# Mortar water content impact on masonry strength

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**ABSTRACT**
*Building without sufficient knowledge can entail risk concerning structural safety and resource efficiency. The authors of this paper share the view that mortar water content are subject to large variations, and that the consequences of these variations are unknown or neglected. A literature review and a test program has therefore been conducted in order to investigate how the mortar water content influence the following important strength properties of masonry: Flexural strength, initial shear strength and compressive strength. Prior to the test program, the first-author visited six different buildings sites in order to document on-site mortar consistency. Based on this, three mortar mixes (dry, medium and wet) were chosen for the test program. The testing is conducted basted on NS-EN 1052 series [1-3], and comparison is made to values given in Norwegian Annex of Eurocode 6 [4].*

*It is found that there is a lack of knowledge on this issue in literature, and further that the guidelines for masons regarding mortar water content is insufficient. The test program showed that the structural properties vary considerably based on the water content of the mortar. Flexural and initial shear strength increases strongly by increasing the water content, seven-fold for shear. The compressive strength of masonry specimens show on the other hand consistent strength that seems independent of reduced mortar strength by increased water content.*

*The recommendation of using wet mortar ought to be included in the curriculum of masons. Since the scale of the presented research is rather limited, further testing ought to be carried out.*

**KEYWORDS:** Brick, mortar flow, masonry strength, shear, flexural, compressive.

## 1. INTRODUCTION

Masonry quality depends in essence of three factors – mortar, bricks and the workmanship involved in the construction [5]. Further the masonry quality is complicated by the interaction between the mortar and the bricks [6]. In this paper, we address one of these factors – masonry mortar, hereafter mortar – and investigate the influence of one of the sub-qualities of mortar quality – water content and its influence on masonry strength. More specific, we examine the effect on hydrated masonry specimens due to change in water content in fresh mortar.

Mortar strength depends in turn on several factors. Of these, the most important are the binder, water binder ratio, composition of sand and additives. Further, the strength of the mortar depends on the nature of the clay bricks used, since the suction of the bricks affects the water content of the mortar during curing.

Mortar strength forms the basis for masonry quality. With weak mortar, the quality of the whole masonry ensemble is left uncertain, if not to say dangerous. Based on the experience of the authors, the implications of practical masonry work on worksites are little understood, constituting potential hazardous conditions. In addition, both pecuniary and environmental concerns concerning the mortar qualities are significant [7,8].

In Europe, Eurocode 6 [4, 9] gives guidelines for designing masonry structures, and tabulated values for masonry strength on basis of mortar and brick strength is given in the national annex. What the standard does not include to a significant extent, however, is the influence of actual workplace conditions concerning the water content of the mortar on the physical strength of the solutions chosen. Some research has been carried out concerning factors affecting the flexural strength on brick masonry [10]. Little seems to have been done, however, within the field of examining the influence of mortar water content for masonry strength, since Baker published an article in 1982 [11]. A notable exception to this is reported in Costigan and Pavia [12]. We in this paper analyse the influence of the work-site added level of water in factory-made designed (dry) mortar, according to the specifications of NS-EN 998-2 [13].

The hypotheses that initiated the research behind this article was the following: Use of fresh stiff mortar (mortar with low water content) by masons leads to weak masonry strength. In other words, we analyse the effect of the water content of mortar on masonry strength, according to flow properties. In order to operationalize this general idea, the following research questions were outlined:

- What is the effect of mortar water content on flexural strength?
- What is the effect of mortar water content on initial shear strength?
- What is the effect of mortar water content on compressive strength?

The analysis presented in this paper is based on an analysis of designed mortar, specifically Weber masonry mortar M5 in combination with Wienerberger Haga Red perforated clay bricks.

