REHABILATION OF MASONRY CONSTRUCTIONS TEMPORARILY SUBMERGED BY WATER – INFLUENCE OF WATER ON THE PROPERTIES OF MASONRY AND FACINGS, DRYING METHODS AND THEIR EFFECT

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ABSTRACT
Within the scope of the research project carried out at the Institute of Building Materials Research (ibac), RWTH Aachen University, the influence of intensive and long-term water storage on the mechanical properties of masonry components was examined and analysed. The experimental tests were carried out on different masonry unit types with commonly used mortar combinations and plasters respectively. Non-plastered single units, single-sided and/or double-sided plastered single units as well as on non-plastered 2- and 5-units specimens were tested. Besides, the literature available referring to the topic was collected, reviewed and evaluated.

According to the present results, it can be concluded that the influence of the water-storage on the mechanical properties of masonry components is to be rated as relatively small after they have dried to the initial humidity content. Both, compressive strength and tensile strength tests showed that the mechanical properties of water-saturated and dried specimens were not affected at all or rose to a higher level than before the water admission. Tests on plastered single units revealed that not only the external but also the interior plasters reached the same or higher adhesive tensile strength values after the drying process than before the water-storage.

KEYWORDS: masonry, mechanical properties, water-storage, drying

INTRODUCTION AND SCOPE OF THE RESEARCH PROJECT
In recent years, more and more frequently, flash floods caused substantial damage to buildings and infrastructure. Due to these extreme weather occurrences, masonry constructions are often imbued for a long time or completely water-saturated respectively. So far, it is not well-known to what extent the strength and serviceability of masonry are affected negatively. Findings about appropriate restoration measures as well as measures for a fast and preferably complete drying still are not fully understood or their effectiveness has not been proven yet. Besides, the damage caused by floods is only partly comparable with conventional moisture damages due to high

moisture penetration and contamination rates of masonry components. For this reason, the influence of water on the mechanical properties of masonry should be examined and analysed within the scope of the present research project [1], in order to be able to avoid incorrect or insufficient damage evaluations in future as well as structural damages resulting from inappropriate restoration measures. Besides, an overview of the literature concerning the topic "flood" should be given by a comprehensive literature research.

SELECTED APPROACH

At first, the literature available referring to the topic was collected, reviewed and evaluated. During the experimental investigations, changes of the mechanical properties of masonry components by storage in water should be determined in comparison to the mechanical properties of dry specimens. Hence, first the properties of the dry specimen were determined after storage for at least 30 days in the laboratory climate 20 °C/65 % humidity. Afterwards, the mechanical properties were determined on specimens, which have been stored in water up to mass constancy, see Figure 1 left. Following, the remaining specimens were sealed in such a way so that the drying process of the units could take place analogously to the drying process possible in a masonry wall. The drying process of the specimens took place in a custom-built drying chamber, see Figure 1, right.

Water storage   Drying chamber

Figure 1: Storage of specimen

The specimen mass was determined during the drying procedure in regular time intervals. After reaching about half of the maximum humidity content of the saturated specimen, the mechanical properties were determined again. Finally, the same properties were determined when the specimens reached their initial humidity content before the water admission. All test results were recorded and presented as tabulations and graphics.

The test method to determine the temporal change of the mechanical properties is schematically illustrated in Figure 2.

