PLASTER FINISHES IN HISTORICAL BUILDINGS – MEASUREMENTS OF SURFACE STRUCTURE, ROUGHNESS PARAMETERS AND AIR FLOW CHARACTERISTICS

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ABSTRACT

Soiling of surfaces in historical buildings by deposition of particles is a common problem. Minimizing soiling is an important goal for conservation of structures and objects. The surfaces give rise to an interference with the air motions along the surfaces. The properties of surfaces may therefore influence the particle deposition. It is well known that with the increasing roughness of the surfaces the particle deposition rate increases. The properties of surfaces in historical buildings are not well documented. We have investigated samples of surfaces finished in wood float finish, steel float finish and brushed finish. As a reference we have used an MDF board. The geometrical properties of the surfaces were documented by using the stripe projection method. The resistance to airflow along the surface and the turbulence generated by the surfaces were investigated by recording the boundary layer flow over the surfaces in a special flow rig. The work reported is part of a project where the process of soiling is studied both in the laboratory and in field studies. The air velocity adjacent to the surfaces will be recorded with both PIV (Particle Image Velocimetry) and hot-wire technique. The temperature gradient close to the walls will be recorded with cold-wire technique.

Keywords

Soiling, Plasters, Particle deposition, Surface structure, Surface roughness

1. Introduction

1.1 Soiling

Particle deposition on surfaces in historical buildings gives rise to soiling. An example is shown in Figure 1. The black parts of the walls indicate the location where airborne particles have been deposited on the wall. The problem with soiling in historical buildings is mainly aesthetic, high cost for cleaning and degradation of artifacts [1]. One benefit of soiling is the reduction of the inhalation exposure [2]. The increase of roughness of a surface is expected to increase the deposition of particles. Experiments reported in [3] showed a 10 fold increase in deposition velocity when changing from a standard sheet vinyl surface to a concrete surface.

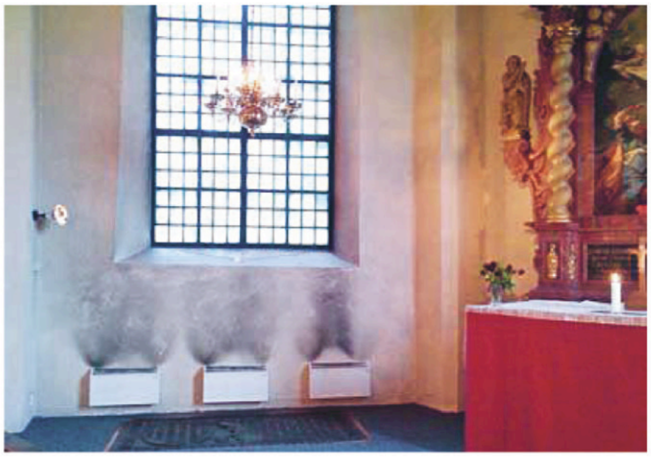

Figure Soiling in the vicinity of a radiator in a church.

1.2 The sequence from particle source to deposition

The source of generation of particle can both be external and internal. During a few rudimentary particle measurements in churches we noted that significant particle emission sources are: candle burning (submicron particles during burning, supermicron upon extinguish), infiltration from outdoors (virtually any particle size) and to some extent visitors (supermicron particles). The transport of particles from outdoor to indoor by infiltration suggests the need to consider the tightness of the building envelope as an issue of importance for soiling.

The rate of particle deposition onto surfaces is related to the loss of airborne particles through the deposition velocity. Depending on particle size and the prevailing conditions close to the surface regarding velocity, turbulence intensity, temperature difference between surface and adjacent air different mechanisms will give rise to deposition. Beside Fickian diffusion (Brownian and turbulent) motion of particles occur due to temperature gradient (thermophoresis) , motion due to interaction between particle inertia with the homogeneity of turbulence field (turbophoresis), due to electrical forces (electrophoresis), due to gravity and Saffman lift forces. The surface roughness influences the boundary layer flow close to the surface. A rough surface will displace the boundary layer flow outwards and change the turbulence structure.