## 2. THEORETICAL FRAMEWORK

### 2.1 Literature review

Goodwin [14] carried out a comprehensive literature review concerning the literature on brick/mortar bond in 1982. A few outtakes from Goodwin's summary: "There is abundant evidence in the literature to conclude that the rate of absorption of the masonry units is the most important single factor affecting the bond. … The most desirable value of initial rate of absorption (IRA) to achieve maximum strength would appear to be in the range 0.8 – 1.2 kg/m$^2$/min, but an optimum value less than this is required to provide walls resistant to water penetration." (p. 33) "The water retentivity of the mortar, which is a measure of the ability of the mortar to resist the suction of the bricks, is considered by many investigators to be the most important property of the mortar affecting the bond. A considerable amount of work has been carried out in an effort to increase the water retentivity of mortars. There is, however, evidence that consistency, or the quantity of water in the mortar, is as important as water retentivity in obtaining good bond strength. This is considered to be the case particularly with highly absorbent masonry units." (p. 34)

Following the work carried out there, and according to the literature review carried out within the context of the research presented in this paper, the main trend in research on the effect of masonry/brick interaction on masonry strength is typically focusing on the following four aspects:

2.1.1 Properties of the mortar
Modified composite mortars have been developed by the replacement of certain part of lime with pozzolana, such as burnt clay or fly-ash. This was found to be of advantage [15]. Gazzola [16] showed significant decrease in tensile bond for mortars made with Portland cement and masonry cement instead of Portland cement and lime.

2.1.2 Properties of the brick
McGinley [17] showed that the IRA of brick units can have a greater influence on the flexural bond strength of the masonry assembly than is generally accepted by the masonry industry. Groot and Larbi [6] found that not only the water flow from mortar to brick (which takes place immediately after mortar-brick contact) but also a reversed water flow from brick to mortar (occurring after compaction and initial hydration of mortar) may significantly influence the bond strength development. Fried and Li [18] showed that the tensile bond strength generally increased as the maximum water absorption capacity of the units decreased. The maximum bond strength occurred at an "optimum" water absorption intermediate between the dry and fully saturated state. Yorkdale [19], however, found the effect of IRA not to be significant enough to taking it into the standards. He recommends, however, further research, as the relation between clay masonry units and mortar is not well understood.

2.1.3 Workmanship
Francis et al. [20] showed experimentally and theoretically that the strength of four-brick prisms declines as the joint thickness increases and as the lateral tensile strength of the bricks diminishes in relation to their compressive strength.
Results from Tabbakhha and Modaressi-Farahmand-Razavi [21] indicate that mortar cohesion has a considerable effect on wall strength under in-plane loads. However, under combined loads, the influence of workmanship quality on wall strength decreases for the in-plane direction and increases for out-of-plane direction.

2.1.4 Water content
Internationally, relatively few articles addressing the specific question of water content in mortar on masonry strength have been identified. One notable exception from this is Baker [11], who analyses bond strength of brickwork and the effect of mortar flow. Baker's first conclusion was that "[t]he flow of mortar is a sensitive and important parameter influencing the flexural-bond strength of brickwork. Maximum strength is obtained with mortars of wettest workable consistency" (p. 86). Baker use terms like "the wettest workable mix" and "the driest workable mix on the flow of the employed mortar, however, he does not specify flow values. In addition, the material properties of the brick examined by Baker indicate that the IRA is high (3.2 kg/m$^2$/min.). In light of this, the results presented by Baker are not very surprising, since prewetting of bricks is a well-known method of improving bond for high suction bricks. A more recent study of Costigan and Pavia [12] show many similarities to the paper of Baker [11]. Costigan and Pavia used, bricks with an IRA of 1.0 kg/m$^2$/min which is equal to the bricks used in this study (IRA 1.0/m$^2$/min), IRA of 1.0 is low to moderate [22].

The findings and conclusions none the less coincide with those of Baker [11]. Costigan and Pavia focused on mortars with a small flow value difference (165 mm versus 170 mm flow). The analysis presented, however, lack any clear analysis of what the actual flow variation can be in workplace conditions. In addition, their analysis focus on lime-based mortar, and not on cement-based mortar (being most commonly used within the Norwegian AEC-industry).