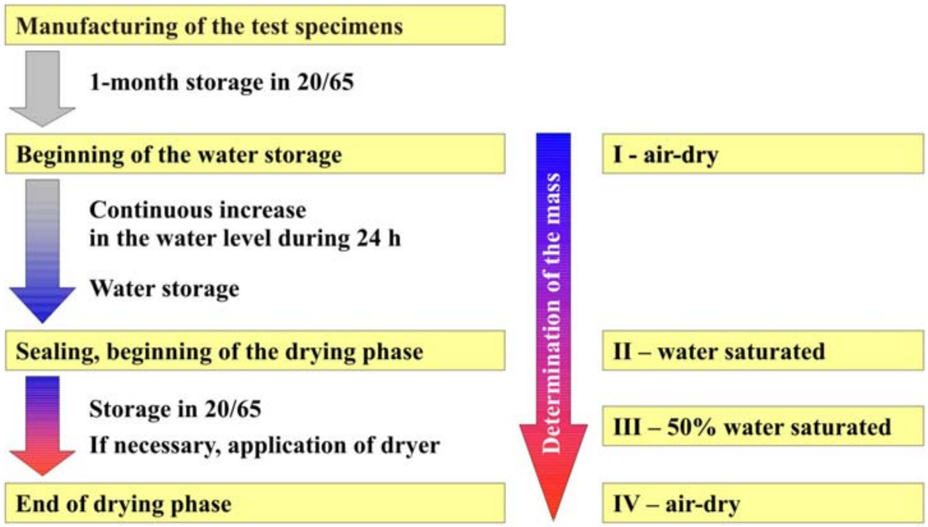


Figure 2: Applied methods

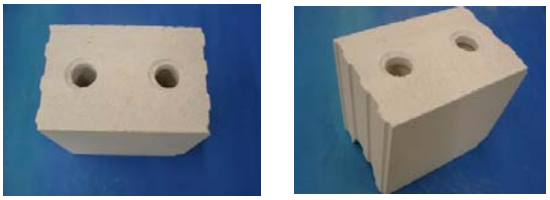
LITERATURE RESEARCH

There is a multitude of most different literature regarding the topic "high water" and the associated damages. After the numerous extreme weather events of the last years, there is high public interest to analyse recent floods and their aftermaths in order to learn from the experiences and the mistakes that are still made in connection with the assessment and the subsequent rehabilitation of flood damage. In this context, the fact seems problematic that the most different opinions do exist regarding the problems related to this subject and that consequently, contradictory courses of action are recommended for practice.

Referring to national and international databases, the respective literature regarding this topic was gathered, reviewed and evaluated. At first, this relates to a survey of the damages normally occurring at flood disasters, which can be classified mainly in statically relevant damages, pollution and moisture damages as well as their causes according to [2], and [3]. Furthermore, some basics of building physics which are taken, among others, from [4, 5] relevant to the drying of masonry components are explained and a detailed survey of the drying techniques for soaked walls presently applied in building practice is given. Here, according to [6], a difference is made mainly between the dehumidification of the air applying condensation or adsorption dryers, respectively, the use of fan heaters, the drying by radiation, e. g. by micro waves or infrared panel heating and more recent drying methods whose effectiveness has not yet been scientifically verified.

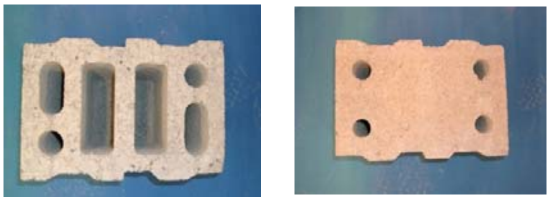
APPLIED MATERIALS AND TEST PROGRAMME

The investigations were carried out on four different kinds of masonry units – hollow clay units, calcium silicate units, aerated concrete units as well as lightweight aggregate concrete units –, in each case on representative unit types with meaningful mortar combinations and commonly used plasters. The applied masonry unit types are shown in Figure 3.

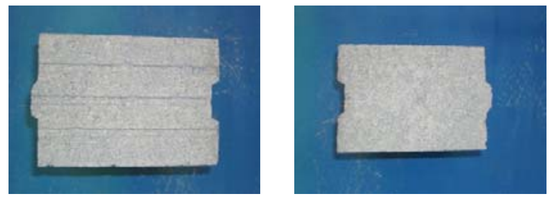


Unit type A

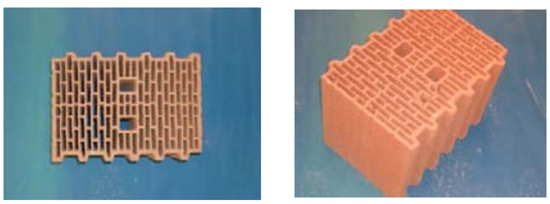
Unit type B



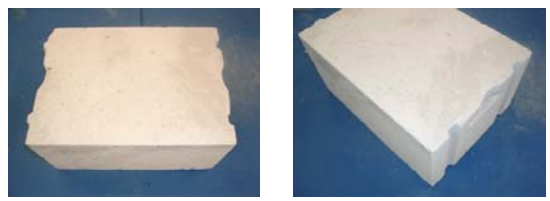
Unit type C



Unit type D



Unit type E



Unit type F

Figure 3: Applied masonry unit types

The test programme and the used material combinations are summarised in Table 1.

