# Dependence of Masonry Properties on the Interaction between Masonry Units and Mortar

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Abstract - Buildings and other structures are erected in order to satisfy certain needs of people. The buildings have to fulfill the appropriate performance requirements under the simultaneous action of external factors, or agents, originating from the environment, the structure itself and the use of the building. This way of thinking can be applied also to the interface and the interaction between the masonry units and the mortar. The paper gives some general considerations and concentrates then on the effects of the suction of the masonry units. Examples are given on the influences on the strength of masonry, bond and winter construction. The conventional ways seem in some cases to lead to erroneous results. Some thougths on future approaches are expressed.

## 1. INTRODUCTION

Each structure has to satisfy certain performance requirements. In the practice, the structure has to perform under the action of certain agents which originate from the environment, the structure itself and from its use. Table 1 lists the requirements and agents according to the proposal [1] by ISO/TC 59/SC 3. A solution has to be chosen with such properties that it performs satisfactorily under the action of the external agents which are actual in each particular case.

| Requirements | | Agents | |
|---|---|---|---|
| 1 | Stability | 1 | Mechanical |
| 2 | Fire safety | 2 | Electromagnetic |
| 3 | Safety in use | 3 | Thermal |
| 4 | Tightness | 4 | Chemical |
| 5 | Hygrothermal | | water and solvants |
| 6 | Atmospheric | | oxidants |
| 7 | Acoustical | | reducing agents |
| 8 | Visual | | acids |
| 9 | Tactile | | bases |
| 10 | Anthropodynamic | | salts |
| 11 | Hygiene | | neutral materials |
| 12 | Suitability of spaces | 5 | Biological |
| 13 | Durability | 6 | Combined |
| 14 | Economic | | |

Table 1. Performance requirements and agents affecting a structure in use [1].

In addition to appearance, many technical requirements are set up. The construction must resist different types of loads and forces, it must withstand effects from the climate and many actions caused by the use of the building. It must be loadbearing, it has to possess a certain strength, it must resist the penetration of rain, be weather and frost resistant, fireproof, acoustically insulating, etc.

The predictive evaluation of the performance is a very complicated matter in the application of the performance concept. Tests can be made to a building, a building element, a product, etc. According the the results of a Delphi-study [2] within the RILEM committee on "Performances of mortars and renderings", the most important level for the evaluation was "product combination", e.g., the interaction between mortars and masonry units. The most important properties to be considered were the following.

Fresh mortars: workability, instant adhesion, water retentivity, stiffening under suction. Internal structure: cohesion, thixotrophy, plasticity.

Hardened mortars: elastic and plastic properties, bond, shear, strength of mortar hardened between masonry units, moisture movements, bond, tensile, shrinkage. Internal structure: interaction between aggregate and binder, pore structure.

Masonry units: water absorption, suction, surface structure, shrinkage and swelling, elastic properties, strength.

This short compilation suggests that there should be possibilities to choose the correct masonry unit/masonry mortar combination for different cases arising in the practice.

## 2. GENERAL PRINCIPLES

The task of the mortar is to bind the masonry units together in order to form a structure which fulfills the stated requirements. The proper interaction between the mortar and the masonry units is a necessary condition for the achievement of this result. The fresh mortar must have such properties that it fulfills its functions in the hardened state in combination with the masonry units in question.

The suction exerted by the masonry units is the most important factor affecting the fresh mortar, and consequently, the properties of the mortar joint. The removal of water affects the mortar bed as a whole, and, especially, the properties of the interface between the masonry unit and the mortar. The suction depends upon the amount of water the unit is able to absorb, the rate of absorption and the power of suction. The capillary suction force is important in cases where the masonry unit consists of a material with fine pores as these pores exert a strong suction for a long time.

The suction is reduced by the water absorbed by the masonry unit. A similar effect can be achieved by wetting the unit. A water gradient may be formed in the mortar. Soluble substances are transported with the water into the unit, sometimes even to its surface causing efflorescence. If solids are collected at the masonry unit/mortar interface, the bond may weaken. Solid particles may fill the pores and lessen the suction. Colloids have the same effect.

There is generally an excess of water in the mortar for workability reasons. In some cases no water is removed from the mortar, the other extreme being that almost all water is absorbed by the masonry unit. In the former case, too much water results in a weak and porous mortar, if too much water is lost, the cement does not harden. The optimal conditions are to be found somewhere between these extremes, but it is important that the strength of the

mortar does not depend on its initial water content but on the amount of water present after suction.

The mortar is laid on the top of the masonry construction being erected. The suction by the bottom masonry units may result in the stiffening of the mortar. In that case the upper masonry unit laid on the mortar bed will get into contact with a different kind of mortar than the bottom unit, and the properties of the upper interface may be different from the lower.