### 2.2 Vocabulary
Though little actual research seems to have been carried out on mortar water content impact on masonry strength, the standards and the literature describes certain properties of mortar, and properties influencing the interrelation between mortar and bricks.

- Flow value – A measure of workability by slump or spread for flow table test of NS-EN 1015-3 [23].
- Initial rate of absorption (IRA) (kg/m$^2$/min) – The mass of water absorbed by the brick's bed-side in one minute in 5 mm of water (note that this value is given with various units and for 3 mm [6, 24] or 5 mm of water [25].
- Water absorption (WA) – The total mass of water absorbed by fully saturated brick as percentage of the bricks dry weight [26].
- Cohesion of mortar – The ability of fresh mortar to stick together/to itself and to the trowel or vertical surfaces. Lack of cohesion could lead to segregation/separation/bleeding (losing water) [27].
- Workability – Property of fresh mortar with main factors consistence and plasticity [28].
- Consistence – That property of a mortar by virtue of which it tends to resist deformation (capable of being changed by the addition or removal of water) [28].
- Plasticity – That property of a mortar by virtue of which it tends to retain its deformation after the reduction of deforming stress to its yield point [28].
- Water retentivity – Ability of mortar to retain its moisture under suction from a masonry unit [29].

On a workmanship level, however, an additional level of definitions is employed, which all express qualities of mortar influencing its performance. The following definitions are based on the experience of the authors:

- Short mortar – Poor consistency, unable to form a long even mortar bed, typically thin (lacking in cohesivity (lacking in binder/lime, air and or filler))
- Creamy mortar – Mortar with a good workability/high flow without losing the ability to maintain its shape after placing. Like whipped cream, it is easy to spread without need of force, still not fluid so it could maintain a slender shape (like a spike) or carry a brick.
- Wet mortar – Referring to mixed fresh mortar with a high-water content looking and feeling wet to the touch, typically having a high flow value.
- Dry mortar – Referring to mixed fresh mortar with a low water content looking and feeling dry to the touch, typically being stiff.
- Stiff mortar – Mortar that in the following is denominated as stiff is characterized by a relatively low workability, requiring more force in handling and placing.

### 2.3 Guidelines for mortar consistency
2.3.1 The codes
Eurocode 6 [4,9] describes to a large extent the physical properties of brick and mortar, providing detailed technical calculation models for assessing the strength of the brick

masonry. The interaction between mortar and bricks is not, however, described thoroughly, other than in a general recommendation to follow the design specifications of the suppliers. Part 1-1 (3.2.3.2) [4] simply states that the "adhesion between the mortar and the masonry units shall be adequate for the intended use". Part 2 [9] proves somewhat more elaborated, yet still leaving much to the judgement of the reader: "Satisfactory adhesion should be achieved by proper preparation of the masonry units and mortar. The necessity for wetting masonry units before use should be obtained from the design specification. Where there are no requirements in the design specification, the recommendations from the manufacturer of the units and, where appropriate, from the manufacturer of factory made mortar, should be followed." [9] 3.5.1 (1). However, the Danish code Tegl 24 [30] have requirements for minimal mortar flow.

In sum, the standard thus leaves the concrete considerations concerning the interaction between the mortar and the bricks to the design specifications of the producers.

2.3.2 Wienerberger bricks

According to their web page, Wienberger is the world's largest producer of bricks. In their technical brochure [31] (translated from Norwegian by the authors of this paper) page 4, they outline the following instructions concerning the interaction between the bricks and the mortar: "The mortar shall have a composition adapted to the initial rate of absorption of the bricks in order to obtain the intended interaction between the mortar and the bricks. Pre-batched dry mortars shall be in accordance with NS-EN 998-2:2016. The properties of the mortar, and the bond between the mortar and the bricks shall be documented by the manufacturer of the mortar."

For on-site constructed lintels with adapted mortar, Wienerberger recommends pre-wetting of the bricks units according to prescribed specifications or priming in combination with water. Further, the bond between the bricks and the mortar ought to be controlled according to NS-EN 1052-3 before start-up.