Table 1: Test programme

Unit type	Mortar type	Plaster type	
		exterior	interior
Solid calcium silicate units (A)	TLM[1)]-a GPM[2)] M5	-	Gypsum-lime plaster (GKP) Gypsum plaster (GP) Thin layer plaster (DLP)
Solid lightweight aggregate concrete units (B)	LM[3)] 21	Lightweight lime-cement plaster (KZLP)	Gypsum-lime plaster (GKP)
Hollow lightweight aggregate concrete units (C)	GPM[2)] M5	Lime-cement plaster (KZP)	Gypsum-lime plaster (GKP)
Solid lightweight aggregate concrete units (D)	TLM[1)]-d	-	Gypsum-lime plaster (GKP)
Hollow clay units (E)	TLM[1)]-e	Fibre-reinforced lightweight plaster (FLP)	Gypsum-lime plaster (GKP)
Solid aerated concrete units (F)	TLM[1)]f	Fibre-reinforced lightweight plaster (FLP)	Gypsum-lime plaster (GKP)

1 Thin-layer mortar (joint thickness t = 1 – 3 mm)
2 General purpose mortar (joint thickness t = 12 mm)
3 Lightweight mortar (joint thickness t = 12 mm)

The tests were carried out on non-plastered single units, single-sided and/or double–sided plastered single units as well as on non-plastered 2- and 5-units-specimens. The fundamental aim of the investigations was to examine and evaluate the influence of intensive and long-term water storage on the mechanical properties of masonry components experimentally.

For this, the following properties were determined:

(1) non-plastered single units:

dimensions, mass, flatness and parallelism of bed faces, gross dry density and unit moisture content, compressive strength und tensile strength.

(2) plastered single units:

dimensions, mass, unit moisture content, gross dry density and plaster moisture content, adhesive tensile strength of the plaster according to DIN EN 1015-12 [7], see Figure 4.

Figure 4: Test equipment for the determination of the adhesive tensile strength of the plaster according to DIN EN 1015-12 [7]

(3) 2-units-specimen:

unit moisture content, bond strength between mortar and unit according to DIN EN 1052-5 [8], joint compressive strength following method III according to DIN 18555-9 [9] and gross dry density of the mortar joint, see Figure 5.

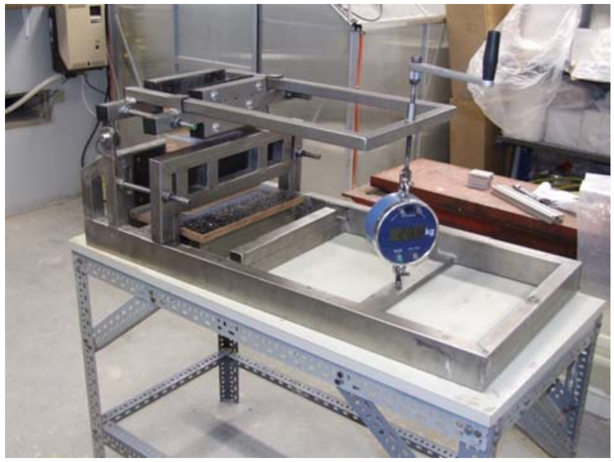


Figure 5: Test equipment for the determination of the bond strength between mortar and unit according to DIN EN 1052-5 [8]

(4) 5-units-specimen:

dimensions, mass, masonry compressive strength, moisture content.

