INVESTIGATIONS INTO THE WATERTIGHTNESS OF MASONRY VENEER WALLS

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ABSTRACT
Masonry veneer walls are typically constructed in temperate regions with rainy winters and periodically high wind days. The following paper describes wall-tests to determine the resistance of masonry veneer walls to driving rain depending on the properties of brick and mortar. 13 wall samples have been constructed and are tested in a check-station with different rain loads. The rain is simulated with defined water spray. Main parameters are the water absorptive capacity of the brick, mortar finish and imperfections during construction. It was shown, that the mortar and the interface between brick and mortar is particularly relevant for the moisture penetration into the wall section in dependence of the applied rain load. Most important for the moisture transport into the bricks are the bed joints, while the outside brick surface is of less significant influence. Insufficient bond between brick and mortar might facilitate a moisture break-through. Special focuses have been made on the workmanship of the joints, of hydrophobing work (application of 7.0 m-%-siloxane solution) and the watertight construction of ground-level door openings.

KEYWORDS: masonry veneer walls, driving rain, design, construction, water penetration

INTRODUCTION
In northern Europe (e. g. Germany, The Netherlands, Scandinavia) masonry veneer walls are typically constructed like shown in fig. 1. They perform as cavity wall masonry with thermal insulation installed inside the air space. The backing load-bearing wall is constructed of solid masonry units like calcium silicate blocks. The facing masonry veneer wall is made of brick and is bearing its own weight only. It serves as a weather barrier and is anchored with stainless-steel-ties to the backing wall. Due to its slenderness – the wall thickness is usually about 11.5 cm – vertical support is required, approximately each 12 m of height. Masonry veneer walls in this context are standardized e. g. in the national German annex of Eurocode 6 “Design of masonry structures”, part 2: “Design considerations, selection of materials and execution of masonry” [1]. Following this standard, the cavity must be less or equal than 150 mm when standard z-ties are applied. Therefore, two layers of mineral wool products with a total-thickness of around 140 mm are frequently used for thermal insulation. With increasing interest in energy economy in buildings, even more insulation is demanded today. Bigger cavity between backing and facing wall requires adequate ties and special hangers and brackets for support above openings.

The advantages of masonry veneer walls are a good functionality and a long durability without maintenance in temperate regions with rainy winters and periodically high wind days. They provide a high potential of environmental, economic and social performance. As a result, they obtain adequate levels of scoring within sustainability assessments of buildings [2]. Therefore, building societies are preferring masonry veneer walls for housing projects, establishing a formative architecture in many coastal areas. Alternative wall systems with facings of composite insulation materials (e. g. polystyrene foam with plaster coating) tend to get moldy after a short period of time in temperate regions, generating efforts like periodical cleaning and sealing with required provision of scaffolding.

The resistance of masonry veneer walls to driving rain is high. Nevertheless, at the bearing point of the walls, at the interface to floor slabs, foundations and at special exposure to humidity moisture might accumulate when certain requirements of building construction are not considered. Figure 1 shows, that various materials and components, referring to multiple standards, are used for the construction of masonry veneer walls. The interfaces between the components require adequate design. Different contractors are involved, like bricklayers and carpenters for the jambs. Their tasks have to be well coordinated and supervised to avoid mistakes. Special contractors for the installation of the insulating materials and the waterproof sheeting and sealing of windows and door jambs are usually not available. Problems like moisture penetration of masonry veneer walls in practice frequently refer to inadequate quality standards and mistakes during design and construction. Common constructional flaws are mortar from the backside of the facing wall falling into the cavity or poor waterproof sheeting around corners. Figure 2 shows an example for the construction of masonry veneer walls. The backing wall is made of calcium silicate blocks, the facing wall will be erected on the waterproof sheeting in the foreground. Insulation materials are two layers of mineral wool and beams of extruded polystyrene foam aside the openings. The tiers are currently bent down.