In sum, however, the responsibility for defining the brick/mortar interaction properties is left mainly to the manufacturer of the mortar. The exception to this concerns the specifications of lintels.

2.3.3 Weber mortar

The main supplier of mortar in Norway is Weber. Their most commonly used mortar is M5, used in a majority of masonry construction in Norway. In addition, Weber supplies designed mortar according to distinct brick properties, be they highly or little absorbent.

In their product data sheet [32] (in Norwegian), Weber in general recommends using stiff mortar in order to reduce spilling during the construction of masonry structures. Equally, the use of stiff mortar is recommended for easing the cleaning of the façade. There are no considerations of what stiff mortar actually implies for the masonry quality, like strength properties.

The vocabulary used, however, proves surprisingly vague. Concerning the use of the mortar M5 used during the research presented in this paper, the term used for describing the consistency of the mortar is "correct" ("riktig"). The interpretation of the term "correct" consistency is in fact left undescribed. In addition, no descriptions of the impact on the structural properties (shear strength, compressive strength, flexural strength) of "correct" consistency are provided.

The question of what "correct" actually means in work-place conditions is thus left to subjective interpretation of the personnel conducting the construction of the masonry work – that is, the mason him/her self.

2.3.4 Curriculum for masons

If the responsibility for obtaining the "correct" consistency of the mortar is left to the mason in place, the foundations for this judgement needs being addressed. The curriculum of the masons' education therefore needs scrutiny.

The textbook used nation-wide in Norway is *Mur* ["Masonry"] [33]. In this (chapter 2), the interaction between mortar and bricks is described in the following manner (translation by the authors of this paper): "It is […] the adhesive properties of the interface between the mortar and the bricks that determine the shear strength, driving rain resistance and the risk of cracks and micro-cracks. The interaction between the mortar and the bricks is determined mostly by the IRA of the bricks and the resistance to water loss of the fresh mortar. A favorable relationship between these two properties is a condition for good adhesion".

The lack in semantic precision observed in the producer technical specifications can again be observed in the context of the textbook description. To describe that the relationship ought to be "favorable" so that "good adhesion" is obtained is of little help to the practitioner seeking to know how to carry out the masonry work in an adequate manner.

2.3.5 Conclusion to guidelines

In the authors' opinion, little actual advice is provided for practitioners in Norway concerning the consistency of the mortar with regards to assuring the interaction between bricks and mortar.

The workplace experience of the main author of this paper indicates that this corresponds both to observed prior practice and focused observation. Prior to the research reported on in this paper, seven work-place visits were conducted. At these, it was observed that – rather than following any predetermined prescriptions – the mortar was mixed according to the preferences of the individual team of masons. Mortar was mixed wet in order to obtain speed, or dry to enable less spill and an increased accuracy.

The research presented in this paper thus differs from existing research by focusing on workplace conditions and actual mason's understanding of mortar, bricks and their interrelation.

As observed in the literature, there seems to be little knowledge concerning the effect of mortar water content on initial shear strength, flexural strength and compressive strength.

## 3. METHODOLOGICAL APPROACH

### 3.1 Literature review

The research presented in this paper was initiated by a scoping literature review, carried out along the guidelines presented by Arksey and O'Malley [34]. The literature review focussed on 1) identifying the main trends existing within the literature, and 2) on establishing the knowledge gaps existing. Based on this, a further close reading of literature found to be of particular interest to the research presented here was conducted. Key words used in the search for literature included brick, mortar flow, masonry strength, and shear-, flexural- and compressive strength. Search engines used included Google Scholar and Oria (Norwegian Library database). In addition, a comprehensive scrutiny of the scientific journals and conference proceedings considered most pertinent to the analysis – in particular Masonry International and the International brick and masonry conference – was carried out. The literature review was carried out during the period August 2016-April 2017.