TEST RESULTS

The tests on non-plastered single units have shown that the long-term water storage and the following drying process up to the original humidity of the units in most cases tends to result rather in a favourable effect on the mechanical properties (compressive strength und tensile strength). With four out of six unit types, higher compressive strength values were measured than before the water-storage. With the other two unit types, the strength values in the original state were almost reached. The results of the tensile strength tests displayed similar tendencies, whereby only two out of six unit types in the dried condition achieved higher tensile strength values than before the water storage. However, only slightly lower test values than at the beginning of the investigations result for the remaining unit types with one exception.

In Figure 6, an overview of the compression test results is presented. The temporal change of the compressive strength during the water-storage (point of time II) as well as during the following drying process (point of time III and IV), related to the properties of the untreated specimens (point of time I) is shown here. The tests were conducted on three specimens per unit type and point of time.

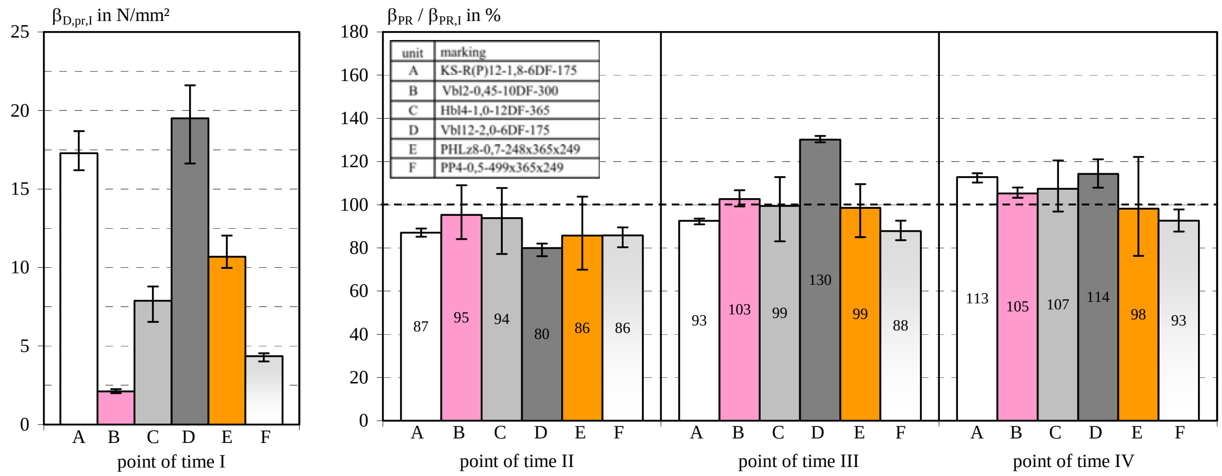


Figure 6: Compression test results; overview

In Figure 7, an overview of the tensile test results is given. Five tests per unit type and point of time were performed.