If the mortar hardens partly before the water is removed, the effects are different from the situation where the water is rapidly absorbed by the masonry unit. As the mortar already has a structure it is not any more a plastic body, and the transfer of water results in volume changes. The fine pore structure of a hardened cement mortar may later revert the water flow, and water may return from the masonry unit to the mortar if the pore structure of the masonry unit is coarser.

Shrinkage and swelling of the mortar and the masonry units due to moisture changes and thermal movements affect the quality of the joint. The shrinkage of the mortar taking place with time is a factor of the same type. Many other stresses and loads are acting on the joint trying to destroy it.

The loss of water from the mortar and its stiffening are necessary to ensure some stability of the masonry during construction. However, in the manufacture of prefabricated masonry panels one may use methods which are very different from ordinary methods. The possibilities to adopt special mortars are interesting. Also, the consistency of the fresh mortar can often be of such a nature that the mortar could never be used at an ordinary building site. For instance, the mortar may be poured in the joints. One has to be careful with such a process in order to avoid problems arising from phenomena like efflorescence.

Two main factors have to be considered in the design and choice of mortar mixes. The workability of the mortar has to be suited to the working methods and conditions and the interaction between the mortar and the masonry units used must lead to a satisfactory construction after the hardening of the mortar. All mortar materials, its composition, preparation, storing and application influence the end result.

## 3. NATURE OF SUCTION

The initial rate of absorption is often taken as a measure for the ability of a brick to remove water from a mortar. The IRA is determined by partial immersion of the unit to a given depth in water - here 10 mm - for a period of 1 min. Anderegg [3] compared the 1-min. absorption with the abstraction of water from lime mortar. He found out that a dry-press nonceramic brick with the highest IRA removed a small amount of water from the mortar. He believes that a unit with a high suction may form a congealed layer at the mortar surface, in any case, the high suction prevents the mortar from making a continuous contact with the brick. For most bricks, the bond strengths increased with the IRA to a maximum, beyound which they decreased. The compressive strength of the joint mortar increased with the IRA. However, with mortars of high portland cement content, strength decreases in contact with highly absorbent bricks were noted. Wetting the unit is an effective measure against too high suction. Blank [4] points out that the bond strength is not proportional to the IRA as masonry units with the same numerical IRA value may give different bond strengths with the same mortar.

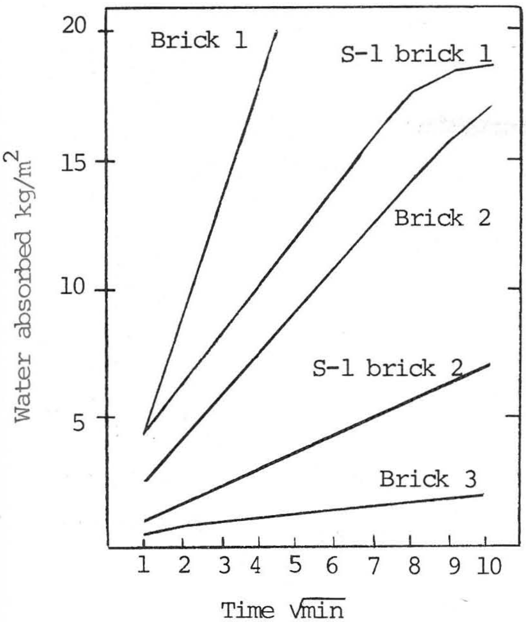


Fig.1. Absorption from a free water surface. Three types of bricks and two types of sand-lime bricks.

Fig. 1 shows the results of a prolonged test of partial immersion. The IRA expressed in kg/$m^2$ for the sand-lime bricks 1 and 2 was 4.5 and 1, and for bricks 1, 2 and 3: 4.5, 2.5 and 0.5. The amount of water absorbed is plotted against the square root of time. Fig. 2 shows what happened when these masonry units were put in contact with a fresh lime cement mortar LC 35/65/450 - lime: cement: sand by weight. The persentage of water left in the mortar was determined by drying the mortar at 105°C. The clay bricks follow generally speaking the order of IRA but the difference between types 2 and 3 is small. Sand-lime brick 2 with the lower IRA removed clearly more water from the mortar than type 1 with the higher IRA. The tensile strength of three lime cement mortars hardened between the sand-lime bricks was determined after 25 days with the splitting test. The mortar strengths were clearly superiour with sand-lime brick 1. The ratios were 1.7 for LC 20/80/400 and 2.0 for LC 35/65/500 and LC 50/50/575.