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1.3 Estimates of magnitude of air velocities at the wall surfaces in churches

Air motions are generated by natural convection due to a temperature difference between walls and adjacent air and the vertical surfaces become lined by boundary layer flows. The magnitude of the total flow in this wall boundary layer flow may be greater than the ventilation flow rate. According to the results reported in [4] from measurements in a medieval stone church the boundary layer flow was around 25 times larger than the ventilation flow rate.

To prevent discomfort due to downdraught of cold air radiators or convectors located at the perimeters of interior space of a church are often used. The warm plumes from the radiators propagate upwards along the walls but may collide with the down draught of cold air which may give rise to complicated air flow patterns [5].

Another source of air motions may be forced convection generated by heat pump fan convectors.

Figure 3, adopted from [4], show measurements of two components (U, V) of the mean velocity close to a wall in a church. Different heating strategies were explored; air-to-air heat pumps with indoor fan convectors and a combination of bench heaters and radiators. Both windows and wall surfaces were explored. The temperature difference indoor –outdoor was 10- 12 °C. The measurements were carried out with an ultrasonic anemometer TR92T/DA650, Kaijo Sonic Inc, see Figure 2, mounted on a computer controlled traversing device. The length of the measuring volume perpendicular to the wall was about 12 mm. This limited the possibility of getting closer to the surface.

Figure 2 Ultrasonic anemometer mounted on a traversing device.

According to Figure 3 the direction of the vertical component (V) is downwards whereas the horizontal component U is directed towards the wall. The direction of the horizontal velocity is presumably controlled by entrainment into the vertical air stream. The variations in velocity were very large and for short time periods flow reversals occurred. This highlights the complexity of the flow we are studying.

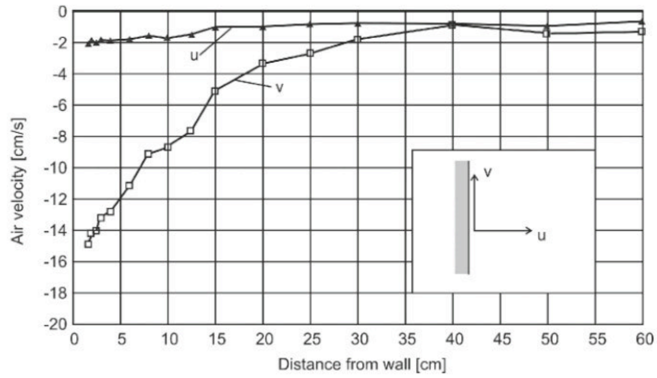

Figure 3 Recorded velocity components in a downdraft along a church wall. Air- to -air heat pump active.

The highest velocity, 0.24 m/s, was recorded at a window surface with a heat pump active.

The flow from a freestanding radiator can be assessed by modeling the radiator as an ideal line source of infinite length. The centerline velocity U_c is constant with height and equal to [6] $U_c = 2.45B^{1/3}$ [m/s]. B [m³/s³] is the specific buoyancy per unit length which is proportional to the total convective power divided by the length of the radiator. The relation is displayed in Figure 4.

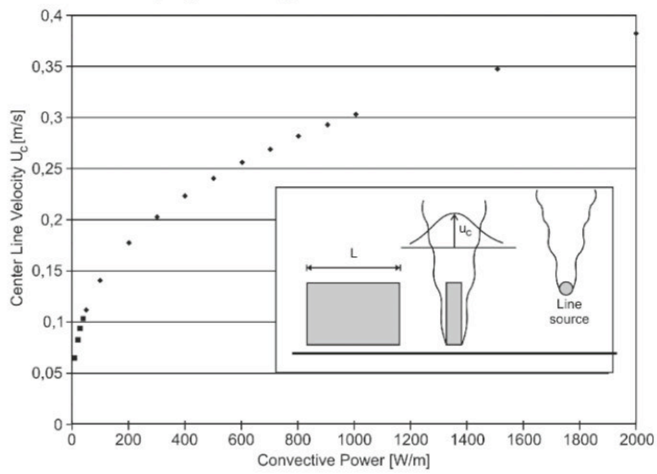

Figure 4 Assessment of velocity generated by a radiator by modeling the radiator as a line heat source.

