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Case study

Monitoring detaching murals in the convent of Müstair (Switzerland) by mirror micrometry

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Abstract

In a parallel study, it has been shown by comparison of successive TV-holography campaigns that murals in the convent of Müstair (Switzerland) have progressively detached from their substrate over a time interval of 5 years (J Cult Herit 2009). Here, we focus on the dynamics of the ongoing detachment processes. In order to regularly measure small surface displacements in situ over a long duration of several years, a new method that we call Mirror Micrometry (MM) has been designed and implemented. This method monitors the reflection of a light beam by a mirror that is mounted to the surface of interest for the duration of the experiment. The mirror is designed to rotate about a pivot as small displacements in the detaching surface occur, thus deflecting the reflected light beam. Measurements over more than three years in the Convent Church and in the Holy Cross Chapel reveal various types of surface displacement perpendicular to the wall surface. These are correlated with relative humidity (RH) changes in the room climate. Reversible short-term variations of approximately ±5–10 μm occur with periods of one to several weeks and relate primarily to weather changes. Reversible long-term variations of ±5–10 μm correspond to averaged seasonal humidity changes. Irregular and irreversible movements in increments of 20–30 μm record very localised progressive detachment steps. A semi-quantitative correlation of approximately 1 μm surface displacement per 1% RH change is calculated. Based on the fact that nearby measuring points can simultaneously move in opposite directions, a geometric model is drawn to explain deformation by hygric swelling and shrinking of different shapes of detached layers.

Keywords: Mirror micrometry; Wall paintings; Detachment of plaster; Detachment of paint layers; Long-term monitoring of detachment; Hygroscopic swelling and shrinkage

1. Introduction and research aims

Shortly after a major restoration (1947–1951), it was recognised that parts of the 800-year-old Romanesque wall paintings in the Convent Church of Müstair (Switzerland) were at risk of partial collapse. This initiated further conservation attempts that have continued until the present date [2]. However, the feared detachment of murals has continued. A similar problem became evident in the Holy Cross Chapel where several super-imposed paintings date from Carolingian to baroque times. Faced by unknown and unpredictable paint detachment processes at both sites, a project to investigate these processes was launched in the year 2000. This included extensive observations, repeated condition recordings, two TV-holography campaigns, monitoring of detachment processes by mirror micrometry (MM), monitoring of the climate, and laboratory investigations. A general introduction to the site and the particular damage occurring, as well as results comparing TV-holography and classical percussion tests are presented in our parallel paper [1]. In short, TV-holography has confirmed that detachment processes have been active over a time span of only 5 years. However, several questions remain: How does detachment actually occur? What physical processes are active? What external and internal influences trigger this? The present contribution deals with these questions and investigates intrinsic detachment processes. The method of MM is introduced and data collected by this method over a 3-year duration are presented and discussed. Based on our findings, a model of mural detachment processes in the convent of Müstair can be drawn.

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2. Detachment processes of wall paintings

Material breaks where and when an exerted stress exceeds the tensile strength of the structure. In the case of heterogeneous laminated structures such as wall paintings, the weakest points are the contact plains (joints) between different layers, which is where fissuring typically starts. The investigated murals at Müstair are superimposed on compounds of stone and mortar; they consist of one or more plaster layers and of several paint layers. Each plaster and paint layer is per se heterogeneous, varying laterally in both thickness and composition. For example, the Romanesque intonaco in the convent church varies in thickness from a few millimeters up to about 2 cm. Plasters are mainly composed of sand, chopped hay and lime-putty as a binder. Paint layers are mixtures of pigments, lime and additional organic binding media such as protein and oil. Shrinkage cracks in the plasters are an obvious deficiency in these murals.

Layers of different composition respond differently to external influences such as temperature and humidity changes. Poorly hygroscopic materials such as a meagre lime mortar remain relatively stable, while hygroscopic materials such as organic fibres and binders swell and shrink when exposed to humidity variations. Adhered layers of contrasting mechanical behaviour build up tensile strength along their separating plane, and eventually can crack, leading to detachment.