### 3.2 Test program

The test program was designed to isolate the effect of water content in the mortar and be relevant to bricklaying in Norway today. The mortar Weber M5 was selected on basis of it being the most commonly used mortar in Norway. Haga Red perforated bricks from Wienerberger were chosen because of its properties in terms of color, WA, IRA and that it is perforated, characteristics that are typical for bricks used in Norway. See Table 1 for brick and mortar data.

The spectrum of the mortar mixes' workability in the test program corresponds closely both to the spectrum observed during building site tests performed autumn 2016, and with the recommended spectrum for water content from producer Weber [32]. The wet mix is close to the wettest workable consistency and the dry is close to the stiffest workable consistency, based on the experience of the authors. The mixing procedure and time was carried out according to Weber's recommendations. After mixing each batch, the flow table values were determined according to NS-EN 1015-3 [23]. See Table 2 for test specimen characteristics.

Tests are based on the European norms, specifically the NS-EN 1015 [1-3] series. Previously mentioned building site visits and all mixing, bricklaying, conditioning and testing was performed by the first author of this article.

Bond and strength of masonry depend on good curing conditions. NS-EN 1052 [1-3] specify that the specimens should be covered for three days in order to avoid rapidly drying out. The laboratory is characterized by higher temperatures and lower relative humidity for the main part of the year than outdoor conditions, thus forming a harsher curing environment for masonry specimens. Even so, the sun and wind of the outdoors environment can dry out masonry faster than the laboratory air. In order to render the test conditions closer to outdoor conditions (in accordance with observed work-place conditions in summer) than what is described in the standard, it was decided not to cover any of the specimens during curing. Such non-covering of the specimens is considered by the authors to result in conservative testing results.

3.2.1 Specimens for four-point flexural bending test

NS-EN 1052-2 [2] specify spacing of inner bearings to be 0.4 – 0.6 of the outer bearings spacing. Initially, a ratio of 0.5 was selected. This resulted in breakage outside the inner bearings. Therefore, the rig was rebuilt to a ratio of 0.4 in order to maximize the moment between the inner bearing. After this adjustment, all breakage occurred in-between the inner bearings as required [2].

3.2.2 Specimens for initial shear strength

The specimens where not preloaded after building (that is, contrary to the procedure [3]). The specimens where jointed (front and one end) and brushed to a typical concave finish.

3.2.3 Specimens for compression

The compression specimens were three courses high (212 mm), less than the five courses demanded by NS-EN 1052-1 [1]. The main reason for this deviance was limitations in material availability and time restrictions. The analysis was, however, considered to be adequate, since its main purpose was comparing the relative compressive strength of the three sample series.

Specimens where constructed on a plane surface. Prior to testing, both sides received a quick hand grinding to remove any protruding parts before being placed between 12 mm wood fiber plates. ½-stones where cut on a diamond saw, washed and dried before construction.

## 4. RESULTS

Table 3 and Figure 1 provides an overview of the results. They show a clear impact of water content on the flexural and initial shear strength. Shear strength is clearly the most affected structural parameter, with characteristic values ranging from 0,04 to 0,28 N/mm$^2$ for the three mortar mixes, that is a factor of seven. The specimens made by the wet mortar resulted in the strongest masonry. Also, the flexural strength is clearly influenced by water content. The wet mortar gave specimens 1.6 times stronger than specimens built with dry mortar.

The measured average compressive strength on mortar prisms, tested according to NS-EN 1015-11 [35] (without absorbent filter paper), decreases when the flow value increases. The compressive strength on masonry specimens is, however, influenced in a negligible manner by the flow values. The variation within each of the compressive strength series was low, with a relative standard deviation ranging from 2.3 % to 4 %. Results from the flexural, initial shear and compression tests on masonry specimens were calculated into the characteristic values according to NS-EN 1052 [2, 3] and Eurocode 0 [36]. This procedure was followed to compare them with the tabulated characteristic strength values in the Norwegian annex of Eurocode 6 [4].