Due to the finite length, L, the velocity is not entirely constant but there will be a small decay with distance from the heat source [7].

2. Surface roughness

2.1 Different types of roughness

Roughness may be divided into two categories. The first category, referred to as "sand-grained" or "sand-type" roughness consists of tightly packed roughness elements characterized by a mean roughness height and standard deviation height. The other extreme is roughness elements consisting of well-defined objects with well-defined dimensions, e.g. ribs with certain dimensions (width and height) and spacing.

3. Recorded geometrical properties of the surfaces

Three samples of plastered surfaces (Length x Width =114 x 44 cm) were prepared by a skilled plasterer. The substrate for the sample was a wood wool cement board. The surface roughness was recorded along a 40 mm long line with striped projector method which is an optical technique. The resolution of the strip projector was 0.06 mm. The recorded profile is shown in Figure 5. There is different roughness parameters defined in ISO standard ISO 4287(1997). As a measure we take the vertical distance between the deepest valley and the highest peak. An eye-ball analysis based on Figure 5 suggests that this measure for the height variation for the surfaces is roughly within the range; wood float finish (0.6 mm); brushed finish (0.8 mm) and steel float finish (0.4 mm). The surfaces with wood float finish and steel float finish have the same character whereas the surface with a brushed float finish exhibits a relatively smooth plateau with deep valleys. This is typical for porous media. We can compare the above values with what is given in the literature. In particular for different pipe materials values are listed. For instance concrete has roughness height of between 0.3-3 mm and cast iron 0.26 mm.

4. Flow parameters quantifying the roughness

A surface gives rise to an opposing force to the flow over it quantified as wall shear stress [Pa]. The wall shear stress was obtained by recording the velocity gradient close to the surface. From the wall shear stress several parameter characterizing the roughness can be derived. The wall shear stress can be expressed in a non-dimensional form as a friction factor f = [-] where ρ(kg/m^3) is the density of air and U_∞ [m/s] is the free stream velocity. The most important parameters related to the flow above the surface are the friction velocity and the viscous length scale. The friction velocity is calculated as =√ [m/s]. With the aid of the friction velocity and the kinematic viscosity ν [m^2/s], one defines a length scale; the viscous wall length [m].

The extent to which the flow is affected by roughness depends on the dimensionless roughness height e^+ defined as $e^+=e/l_*$ where e is a characteristic height of the microscopic profile..

5. Velocity measurements in a test rig

5.1 Test rig for velocity measurements

A purpose made rig was used, see Figure 6, to generate controlled flow over the plaster samples. The samples of the plastered surfaces were placed on a table consisting of an MDF board. Air was blown along the sample of plaster from a wide round nozzle (internal diameter 0.235 m) belonging to a calibration rig for velocity transducers. As shown in paragraph 1.3 we cannot expect that the velocity in boundary layer flows generated by natural convection to be higher than about 0,5 m/s. However the purpose of this study was to estimate the magnitude of the roughness of plasters and to explore if there is any difference in roughness between the different types of plasters. For this reason, we wanted to generate a stable velocity profile which enabled us to measure the velocity just a few tenths of a millimeter from the surface. We selected a velocity equal to 1 m/s. The velocity profile from the nozzle was uniform so 1 m/s is the free stream velocity U_∞. The velocity was recorded with a hot-film sensor with a diameter of 20 μm. The vertical position of the sensor was controlled with a precision micrometer.

The recorded mean velocity and the standard deviation (RMS) of the velocity fluctuation are shown in Figure 7.

5.2 Assessment of shear stress, friction velocity and friction factor

The shear stress was calculated from the gradient of the recorded mean velocity U close to the surface within the region where the velocity is a linear function of the distance from the surface, i.e. in the viscous sublayer. In this region the relation between the shear stress and the velocity gradient is where μ[is the dynamic viscosity. This relation implies that shear stress can be obtained from the slope of the velocity profile as indicated in Figure 8.

In Table 1 the recorded and calculated near wall air flow properties are compiled and Figure 9 exhibits the recorded friction factor.