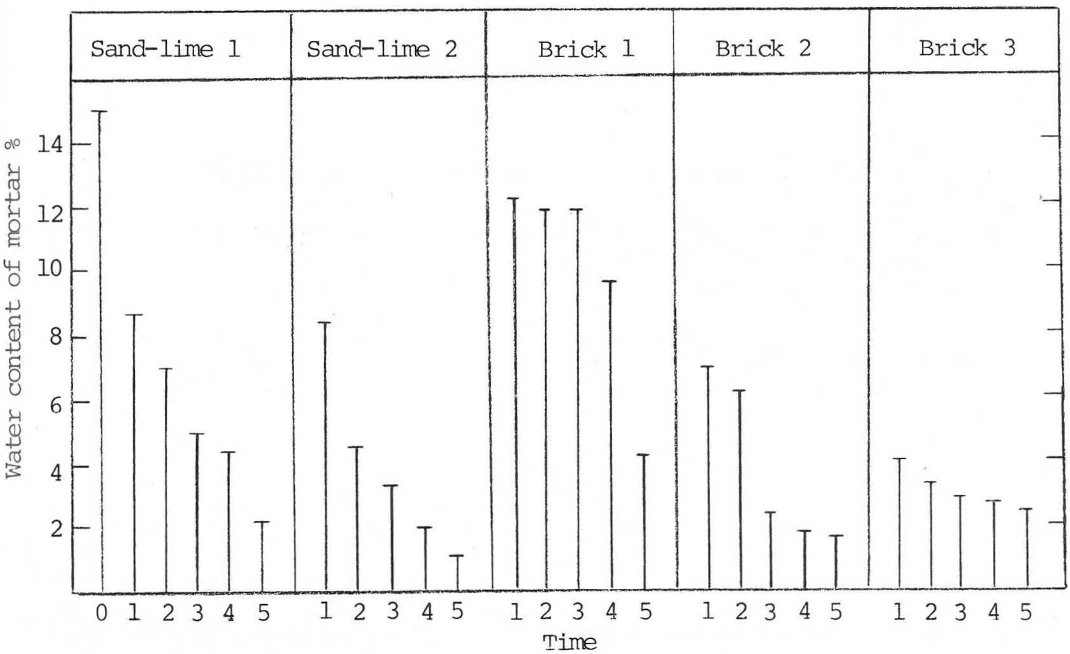


Fig.2. The water left in lime-cement mortar LC 35/65/450 (lime/cement/sand by weight) after a contact with the bricks of Fig.1 after following periods: 0 = initial, 1 = 10 min, 2 = 30 min, 3 = 60 min, 4 = 240 min and 5 = 1440 min

## 4. EFFECTS OF SAND

Many masonry standards contain some requirements or recommendations concerning the mortar sand. Because of some discrepansies in test results, a lime cement mortar LC 35/65/500 was prepared using three sands with different corn size distributions (Fig.3):

C = high content of coarse fraction
S = standard sand
F = high content of fine fraction

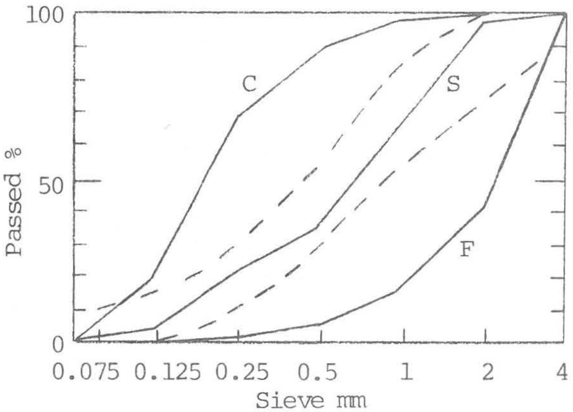


Fig.3. Composition of mortar sands. S = RILEM standard sand which falls in the recommended area, C = coarse sand and F = fine sand.

The bending and compressive strengths of the mortars were determined using the Scandinavian method where prisms in the size of 25x25x170 $mm^3$ are cast and subjected to the suction of four sheets of blotting paper on both sides of the mould. From an initial water content of 15 %, the papers lower it to about 10 % in half an hour. As has been shown above, the loss of water to many masonry units is much higher.

The bond of the mortars to clay bricks with an initial rate of absorption of 3 to 4 $kg/m^2$ min was also measured. Bricks were cut into two and a small column, a stack bonded test specimen, was built of five such halves. These columns were loaded to rupture and also the compression of the specimen was measured during the test. According to previous experience, this test gives indications on the influences of different mortars.

The results are given in Fig.4. Starting with the standard prism tests, the results obtained with the fine sand (F) show that both the bending and the compressive strengths are much lower than with the standard (S) or with the coarse (C) sand. One reason to this is that the suction in the preparation of the standard prisms is rather low and the water content of the mortar remains high as the amount of water in a mortar made with fine sand is necessarily high from the beginning. A low prism strength is the result and according to the conventional approach the fine sand mortar would be rejected after the prism tests. However, the picture is quite different in the tests involving an interaction with the masonry units. The interaction results in the best bond and with small collumns in about the same strength as the standard sand. Also the compressionduring the test was of the same order. The mortar with the coarse sand (C) is clearly inferior in this test. The effects of the high water content of the F-mortar have been positive when the mortar has been put into contact with bricks with a rather high suction.