Current knowledge (e.g. the compilation of Agrawal and Pathak [3]), suggests that detachment processes on wall paintings can be attributed to a series of external and internal factors:

- heating and cooling (producing thermal stress);
- crystallisation of salts (producing crystal growth pressure);
- moisture and humidity (producing hygric and hydric expansion/contraction, weakening, and dissolution of binding media and other components);
- initial shrinkage and hardening of materials (producing mechanical stress within and between plaster and paint layers);
- earthquakes, heavy traffic, thunder, explosions, construction activities and other processes which produce vibrations and mechanical stress.

To some extent, all of these factors have probably contributed to the deterioration and detachment of the considered paintings. However, the following factors and events are considered most critical:

- original deficiencies of plaster and paint layers (e.g. shrinkage cracks, inappropriate material composition and manufacturing);
- occasional mechanical shocks and vibrations due to construction, earthquakes, several over-paintings and restoration actions;
- climatic impacts such as extreme temperature and moisture variations, particularly between the 1950's and the 1980's due to heating events, and sporadical condensation events.

As a result of these influences over many 100 years, the murals survive as delicate and sensitive compounds.

3. The Mirror Micrometry method

In order to get new insights into actual plaster and paint detachment processes, it is necessary to detect very small surface dislocations happening sporadically and unpredictably. In other words, we aim to detect not the presence and exact location of defects (as most methodologies deal with) but to trace surface dislocations over a long period of time. A method that had been tested for this purpose is Electronic Speckle Pattern Interferometry (ESPI) [4]. However, this is inappropriate for areas larger than a few square centimeters, and would be too expensive and complicated to operate continuously over a year-long duration. Another method to be considered, the use of Triangulation Laser Displacement Sensors, was just in the testing phase at the time of this project [5]. Therefore, it was essential to get inventive.

A novel technology fitting the particular requirements of the site of study has been designed and implemented. This approach, named MM, derives from the intercept theorem: Small dislocations on a wall surface can be multiplied and measured by the shift of a projected light reflection, which is deflected by a tilting surface. The device and the measuring principle are shown in Fig. 1. A hinged mirror is fixed to a nail, which passes through the detached plaster or paint layer and is attached to the wall beneath. The movable mirror also rests on a stylus, which contacts the surface of the detached layer. Thus, a back or forth movement of the detached layer is accompanied by change in the angle of the mirror. This angle can be measured by monitoring the position of a reflected light spot from a stationary source on a screen. Depending on the geometry of light source, mirror and screen, a small dislocation of the wall surface can be enormously amplified. At a working distance of 5 m, a resulting amplification of approximately 800 times was achieved. A light spot directed from a commercial laser pointer via the mirror to the screen yields a reading accuracy of ± 1 mm. This equates to approximately ± 1.25 μm surface displacement perpendicular to the wall. Accurate measurements and long term arrays require the stable position of the "light source – mirror – screen" triangle. A commercial tripod for photography was used to hold and fix the laser source and the screen. In order to reproduce exactly the same position with each measurement, a plumb was hung from the centre of the tripod and its tip precisely positioned over a permanent floor marker. In addition, fixed mirrors without hinge were placed in the vicinity of the rotating mirrors. These allowed a repeatable reference reflection in order to compensate for minor inaccuracies in the tripod position between measurements. Displacement values represent net displacements with reference to the fixed mirrors, starting from an arbitrary zero value at the beginning of each array. Displacement is termed as positive when the surface moves outwards and negative when moving inwards. The burden of the mirror on the wall was adjusted by a counterweight visible as a metal cylinder in the lower part of Fig. 1b. This was set to a weight of 1–1.5 g, depending on the type of layer to be studied. The entire device weighs about 20 g.

An essential requirement of this technique is perforation of the detached layer and drilling of a small screw hole in the stable substrate, both holes having a diameter of approximately 2 mm.