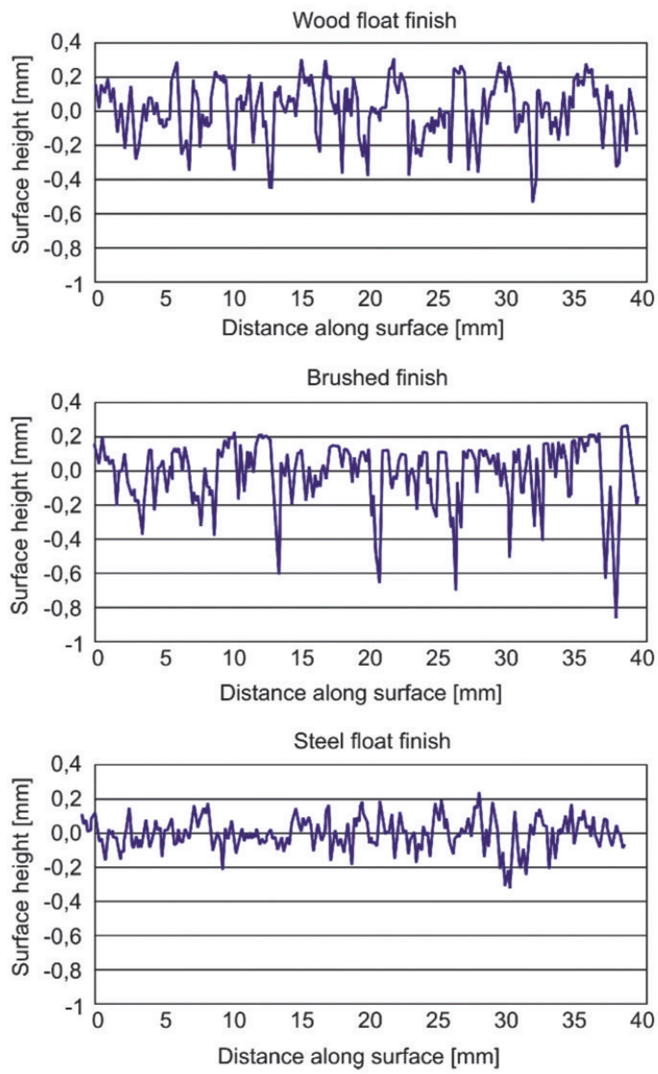

Figure 5 Recorded surface height profiles for three different finishes of plaster.

5.3 Degree of roughness of the surfaces

The degree of roughness of a surface is based on the magnitude of dimensionless roughness height e+. As a characteristic height of protrusion we take the estimated height variations presented in paragraph 3. Combining these values with the estimated viscous length scales given in Table 1 results in the following dimensionless roughness heights e+ for the different plasters; wood float finish (2.5), brush finished (3.2) and steel float finish (1.5).

Depending on the magnitude of the protrusion three flow regimes are usually identified;

For $e^+<5$ the hydraulically smooth region, for $5< e^+ <30$ the transition region and for $e^+ > 70$ the completely rough region. According to this classification our samples are hydraulically smooth.