The results show that a conventional evaluation of the tests with standard prisms is not always reliable. Results of this kind suggest also that norms for masonry constructions where the corn size distribution of the sand has been standardized, may be too restrictive. However, the main point is that the results prove that tests on interaction are very useful.

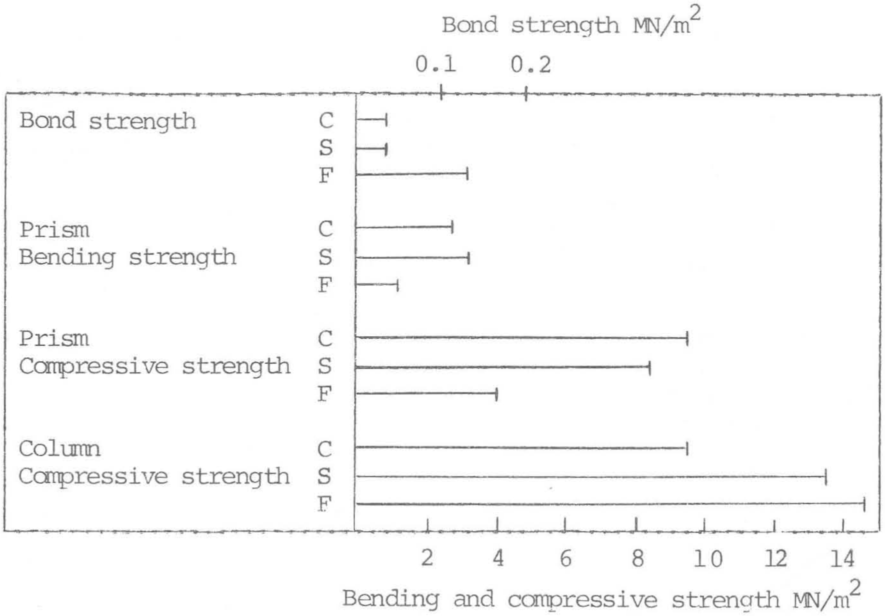


Fig.4. Bond strength, bending and compressive strengths of mortar prisms and compressive strength of small columns at rupture. Sand types: C = coarse, S = standard and F = fine

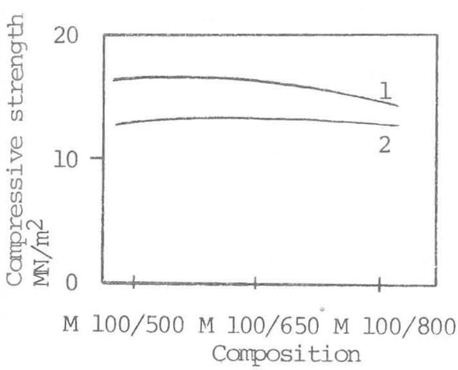


Fig.5. Dependence of the load at rupture of masonry columns on the composition of masonry cement mortars. Clay bricks of strength class 35 $MN/m^2$ (1) and 25 $MN/m^2$ (2).

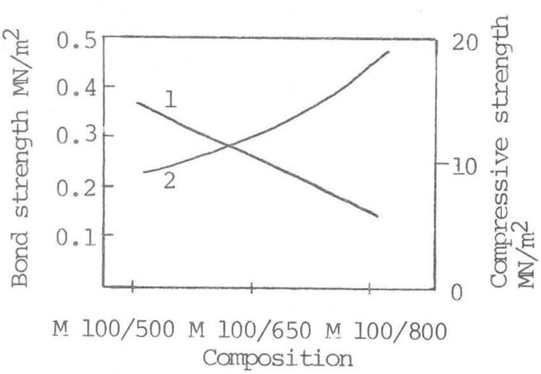


Fig.6. Compressive strength of standard prisms (1) and the bond strength of the same mortar mixes (2) to clay bricks with an IRA of 1.5 to 1.9 $kg/m^2$ min.

In this connection it may be appropriate to deal with a couple of practical cases even if they are not connected with sand problems. According to the conventional approach to masonry design, masonry units meeting specification requirements - mainly strength - are used together with a mortar of a specified composition. Certain levels of allowed stresses are then met. Some decades ago cement mortars with air entraining admixtures were introduced in order to replace lime. Using different amounts of sand the same strengths could be obtained with these airentrained cement mortars as with conventional lime cement mortars.