Since the tested specimens were two courses lower than required by NS-EN 1052-1, the characteristic compressive strengths were multiplied by a shape factor of 0.84. Researcher's [37,38] maintain that the shape factor from NS-EN 772-1 [39] is uncertain and that the slenderness is the key factor. The shape factor of 0.84 was obtained from converting table 1A in [39] to slenderness. Even after this correction, the compressive strengths identified are considerably higher than the tabulated values in the Norwegian annex of Eurocode 6 [4].

## 5. DISCUSSION

### 5.1 Effect of water content on flexural and initial shear strength

The results concerning shear strength, flexural strength and the relation of these two to water content are in agreement with Baker [11]. Equally, they increase the validity of Costigan and Pavia's [12] conclusions, both by type of mortar and flow range of the fresh mortar.

Further, the results confirm the general challenge in achieving designed flexural strength [5], none of the masonry specimens achieved the flexural strength values tabulated in the Norwegian annex of Eurocode 6 [4]. The specimens built with wet mortar came, however, closest.

Only the specimens built with wet mortar achieved the tabulated initial shear strength from Eurocode 6 [4]. The declared initial shear strength from Weber of 0.15 N/mm² [40] is achieved by specimens built from both medium and high flow mortar.

The characteristic values achieved are in general on the safe side. Since there are relatively few (5-7) specimens in each series, characteristic values will be small. In other words, the characteristic strength is likely to be higher than reported here, and this could have been documented by testing more specimens. The relationship between the different series is more accurate than the characteristic values, since they would not be as affected by the number of specimens.

### 5.2 Effect of water content on compressive strength

The water content has a negligible influence on the compressive strength of the masonry specimens, while the mortar prisms loose almost 40% of their compressive strength from the same variation in water content. This could be explained by the fact that there are two contradicting effects here. First stronger mortar provides stronger masonry, and second, higher bond strength provides stronger masonry. Sarangapani et al. [41] concluded that "[a] four-fold increase in flexural bond strength resulted in a doubling of the masonry compressive strength" (p. 237). In accordance with this, the low water content results in strong mortar, while leading to weak bonding. Correspondingly, a high water content gives weaker mortar but stronger bond. The effects consequently cancel each other out, and compressive strength is left seemingly unaffected by the large variations in flow and water content.

The first crack on the masonry specimens was logged. They seem to appear randomly between 40% and 90% of failure load, thus not providing any valuable information. The specimens appeared to handle the loads mainly unaffected until approximately 95% of ultimate loading. At this point the specimens showed clear signs of being close to collapse.

## 6. CONCLUSION

Results reported on in this paper has identified a lack of knowledge concerning water content on masonry mortar in Norway. Equally the guidelines for masons on mortar water content are found to be insufficient.

Structural properties are found to vary considerably according to the water content of the mortar within the typical building site variation. Bond strength (as the combination of flexural and initial shear strength) increase strongly by increasing the water content, seven-fold for shear, whilst mainly still not achieving the values prescribed by Eurocode 6 [4]. This can, in effect, create potential hazardous conditions.

The compressive strength of masonry specimens show, however, consistent strength seemingly independent of reduced mortar strength by increased water content, and well within the prescriptions of Eurocode 6 [4].

**ACKNOWLEDGEMENTS**
We would like to present our gratitude to Klima 2050 Centre for Research-based Innovation, its partners and the Research Council of Norway as the founding participant of the research presented in this paper. Likewise, support by Saint-Gobain Weber has been very welcoming.