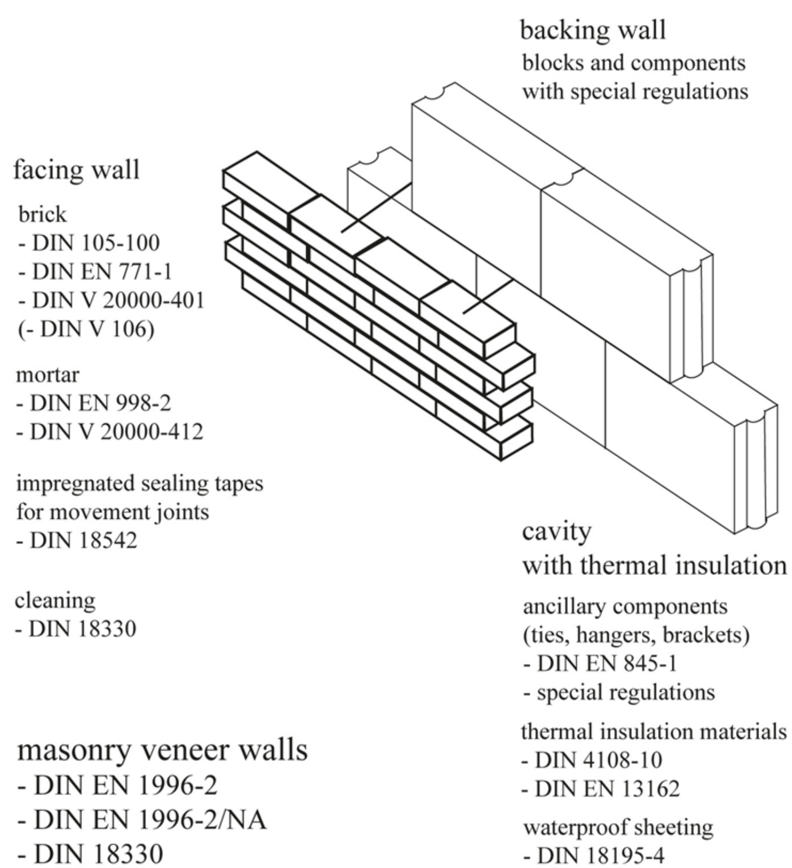


Figure 1: Masonry veneer walls: principle and referring standards [3]

Figure 2: Construction of masonry veneer walls, referring to fig. 1

The tests described in this paper are referring to certain cases of damaging in practice and were performed to understand the moisture transport into the bricks. They are the first step to establish recommendations for the sustainable design of masonry veneer walls with a special focus on damage-sensitive details, like ground-level door openings.

DRIVING RAIN

Rain with wind load generates driving rain penetration. The impinging rain will be absorbed depending on the water absorptive capacity of the surface materials. Wind load might transfer rain water into gaps, cracks or defect sealing sheets. Driving rain is a considerable cause of damaging, like water break-through or - in combination with frost action - detaching of bricks and mortar. The risk of driving rain penetration is widely described as a function of average annual rainfall and average wind speed. The local exposition is an additional considerable factor of influence. Maps of driving rain penetration are developed basing on meteorological data. In Germany, three classes of driving rain penetration have been defined and been outlined in a regional map in standard DIN 4108-4 [4]. The classes are indicatively based on the average annual rainfall, considering cases of special exposition, see table 1. The standard further defines masonry veneer walls as adequate for the most severe class III.

Present European standards for laboratory simulation of driving rain did not fit for the purposes of investigations into the water tightness of masonry veneer walls. They are focusing on components like the standards DIN EN 1027 “Windows and doors, Water tightness, test methods” or DIN EN 13050 “Curtain walling, watertightness, laboratory test under dynamic condition of air pressure and water spray”. The European Standard DIN EN 12865 [4] determines the resistance to driving rain as a function of air pressure differences and is focusing on components as well. Main parameter is water detection at the inside of the wall at an applied level of pressure. Therefore, an own test set-up was used.

Table 1: German classes of driving rain penetration following standard DIN 4108-3 [4]

Class (DIN 4108-3)	Categorization	Average annual rainfall [mm]	Special exposition
Class I	Low driving rain penetration	< 600	Wind-protected areas with higher annual rainfall
Class II	Medium driving rain penetration	600 … 800	High rise buildings of Class I
Class III	High driving rain penetration	> 800	Coastal and mountain regions high rise buildings of Class II

WALL-TESTS

Five test walls were made of 12 or 16 courses with a 1 m² front side for testing, with one unit in thickness, see figure 3 [5]. Three types of brick with different capillarity have been used for the test walls: A low, a medium and a high absorptive brick. All three types of brick are suitable for facing walls and for exposure to severe weathering. Mortar was a commercially available cement-lime mortar. The same batch of mortar was used for all five test walls. Bed joints were average 12.3 to 12.5 mm in height. The average-sizes of the head joints were about 10 to 12 mm.