The same approach was tried with masonry cements consisting of a finely ground mixture of portland cement and an inert mineral with admixtures. The results were surprising as practically no differences were found when masonry panels were loaded to rupture. Three masonry cement mortars were tested: M 100/500, M 100/650 and M 100/800 (binder/aggregate in kgs). Fig.5 shows a very small difference in the loads at rupture with these mortars and two types of bricks. Leiritie [5] shows also that the strength of standard prisms increases with increasing binder content (Fig.6). At the same time, the bond weakens and Leiritie believes that the increasing bond compensates the decrease of the mortar strength. Therefore, the strength of the masonry remains constant with different mortar compositions.

As a result, masonry constructions can be erected with own special rules. Strict requirements on the composition of masonry cement mortars are not necessary as the strength of the masonry does not depend on small variations in the proportions.

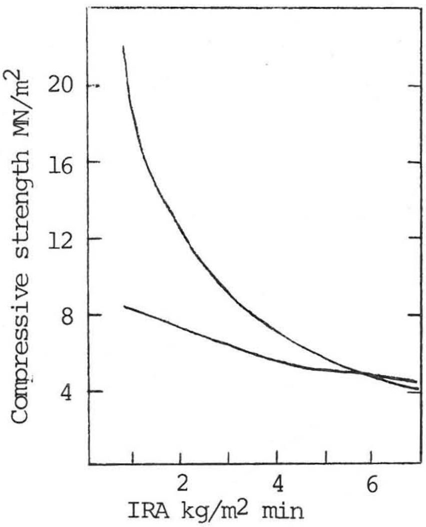


Fig.7. Dependence of a masonry construction on the initial rate of absorption of the clay bricks. The upper curve - cement mortar, the lower curve - lime cement mortar.

At the moment of its publication, the report of Haller [6] on the influence of the initial rate of absorption of the masonry units on the strength of masonry caused discussion. Fig.7 shows the results of test on a wallette of the thickness of 150 mm.

## 5. BOND

As the main task of the mortar is to bind the masonry units together, the bond is one of the most important properties. In the preceding chapters the bond has already been mentioned several times. The phenomenon is of such a complexity that we are far from solving the problems involved.

The influences of the bond are manyfold. Strength properties are of importance but different leakage processes are of special interest. Rain penetration has always been important in driving rain regions but also in less dangerous zones. As the masonry walls are getting thinner, the question of water leakage may become more acute.

Thornton [7] gave a comprehensive picture of the phenomenon. He built small basins, filled them with water and counted the water leakages. He used a blue dye to indicate the lack of contact between the mortar and the brick. He found a clear relation between the area which was dyed blue and the number of leakages.

In principle, water may penetrate through the masonry unit or the mortar but the mechanism mentioned above is the most usual. Water leakage occurs through channels at the interface between the mortar and the unit, as the result of a weak bond [8]. The importance of suction was shown by Anderegg [3] who found out that there was optimal situations of suction.

West et al. [9] have determined the effect of bricks with varying suction rates on the permeability of mortars cast between the bricks. The small mortar slabs were compared by measuring the capillary rise of water. The results tend to show that clay bricks with a very low or high suction rate gave mortars with a high porosity. There seems to be an optimum suction rate for unmodified mortars. With admixtures the results were different.

Blank [4] presents data on the bond properties of Swedish masonry materials. Universal mortars do not exist which could be used with any masonry units. Blank points out that the mortars which have high strengths do not necessarily provide a good bond.

From thermodynamic points of view a good adhesion is impossible if the adhesive does not wet its substrate. This means that the adhesive has to get into a very good and even contact with its substrate. In the case of a substrate like a porous masonry unit the process of wetting becomes rather complicated. From one side, the properties of both the mortar and the masonry unit are altered by the suction. From the other side, the properties of the mortar change with the time of working, anyway.

The stiffening of the mortar as a result of loss of water with the resulting reduction of a property called "bonding ability" by Davison [10] may explain many cases of inferior bonding. However, there is a lack of fundamental knowledge or, perhaps, the existing knowledge has not been organized.

The water removal depends upon the pore structure of the masonry unit and its surface texture. The porosity of the surface layer is often different from the inner parts of the unit. The mortar plays its own role, and the complex and unknown phenomena at the mortar/masonry unit interface need much more study. The interrelation of the pore properties and the properties of the mortar connected with the retention and loss of water, and the influences on the "bonding ability" of mortars should be clarified. The more practically oriented tests provide a good picture of some special cases but the basis for a systematic approach seems to be lacking.

The composition and properties of the mortar layer in contact with the masonry unit and the possibilities to alter and develop it are evidently interesting objects of study. There are admixtures which in some cases provide bond strengths of such a magnitude that the masonry unit is broken. There are also rather significant bonds where the rupture takes place at the interface. In other cases the mortar itself breaks, and often the rupture takes place partly in the mortar, partly at the interface.