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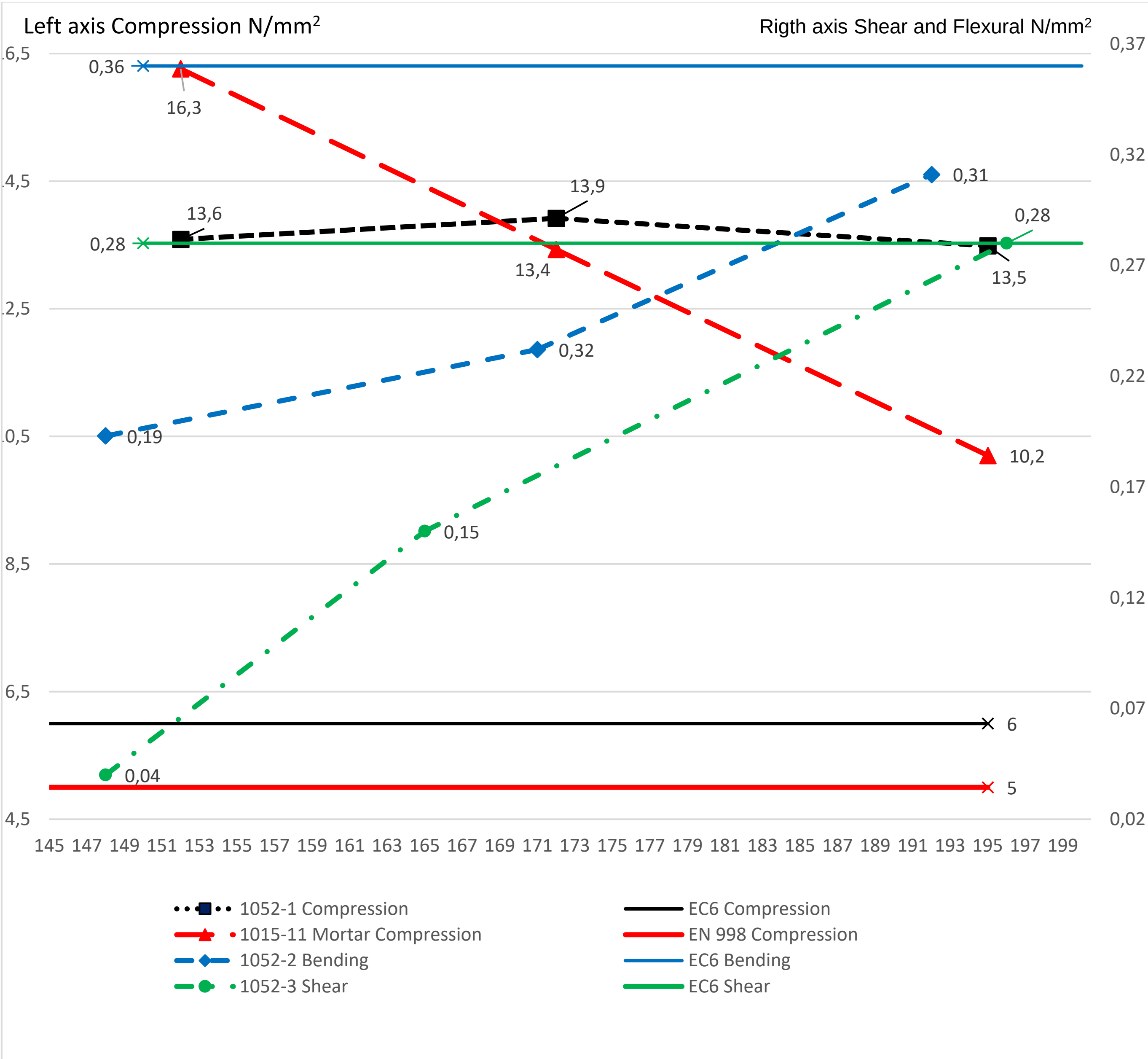