To assess influences of pointed joints and of detachments between brick and mortar, three test walls have been built with the medium absorptive brick. For pointing, 15 mm of the surface of the masonry joints were filled and finished after the masonry was laid with a cement mortar. Finish was a flat joint. Detachments - respectively loss of bond between brick and mortar - are occurring in practice due to quality failures in masonry works, like poor mortar workability. Detachments are resulting into local zones with high capillarity. In laboratory, every second course was completely manually detached, after the masonry was laid and then put again into place. Table 2 gives an overview about the laboratory test walls. The properties of the bricks and mortar were tested comprehensively in laboratory. Selected results are shown in table 3 and 4.

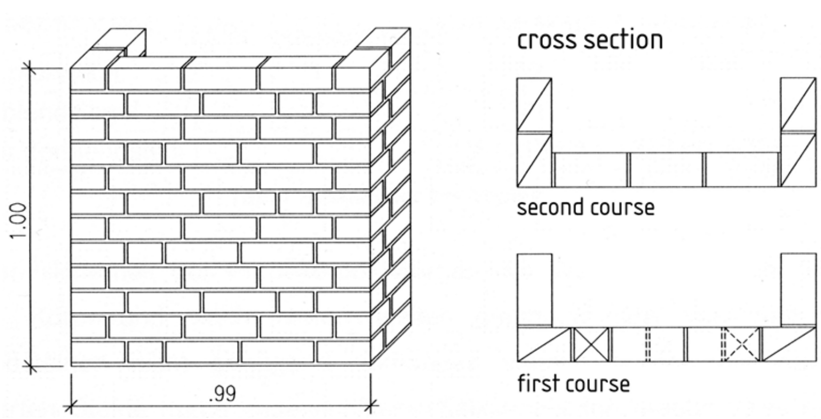


Figure 3: Laboratory test walls

Table 2: Overview about the properties of the five test walls

No.	Type of brick	Size of bed joints/ Size of head joints (average) [mm]	Joint finishing	Additional parameter
1	Low absorptive hard burned brick (“sewer clinker”)	12.3/10.0	Tooled flush joint, no pointing	-
2	Medium absorptive brick			
3	Medium absorptive brick		Flat-joint-pointing	
4	Medium absorptive brick		Tooled flush joint, no pointing	Detachments: every complete second course
5	High absorptive brick	12.5/12.0		-

Table 3: Selected test results of the properties of the utilized brick types

Tests following European Standard DIN EN 772 “Methods of tests for masonry units”		Low absorptive hard burned brick (“sewer clinker”)	Medium absorptive brick	High absorptive brick
Size (L/W/H) (mm)		240/115/71	240/115/71	210/100/50
Part 1	Compressive strength (MPa)	76.34	66.1	19.17
Part 2	Areas of void (%)	1.68	1.24	10.84
Part 13	Net dry density (kg/m³)	2319	2021	1785
	Gross dry density (kg/m³)	2280	1996	1591
Part 7	Water absorption by boiling in water (%)	4.5	10.7	15.5
Part 11	Initial rate of water absorption (kg/(m²·min))	0.2	1.3	3.3
Test following DIN EN ISO 15148 Water absorption coefficient (kg/(m²·h$^{0.5}$))		complete unit	complete unit	complete unit
		0.22	6.14	14.94

Table 4: Selected test results of the properties of the utilized mortars

Tests following European Standard DIN EN 1015 “Methods of tests for mortars for masonry”		joint mortar (lime-cement mortar)		point mortar (cement mortar)
Part 3	Consistence of fresh mortar (mm)	144		-
Part 6	Bulk density of fresh mortar (kg/m³)	1730		-
Part 7	Air content of fresh mortar (v-%)	18		-
Part 11	Type of consolidation	tamper	vibration	tamper
	Bulk density of hardened mortar (kg/m³)	1654	1662	1927
	Flexural strength (MPa)	3.2	3.3	5.4
	Compressive strength (MPa)	9.1	10.8	30.8
Part 17	Water-soluble chloride content (m-%)	$6.14 \cdot 10^{-3}$		$9.56 \cdot 10^{-3}$
Test following DIN EN ISO 15148		prisms	prisms	extracted joints
Water absorption coefficient (kg/(m²·$h^{0.5}$))		0.66	1.64	0.43

LABORATORY RAIN EXPOSURE

To evaluate the water absorption during driving rain exposition an own test set up has been developed. It was the target to generate a continuous water film on the surface of the facework. Air pressure was not evaluated as additional parameter because its influence for masonry veneer walls is considered less different to thin surfaces. Those are much more sensitive to wind load induced water penetration thru leakages.