Interesting studies on the mortar layer in close contact with the masonry unit have been performed by Farran et al. and the formation of a layer of ettringite at the surface of the bricks has been proved [11]. The ettringite forms some kind of bridge between the brick and the hydrated tricalsiumsilicates. The authors seem to believe that the size of the ettringite crystals as seen in contrast to the pores in the brick have an influence on the bond. The crystals cannot enter in pores smaller than themselves.

Another study of the same fundamental kind is the investigation of the stiffening of mortars in contact with a porous substrate. Détriché and Grandet [12] are using a needle which resembles Vicat, and they are mainly thinking at renderings.

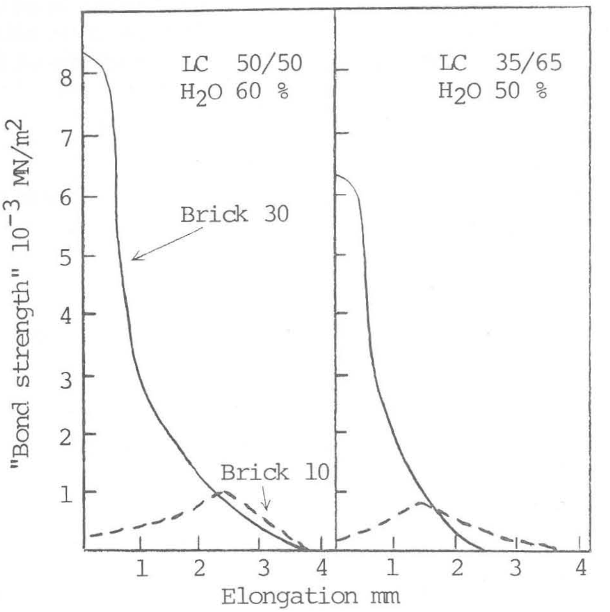


Fig.8. Measurement of the force and the elongation of binder mix at rupture in an instant adhesion test. At left a lime-cement mixture 50/50 by weight with 60 weight-% water. At right LC 35/65 with 50 % water. Bricks with an IRA of 30 and 10 kg/m$^2$ were used. Time of contact 5 min.

Own preliminary tests on the instant adhesion of masonry units to fresh mortars have shown that there are indications for rupture by adhesion in some cases and by cohesion in others. It also seems to be evident that the time of applying the mortar after its preparation is of vital importance. Indications by short-time tests on adhesion would be of interest for product development. The tests mentioned here have been performed by placing a test specimen made of a masonry material in contact with a binder, binder mix or a mortar. The test specimen is left in contact with the wet mix for a known time and then pulled off. In some cases the mortar breaks away immediately, in some cases it hangs on for long times. The force and the distance the test specimen has to travel until the mortar loosens or breaks is plotted by an XY-recorder. Fig.8 shows the results of one test. The procedure seemed to be usable but no action is taking place at present.

## 6. WINTER MASONRY

The amount of water present in the mortar at the time of freezing is quite deciding. If the water content is reduced enough by the suction, or the mortar has hardened enough before freezing, or the mortar freezes immediately, damage of the mortar can be avoided [13]. Fig.9 shows how much the strength of the mortar depends upon its water content during hardening but it also shows that the mortar strength is not significantly weakened by immediate freezing. In fact, the strength of frozen prisms has in some cases been higher after thawing and curing. Fig.10 shows one of the critical moments. A frozen mortar has a very high strength which is reduced to zero by thawing. Similarly with Fig.9 the strength of the frozen mortar was 28 after preparation stronger than the unfrozen mortar, although its curing period was 7 days shorter.

In addition to mortar tests, also the bond and the strength of columns was studied.