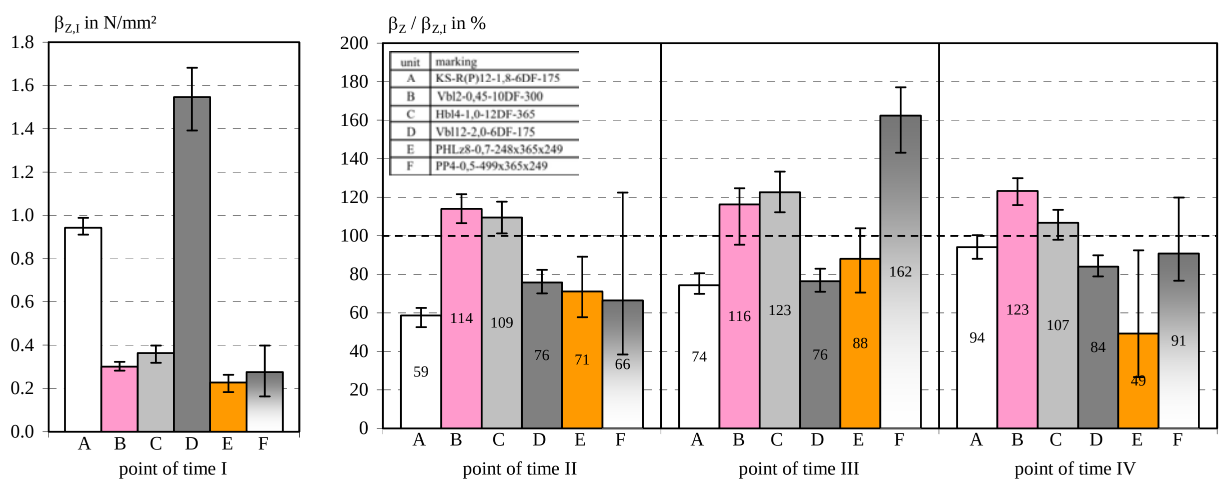


Figure 7: Tensile test results; overview

The tests on the internal plasters have shown that the adhesive tensile strength values on different backgrounds partly fall to very low values after the water storage (up to 15 % of the initial values). However, in many cases the adhesive tensile strength values "recovered" after the drying process to the initial humidity content and only insignificantly lower values were reached than before the water-storage. In two cases, even 11 % and 83 % higher test values were reached after the drying process than before the water-storage.

The tests on the external plasters resulted in similar values. Only in one case, slightly lower values than before the water storage resulted from the tests. With the remaining unit-plaster combinations either the same or clearly higher mechanical properties were reached at the point of time IV than at the beginning of tests.

Table 2 gives an overview of the results of the tensile bond tests on all plaster types. The tests were conducted on 12 specimens per unit type-plaster-combination and point of time.

Table 2: Adhesive tensile strength of the plaster (mean values)

Unit type	Plaster type	β_{HZ} at point of time				$\beta_{HZ,IV}$ / $\beta_{HZ,I}$
		I	II	III	IV	
-	-	N/mm²				-
A	GP	0.46	0.10	0.24	0.51	1.11
	GKP	0.26	0.04	0.10	0.15	0.58
	DLP	0.51	0.16	0.61	0.94	1.83
B	GKP	0.23	0.07	0.06	0.16	0.71
	KZLP	0.15	0.11	0.15	0.21	1.37
C	GKP	0.28	0.10	0.16	0.23	0.80
	KZP	0.08	0.05	0.22	0.20	2.63
D	GKP	0.20	0.08	0.10	0.18	0.89
E	GKP	0.14	0.06	0.07	0.09	0.68
	FLP	0.23	0.18	0.16	0.21	0.90
F	GKP	0.23	0.06	0.14	0.21	0.87
	FLP	0.21	0.12	0.15	0.21	1.00

The bond strength tests between mortar und unit carried out on 2-units specimens have shown that the water-storage up to water saturation of the masonry units and the following drying to the initial humidity content mainly affects the bond strength between mortar und unit in a positive way or there is no recognizable influence on the respective strength values, see Tab. 3. The number of performed tests averaged five per unit type-mortar combination and point of time.

Table 3: Bond strength between mortar und unit (mean values)

Unit type	Mortar type	β_{BHZ} at point of time				$\beta_{BHZ,IV}$ / $\beta_{BHZ,I}$
		I	II	III	IV	
-	-	N/mm²				-
A	TLM-a	0.40	0.55	-	0.66	1.62
B	LM21	0.33	0.29		0.30	0.92
C	GPM M5	0.15	0.12		0.15	1.00
D	TLM-d	0.82	1.09		1.02	1.25
E	TLM-e	0.09	0.06		0.07	0.88

The joint compressive strength following method III according to DIN 18555-9 [9] was tested on three different unit-mortar combinations (GPM M5/ Unit type A, LM21/ Unit type B, GPM M5/ Unit type C). Related to the initial strength after 28 days, either slightly lower or significantly higher values of the mortar compressive strength in the joint occurred due to the water storage and the subsequent drying to the initial humidity content. The lightweight mortar of the joint almost reaches the initial state ($\beta_{D,III,IV}$ / $\beta_{D,III,I}$ = 0.97). Both general purpose mortars yield values up to 70% higher than the initial strength, see Figure 8. To be able to explain the high joint compressive strength values of the general purpose mortars compared to the joint compressive strength of the lightweight mortar, further investigations are recommended.