Test rain was sprayed from a defined frame with four spray nozzles at two beams. The applied amount of water was based on a precipitation that is expected one time a year (5 l/m² in 5 minutes). The test rain has been created with tap water filled into a reservoir. The required pressure of 6 bar (10^5 Pa) was generated with an own wet-pit pump inducing a constant flow of 0.5 l/s. The spraying distance was adjusted to obtain realistic driving rain drop diameters (d = 2 mm) and was constant during the tests. The test rain might be categorized intense to heavy rain referring to standard DIN IEC 721-2-2 [6]. Basic test parameter was the total amount of sprayed water controlled via spray time at constant flow.

Within two different programs, total water amounts of 5, 10, 20 and 40 l/m² were applied. The first program was constant spraying with a spray-time of 10, 20, 40 or 80 seconds at 0.5 l/s. The second program was interval spraying during 5 seconds per minute at 0.5 l/s, resulting in a total time between 1 and 15 minutes. The applied water amounts are correlating with precipitations between 14 and 30 mm/m²/h. A number of 10 tests have been performed totally in the first series. Sides and top of the test walls had been sealed before the application of rain. After testing, one stone was extracted for further investigation and to assess the depth of water penetration. The extracted stone was replaced with the same type of brick and mortar.

TEST-RESULTS

Summarized test results are outlined in the diagrams figure 4 and 5. The moisture is basically transmitted into the facing wall via the joints. The effect of water penetration via the joints is independent of the type of brick. Even bricks with high capillarity are absorbing water mainly through the brick-joint interface, not through their front sides. Water break-thru of the facing wall withe has particularly been observed around cross joints. Figure 4 shows results of test walls No. 2, 3 and 4 with medium absorptive brick at interval spraying, compare table 2. Pointed joints are slightly tighter, than standard tooled joints. Ongoing research indicates that this difference is due to the slower rate of hardening of the lime-cement [7]. It will be less with continuing carbonation. Detachments (loss of bond between brick and mortar) are a significant influence on increasing water penetration. The joint penetration depth is increased by factor of 3, compared between tooled joint and detachment at 40 l of applied water during test rain.