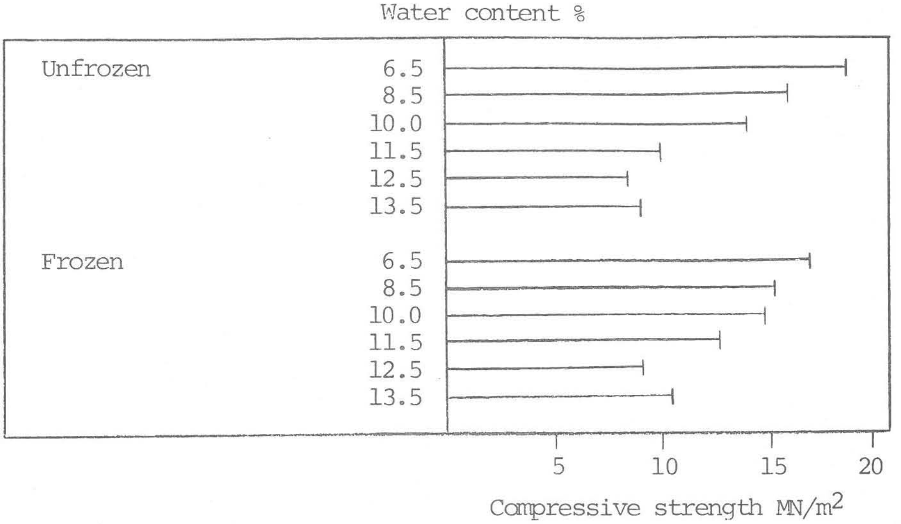


Fig.9. Effects of immediate freezing on the strength of mortar prisms with different water contents. The mortar was LC 35/65/450 and its water content was adjusted by the suction of bricks. Storing: Unfrozen 28 day at +20°C, 95 % R.H. Frozen -16°C for 1 day, then 28 days at +20°C, 95 % R.H.

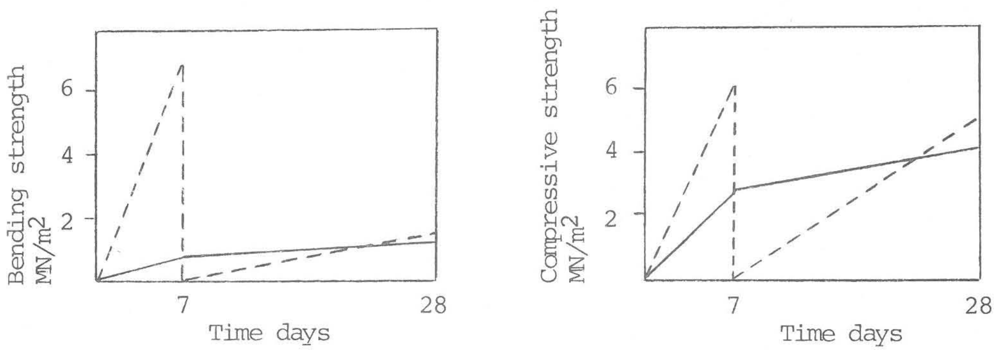


Fig.10. Development of the strength of mortar prisms of LC 50/50/600 on the cycle freezing at -16°C for 7 days, thawing and curing at +20°C, 95 % R.H. for 21 days. The unfrozen prisms were at the curing conditions for 28 days.

Freezing did not necessarily destroy the bond. Cold bricks with low IRA were detrimental. The tensile strength of the mortar hardened in joints was dependent on the IRA of the bricks, and it was adversely affected by low IRA when cold bricks were employed for bricklaying. As the bond is a very controversial property, more evidence is needed.

The influence of freezing on the compressive strength of small columns was not decisive. The compression increased and the modulus of elasticity decreased, particularly with cold, low IRA bricks. Thawing under a constant load, columns laid of warm, high IRA bricks had the lowest and columns with low IRA bricks the highest compression.

Larger frozen columns showed generally higher strengths than unfrozen columns of the same age. A low water content of the mortar at freezing had a beneficial influence on the compression at rupture.