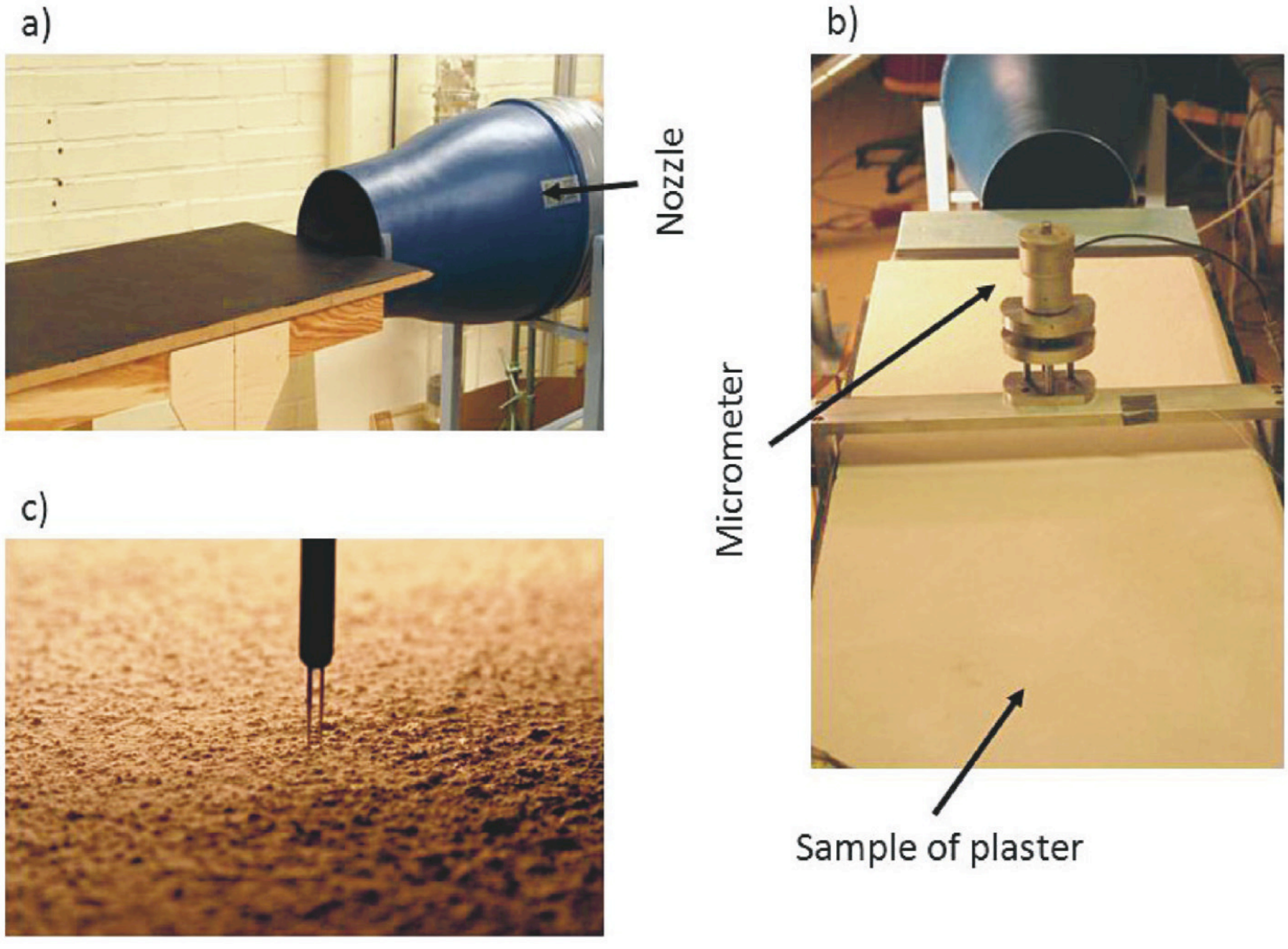

Figure 6 Set-up of test rig, a) with MDF board, b) with plaster sample + micrometer visible, c) hot film sensor.