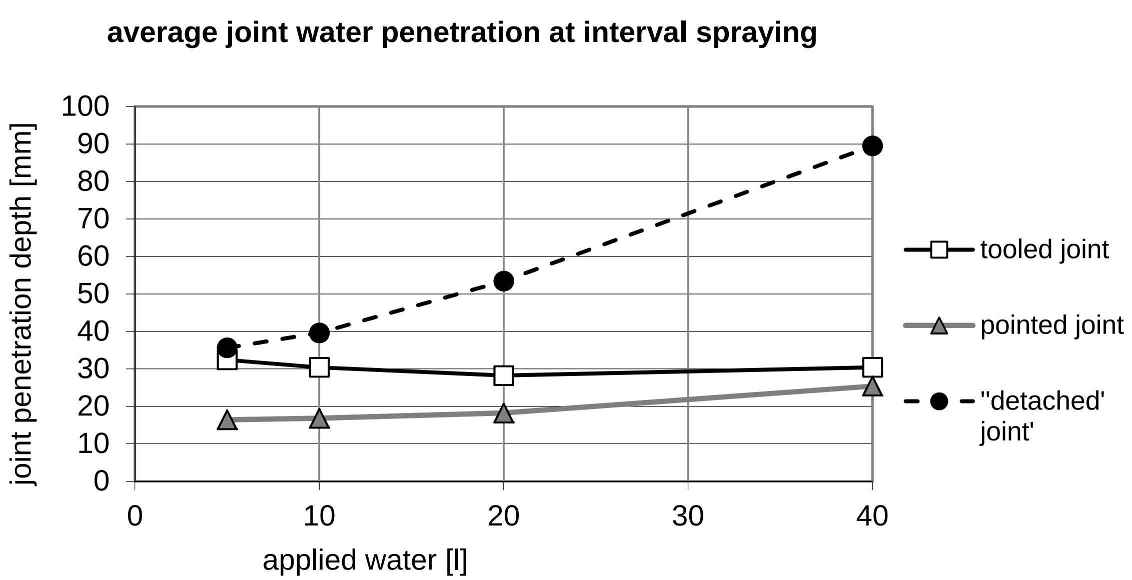
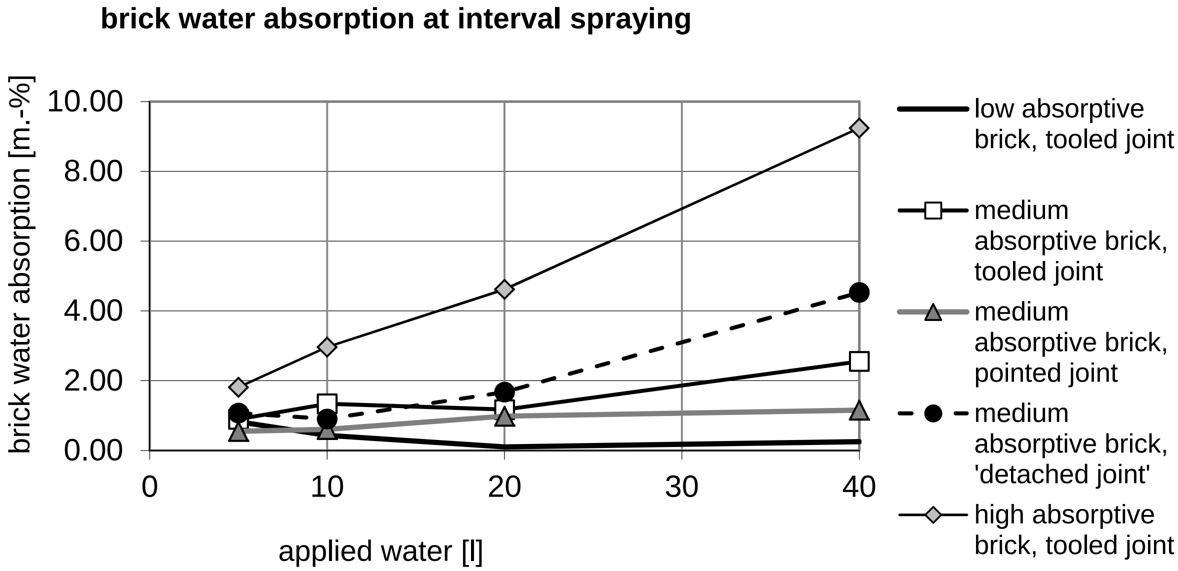


Figure 4: Average joint penetration depth as a function of amount of applied water

The amount of water absorbed by the bricks depends not only on the amount of applied water but also on the rain exposition time. Figure 5 compares brick water absorption at constant and interval spraying. With the same amount of applied water, the absorption increases with the exposition time at interval spraying. For example with high absorptive bricks the absorbed amount of water increases from 5.3 m-% at constant spraying to 9.2 m-% at interval spraying with 40 l of applied water total in both cases. This result was expected, because excess water will be running down the façade, if the applied amount of water is increasing and getting higher than the absorbed amount of water. The diagrams in figure 5 are quantifying this aspect.