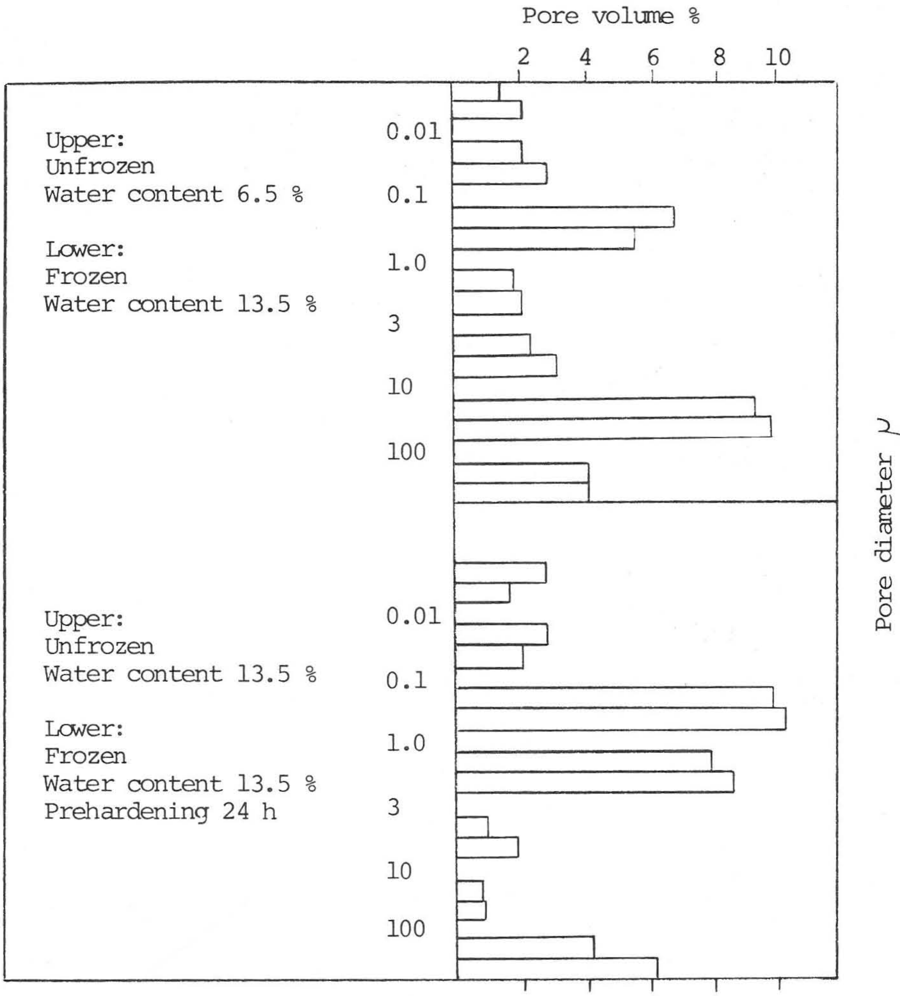


Fig.11. Pore size distribution of unfrozen and frozen mortars measured with a mercury porosimeter. An unfrozen mortar is compared with a frozen mortar with a high water content above, and below, an unfrozen mortar with a high water content with the same mortar frozen after 24 h.

From a more fundamental point of view, determinations of the pore size distribution indicated that the effects of freezing on a mortar of high initial water content immediately after preparation were similar to those observed with a normally hardening mortar with a low water content. No clear effects on pore size distribution were observable if the same mortar froze after prehardening for 24 hours (Fig.11). It is possible that the freezing of a fresh mortar results in a higher strength, attributable to the physical changes arising from freezing.

The problems are particularly challenging in winter masonry where questions arise like the rate of hardening reactions and of the temperature resulting from the contact between cold bricks and warm mortars. The directives for winter masonry need improvement [14]. However, all previous chapters give evidence on the general importance of basic research of the interaction between masonry units and mortars to aid the development of the appropriate masonry technology suited for different regions of the world.

## 7. REFERENCES


1. ISO/DP 6241: Guidance on the preparation of performance standards in building. British Standards Institution, 1979.

2. T. SNECK: RILEM-MR/VTT Delphi study on masonry and rendering mortars. Otaniemi 1972. State Institute for Technical Research, Laboratory of Building Technology, Report 12.

3. F.O. ANDEREGG: The effect of brick absorption characteristics upon mortar properties. American Society for Testing Materials, Proceedings 42(1942) pp. 821-830.

4. R. BLANK: Mortars and interaction between mortars and masonry units (in Swedish). Fourth Nordic Masonry Symposium. Part I. Espoo 1981. Technical Research Centre of Finland, Symposium 13/1981, pp. 223-264.

5. M. LEIRITIE: The use of masonry cement (in Finnish). Tiili (1973):3, pp. 19-21.

6. P. HALLER: Hochhausbau in Backstein. Zürich 1959. Verband Schweiz. Ziegel- und Steinfabrikanten.

7. J.C. THORNTON: Relation between bond and the surface physics of masonry units. Journal of American Ceramic Society 36(1953) p. 105.

8. T. RITCHIE & J.L. DAVISON: Factors affecting bond strength and resistance to moisture penetration of brick masonry. Philadelphia 1962. ASTM, Special Technical Publication No. 320, pp. 16-30.

9. H.W.H. WEST, R.W. FORD & F. PEAKE: The effect of suction rate of bricks on the permeability of mortar. Stoke-on-Trent 1976. The British Ceramic Research Association, Technical Note No. 254.

10. J.L. DAVISON: Loss of moisture from fresh mortars to bricks. Materials Research and Standards 1(1961)5, pp. 385-388.

11. J. FARRAN, J. GRANDET & J.-C. MASO: Variations des concentrations de portlandite et d'ettringite dans les pâtes des ciments Portland au contact des terres cuites poreuses. Comptes Rendus d'Académie des Sciences, t. 271, Série D, pp. 4-7.

12. C.H. DÉTRICHÉ & J. GRANDET: Influence de la suction des supports poreux sur la prise et la résistance au cisaillement des mortiers moulés à leur contact. Matériaux & Constructions 14(1981)80, pp.91-102.

13. T. SNECK, L. KOSKI, H. OINONEN, S.D. SVENDSEN, A. WALDUM, H. DÜHRKOP & E. HELANDER: Winter Masonry. Helsinki 1972. Building Technology and Community Development, Technical Research Centre of Finland, Publication 1.

14. T. KANKO: Winter masonry (in Finnish). Tiili 33(1981)4 pp. 36-41.