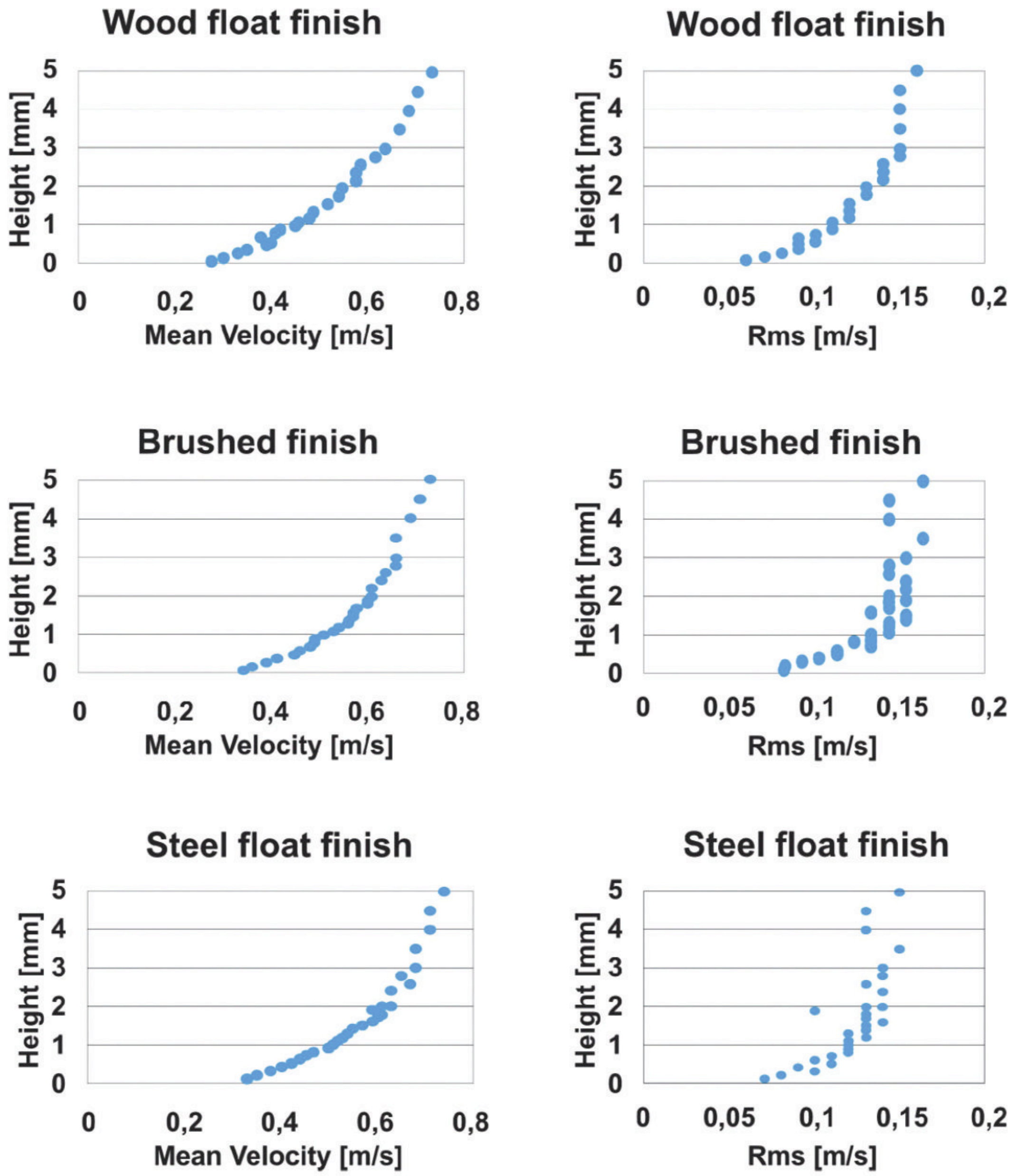

Figure 7 Recorded mean velocity and RMS of velocity fluctuations above plaster surfaces.

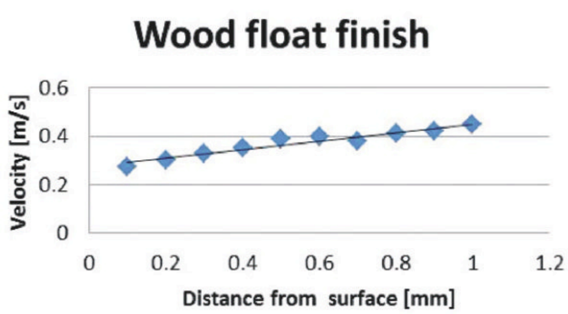

Figure 8 Determination of the shear stress from the slope of the Velocity-Distance graph.

Surface	Shear stress [Pa]	Friction Velocity [m/s]	Viscous length [mm]	Viscous sublayer [mm]	Friction factor f [-]
MDF board	0,0038	0,056	0,27	1,35	0,0063
Wood float finish	0,0046	0,062	0,24	1,20	0,0078,
Brush finished	0,0043	0,060	0,25	1,25	0,0072
Steel float finish	0,0036	0,055	0,27	1,35	0,0060

Table 1 Recorded near wall air flow properties.