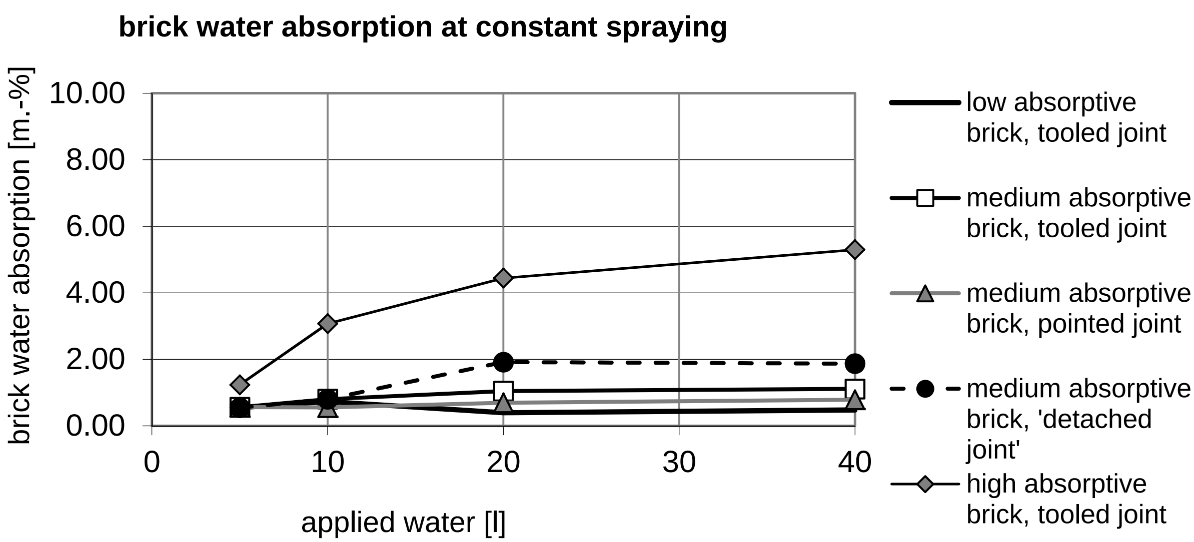


Figure 5: Brick water absorption as a function of amount of applied water, compared at interval and constant spraying

The picture in figure 6 on the left provides an impression from the test series. A brick has been extracted off test wall no. 2 after interval spraying of 5 l of applied water. The water penetration front is clearly visible at the interface between mortar and the following brick of the course. The schematic drawing on the right of figure 6 illustrates the basic principle of water absorption during driving rain exposition like discussed before.

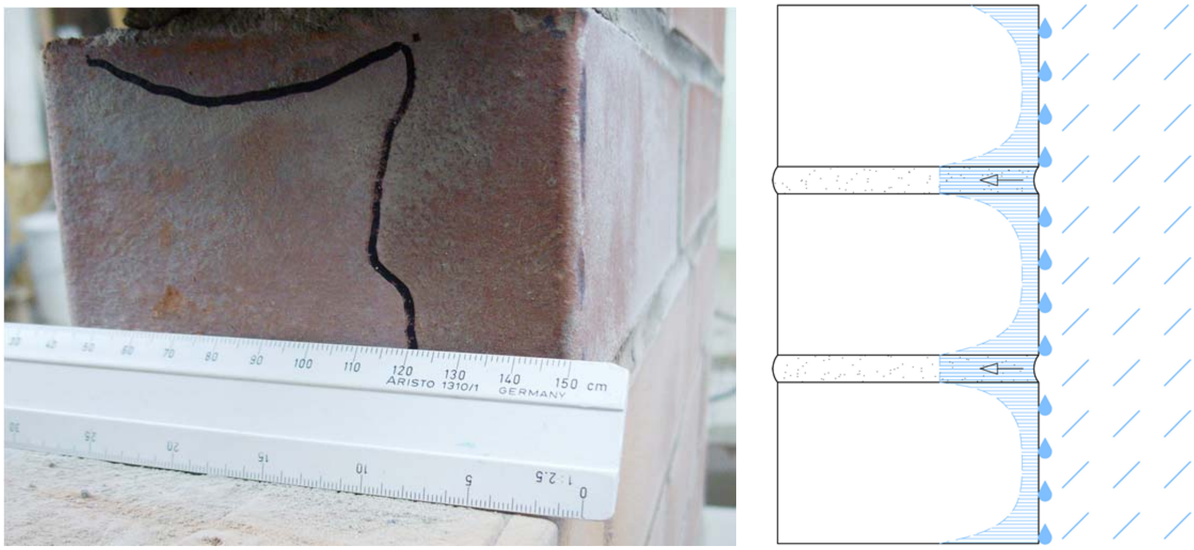


Figure 6: Test wall No. 2, water penetration after interval spraying of 5 l of applied water (left), schematic of water absorption during driving rain exposition (right)

ONGOING INVESTIGATIONS

For improved driving rain protection of higher absorptive brick facework, contractors in some cases recommend hydrophobing agents like siloxane solution. Fundamental problem with hydrophobing of masonry are the joints that are impossible to be entirely impregnated. Because the joints are the most important influence for driving rain penetration the effectiveness of hydrophobing is questionable. For laboratory investigation the test walls have been sealed with a 7.0 m-%-oligomer-siloxane solution. The test wall with the detachments (no. 4) was not included into the investigations. The siloxane-application was very carefully performed and documented, considering the water absorptive capacity of the bricks and following the recommendations of the manufacturer.