**Figure 1 Strength dependent of flow value**

**Table 1**
**Properties of brick and mortar**

| **Brick Wienerberger Haga Red** | | **Mortar Weber M5** | | | |
|---|---|---|---|---|---|
| Category | 1 | | Water added mortar [kg/25 kg] | Flow average | Compressive and flexural strength |
| Dimension | LWH 228x108x62 mm$^3$ T1, R1* | Declared value | Masonry 3.6 – 4.0 (4.2 for rendering) | | Declared** Compressive >5 N/mm$^2$ Flexural >2.2 N/mm$^2$ |
| Compressive strength | Declared: 35 N/mm$^2$* | Dry | 3.60 – 3.75 | 149 mm | Comp. 16.3 N/mm$^2$ Flex. 3.15 N/mm$^2$ |
| Water absorption | Declared: 8 %* | Medium | 3.90 – 4.00 | 169 mm | Comp. 13.4 N/mm$^2$ Flex. 3.02 N/mm$^2$ |
| Initial rate of absorption | Declared: 0–1.6 [kg/m$^2$/min]* Measured: 1.2 [kg/m$^2$/min] | Wet | 4.15 – 4.30 | 193 mm | Comp. 10.2 N/mm$^2$ Flex 2.19 N/mm$^2$ |
| Holes | 22 %* | Proportions | Portland Cement 11.7 %, Lime 1-5 %, Filler 11.4 %, Chemicals 0.5 % Natural sand 0-2 mm 60-100 %*** | | |

*Product Data Sheet Wienberger Haga Red [42]
** Weber M5 DoP [40]
*** Weber M5 EPD [43], Weber M5 DoP [40]

**Table 2**
**Overview of test specimens**

| Specimens | Height x Length [mm²] | Flow values: Dry, Medium, Wet* [mm] | Number of specimen [pcs] | Curing conditions and age of specimens when tested |
|---|---|---|---|---|
| Flexural NS-EN 1052-2 | 362 x 469 | 148, 171, 189 | 15 | 19.8 °C (σ=0.5), 21,5 %RH (σ=7.3), 28 days |
| Shear NS-EN 1052-3 | 212 x 228 | 148, 165, 196 | 21 | 19.7 °C (σ=0.4), 22.4 %RH (σ=6.8), 28 days |
| Compression NS-EN 1052-1 | 212 x 469 | 152, 172, 195 | 15 | Approx. 22 °C, 30% RH 27 days (6pcs) and 28 days (9pcs) |
| Flexural and compression NS-EN 1015-11 | 40x40x160 | 148, 171, 189 | 9 Flexural 18 Compression | 19.8 °C (σ=0.5), 90-100% RH, 28 days |

*Flow table values after mixing prior to building. If more than one batch (approximately 14l) was made to complete the series, weighted mean value for the batches is given.

**Table 3**
**Results of tests**

| | **Flexural strength NS-EN 1052-2** | | **Initial shear strength NS-EN 1052-3** | | **Compressive strength NS-EN 1052-1** | |
|---|---|---|---|---|---|---|
| **Mix** | Range [N/mm²] | $f_{xk1}$* [N/mm²] | Range [N/mm²] | $f_{vk0}$** [N/mm²] | Range [N/mm²] | $f_{ky}$*** [N/mm²] |
| Dry | 0.24 – 0.35 | **0.19** | 0.08 - 0.34 | **0.04** | 17.2 – 19.2 | **13.6** |
| Med. | 0.25 – 0.46 | **0.23** | 0.16 - 0.35 | **0.15** | 16.9 – 18.1 | **13.9** |
| Wet | 0.33 – 0.57 | **0.31** | 0.36 - 0.58 | **0.28** | 16.6 – 17.6 | **13.5** |
| Characteristic **** | | **0.36** | **0.28** | | **6.0** | |
| Design***** | | 0.19 | 0.15 | | 3.2 | |

* Characteristic strength calculated from NS-EN 1052-2 [2]
** Characteristic strength calculated from NS-EN 1052-3 [3]
*** Characteristic strength calculated from NS-EN 1990 [36], corrected with shape factor 0.84 based on NS-EN 772-1 [39] Table A.1.
**** Tabulated values from NS-EN 1996-1-1 [4] Norwegian annex Table NA.904
***** Design strength (incl. material safety factor $\gamma_m$ = 1.9) calculated from NS-EN 1996-1-1 [4] Norwegian annex based on Normal control class 3 and M5 designed mortar