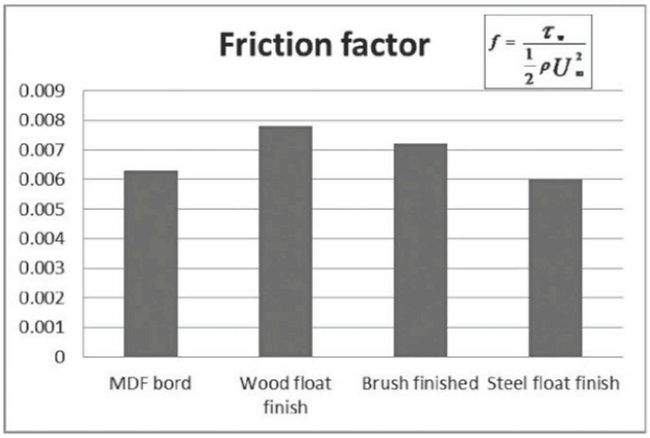

Figure 9. Recorded friction factor, f.

Figure 9 shows that the method is so sensitive that it records a difference between the different finishing methods. We have chosen an MDF board as a reference surface and according to Figure 9 the steel float finish has about the same friction factor as the reference surface. This is not what we had expected before we started the tests. We had expected a plastered surface to be rougher. However the result is in consort with the finding above which shows that our surfaces are hydraulically smooth surfaces.

6. Discussion

The samples of plasters we have investigated have been prepared under ideal conditions. The surfaces were prepared on a substrate consisting of a wood wool cement board. The plastering was done with the substrate in a horizontal position. In practice one does not have an even and homogeneous substrate.

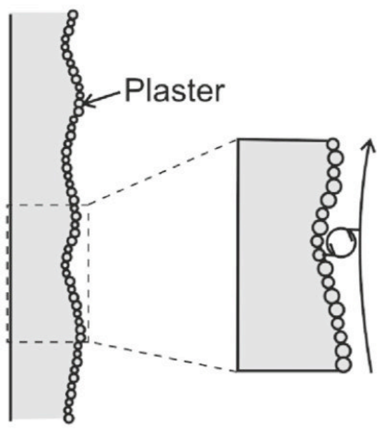

Figure 10. Macro- and micro variations

A real wall may both have macro variations in the sense that the wall itself exhibits large-scale variations, e.g. undulations as shown in Figure 10. This kind of variation we call macro-variations. On top of the varying surface, the plaster is applied, which in turn exhibits micro-variations. If the macro variations have a suitable character air pockets with recirculating air may be generated. Particles which are captured by the air pocket will reside there for a long time and the probability for deposition of the particles will increase.

The roughness samples we have investigated were prepared in ideal "laboratory" conditions and can probably be regarded as lower estimates of the roughness in practice. Therefore in the next step of the project measurements of the roughness in real buildings will be made. Then the humidity will also be recorded.

7. Conclusions

According to our measurements of the topography and viscous length scale of the samples of plastered surfaces the surfaces were found to be hydraulically smooth surfaces. At a free stream velocity of 1m/s the thickness of the viscous sublayer was about 1.2 mm. The friction factor is of the same magnitude as the reference surface, MDF board. The surface prepared with a wood float finish had the highest friction factor while the surface prepared with steel float finish had the lowest friction factor. The difference in friction factor between the surfaces is relatively small. Therefore there is probably no difference between different plastering methods on the influence on the deposition velocity. The fact that the method could reveal the small differences in roughness that exists between the plasters we consider to be a strength of the methodology used.

That the surfaces were all hydraulically smooth was a surprise to us. However, it should be kept in mind that our surfaces were prepared under ideal conditions. They were prepared on a flat substrate in a horizontal position. In reality, surfaces are vertical and the wall itself is not always even. A real surface may also exhibit large scale variations, e.g. undulations.

A limitation in our study was that we were able to determine the roughness parameters at only one location for each sample. Surfaces are not uniform and there will be variations across them.

8. Acknowledgements

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9. References

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