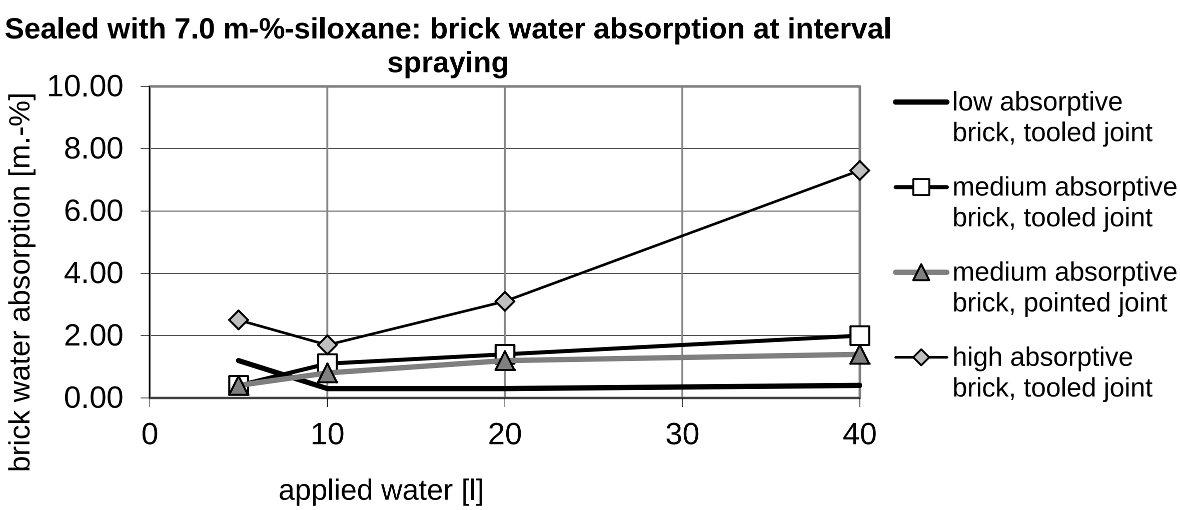


Figure 7: Brick water absorption after application of a hydrophobing agent as a function of amount of applied water at interval spraying [7]

The solution was sprayed at the mechanically cleaned surface of the test wall. Main problem during application is the loss of unabsorbed solution that is flowing down the façade. Therefore, in practice qualified contractors are needed to fulfill the task in the required quality. Flawed hydrophobing work may result into increased accumulation of moisture, because the bricks are drying slower according to reduced capillarity. Figure 7 shows the brick water absorption after application of 7.0 m-%-oligomer-siloxane solution as a function of amount of applied water at interval test rain spraying. Compared with the upper diagram in figure 5 the obtained difference in brick water absorption is small. Only the high absorptive brick takes 2.0 m-% less humidity at the highest amount of applied water (40 l). Therefore, the benefit of the laboratory hydrophobing work has to be classified moderate. Considering the risk of flawed work and the unclearness in durability, hydrophobing works are generally not recommended based on the test results.

Current investigations are focussing on the detail of watertight construction of ground-level door openings. Those are required increasingly in practice due to accessibility (freedom of barriers). The waterproofing at the interface between basement or foundation slab and ongoing wall is damage-sensitive, because available sheets cannot be bent around corners and edges. Eight test walls with masonry veneer walls and different types of waterproofing have been constructed and are going to be tested with laboratory rain (figure 8).

Figure 8: Test walls to investigate the watertight construction of ground-level door openings considering corners and edges

SUMMARY

The paper is focusing on the resistance of masonry veneer walls against driving rain penetration. The construction of masonry veneer walls and aspects of driving rain action are summarized. The described wall-tests show, that the effect of water penetration via the joints is independent of the type of brick. Even bricks with high capillarity are absorbing water mainly through the brick-joint interface, not through their front sides. Furthermore, the amount of water absorbed by the bricks depends not only on the amount of applied water but also on the rain exposition time. Mainly investigated and quantified parameters were the capillarity of the bricks, the finishing of the joints (tooled and pointed) and the influence of detachments. While the finishing of the joints is of less influence, detachments (loss of bond between brick and mortar) are a significant influence on increasing water penetration. Water break-thru has only been observed at cross joints and detachments. Hydrophobing work (application of 7.0 m-%-oligomer-siloxane solution) is only significant with high absorptive bricks at the highest amount of applied water. Due to considerable risk, hydrophobing works are generally not recommended based on the test results.

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