this weakens the hair making it more susceptible to failure in a building context.

1. Introduction

For centuries, hair has been added as a reinforcement to mortars and plasters in buildings [1,2]. In recent years, other materials such cellulosic and synthetic fibres have been used for the same purpose [3], though the use of hair has persisted, particularly in lime and earth plasters prevalent in historic and traditional buildings. Fibre reinforcement helps to reduce shrinkage cracking [4] and improves tensile strength.

Over time, historic lime plaster can degrade through natural weathering or through the actions of specific, localised problems such as moisture ingress or physical damage. When failures occur, best practice is to investigate the cause of the failure, then specify which type of repair to carry out.

Conservation philosophy is such that repairs should be presented as a “like-for-like” replacement where possible, and that repair materials should be compatible with the substrate they are applied to. If an exact match cannot be reached, the repair material should preferentially degrade over time to protect the historic fabric [5].

In the case of lime plasters, this usually entails the replication of the traditional plaster with non-hydraulic lime putty, or gypsum gauged lime putty, plasters reinforced with hair for repair and replacement. Commonly, 4–8 kg per m^3 of hair is used in lime plasters or renders [6]. Even with correct specification, however, there have been cases where a repair material has failed, and an investigation carried out. This has led to questions being raised about the quality of hair being used particularly as failure has also been reported where hair has been incorporated into in modern materials used in new works [7,8] (Fig. 1).

As hair employed in lime plaster will exist in a highly alkaline environment (pH 7–12) [9], it is essential for the longevity of the material that the hair be in an appropriate condition and not easily susceptible to deterioration from external factors. In extreme cases, hair could dissolve within the lime leaving a void (Fig. 2) which could cause future problems in terms of moisture movement and structural weakness.

Hair is a slender outgrowth from a follicle in the skin of mammals. A hair shaft is comprised of an outer cuticle, a cortex which makes up the bulk of the shaft, and a medulla at the core. The strength of a hair fibre is derived from the protein keratin. Alpha

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Fig. 1. Hair protruding from a modern failed plaster (left), and from 200-year-old chalk lime mortar (right). The hair from the modern samples was shown to be aligned, stiff and brittle. The sample being taken from new work in a private building in Somerset, England, in which a non-hydraulic lime putty plaster was reinforced with a hair imported from China, with failure of the plaster occurring due to the apparent partial digestion of the hair across the rivets resulting in detachment of the plaster from the walls; the historic hair sample was much softer and more randomly orientated, and was obtained from plaster removed from an early 19th century building on the South Coast of England.

keratin makes up 50–60% by mass of the cortex. Here it exists as two polypeptide chains of different molecular weight (named I and II). Each chain has non-helical N- and C-termini, and a central coiled coil domain. The two chains are parallel in the two-stranded 'rope' segments and in axial register [10–13]. Individual polypeptide chains are cross-linked to each other through disulphide bonds from cysteine residues, which provide much of the mechanical strength [14]. Keratin molecules bundle together to form intermediate filaments (IF), a complex assembly of heterodimers. Between 23 and 32 chains bundle together to form an approximately cylindrical IF, with disulphide bonds from cysteine residues cross-linking between adjacent molecules in the surface lattice structure of the IF [15].

The aim of this work was to determine the structural and chemical properties of hair available for use used in building repairs. For this study, we examined a series of hair samples sourced for use in building repair. Anecdotally, there is a belief that imported hair is more brittle and less oily than indigenous hair sourced from within the UK. By understanding better the chemical and structural properties of these hair types, it may be possible to determine if there is a basis for this anecdotal data, and if that basis is grounded in alterations to the keratin.

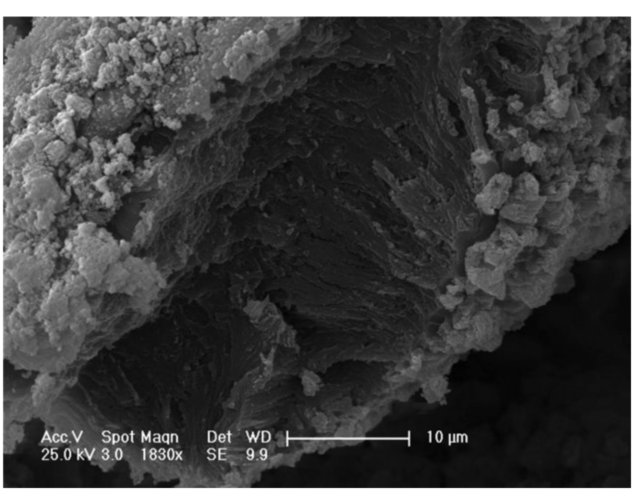

Fig. 2. Scanning electron microscope image of a void left in lime plaster following the dissolution of hair. The lining of the void mirrors the pattern of cuticle scales from horse hair. This sample formed part of a plaster frieze in Elcho Castle, Perthshire, Scotland.

2. Materials and methods

2.1. Hair samples

Fresh, untreated horse hair samples were obtained from a private stable in Perthshire, Scotland. Two types of hair were provided: one dark and one light. Imported horse hair, yak hair, goat hair and mixed hair (including bovine) were purchased from Masons Mortars Ltd., Charlestown, Fife, Scotland, a company specialising in providing materials for historic building repair.

2.2. Small angle X-ray scattering

Small angle X-ray scattering measurements on hair samples were performed at the I22 beamline at the Diamond Light Source, Didcot, UK. Hair samples were mounted horizontally in air. Measurements were taken at a sample-to-detector distance of 2 m, with an X-ray wavelength of 1 Å. Scattered X-rays were collected on a Pilatus 2M detector. Diffraction patterns were analysed using in house software written in FORTRAN 77 and visualised in PGPLOT. Data analysis was conducted using the methods of Wess et al. [16]. Diffraction data were converted to polar plots, and the 2-dimensional detector images represented as a linear intensity distribution. The linear intensity profiles were taken from the equatorial regions of the 2D images (Fig. 3) and normalised so that the sum of the squares is equal to 1.

2.3. Fourier transform infrared spectroscopy (FT-IR)

Analysis was carried out using a Thermo Scientific Nicolet iN10 with Liquid Nitrogen cool MCT detector. Data collection was managed by OMNIC™ Picta™ interface. Mid-infrared Fourier transform spectra were recorded using the attenuated total reflectance technique (ATR) using a Ge crystal-plate. The spectra were captured over the range 4000–400 cm^{-1}, using 64 scans and with a resolution of 4 cm^{-1}, and data collected as reflectance (R) values. Data were then converted to $\log(1/R)$ values for analysis and interpretation.

3. Results

3.1. Small angle X-ray scattering

Small angle X-ray scattering (SAXS) is a technique used extensively in the analysis of large paracrystalline biological polymers