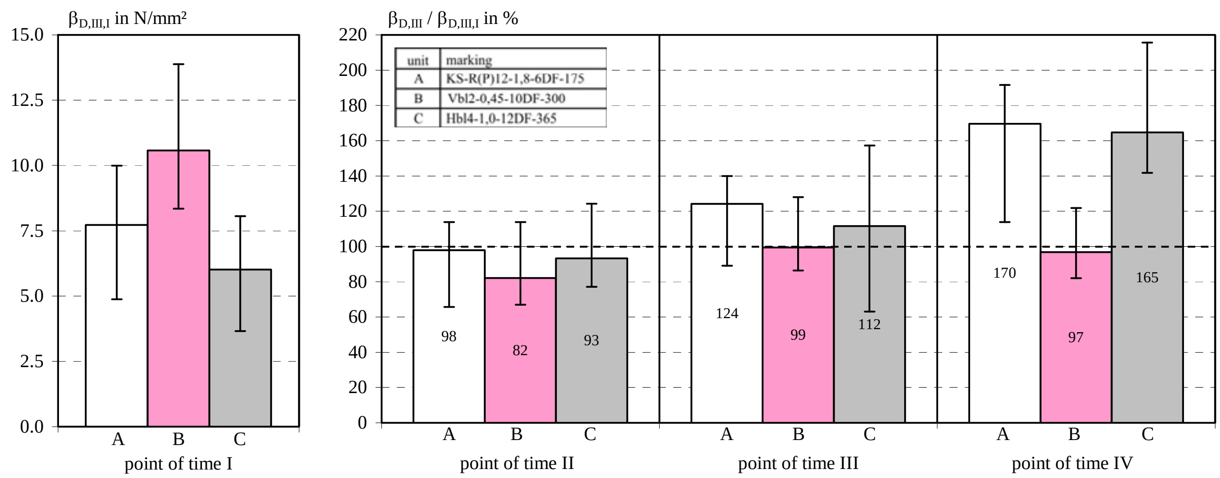


Figure 8: Joint compressive strength test results; overview

After finishing the tests on single units and 2-units specimens, two unit-mortar combinations were selected to carry out further tests on 5-units specimens, the combination that has been affected least and the one that has been affected most strongly by the water storage and the following drying process. To a large extent, similar results as in the case of the tests on single units were obtained.

SUMMARY

It was the aim of the research project to experimentally investigate and evaluate the influence of intensive and long-term water storage on the essential mechanical properties of masonry components.

Within the scope of an extensive literature research, all relevant papers regarding the subject of high water in connection with masonry components are gathered and evaluated. For the detailed literature research on this subject, [1] is referred to.

The applied materials and the test programme were presented. The investigations were conducted on customary masonry units (solid calcium silicate units, solid lightweight aggregate concrete units, hollow lightweight aggregate concrete units, hollow clay units and solid aerated concrete units) with reasonable mortar combinations (normal mortar, lightweight mortar, thin layer mortar). The plasters for the unit surfaces were also chosen according to the respective practical applications. Three different interior plasters were used (gypsum-lime plaster, gypsum plaster and thin layer plaster) as well as three customary external plasters (fibre-reinforced lightweight plaster, lime-cement lightweight plaster, lime-cement plaster)

The conducted investigations and their results were described and illustrated in detail.

According to the results of this project, it can be concluded that the influence of an intensive and long-term water storage on the mechanical properties of masonry components is to be rated as relatively small after they have dried to the initial humidity content. Both, compressive strength and tensile strength tests, showed that the mechanical properties of water saturated and dried specimens were not affected at all or rose to a higher level than before the water admission. Tests on plastered single units revealed that not only the external but also the interior plasters reached the same or higher adhesive tensile strength values after the drying process than before the water storage.

Contrary to the recommendations mostly given in practice, the test results suggest that, after being exposed to flood water, plasters must not necessarily be removed from masonry walls at least regarding their bond to the substrate. With regards to the mostly occurring soiling and the drying period of soaked plastered masonry walls, it is presumably reasonable to renew the plastered areas after exposure to flood water. The influence of the plaster on the drying period of masonry components was however not investigated explicitly within the scope of this research project. Due to the partly inexplicable results occurring at the examinations on masonry columns and to be able to make a more generally applicable statement, further investigations are recommended.

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