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MORTAR SELECTION IN DESIGN PRACTICE – DESCRIPTION OF THE PROBLEMS, SOLUTIONS AND REQUIREMENTS

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Abstract

Practically, all buildings just after erection and while in use are subject to displacements and deformation due to settlement as well as rheological, thermal or climate influences. Whether this leads to masonry structure damage depends on a number of factors, one of which, and incidentally one of the main ones, shall be mentioned here: the type and properties of mortar used. Mortar whose parameters are well-matched to the type of masonry units will largely prevent wall damage. On the other hand, using mortar whose properties are inappropriate may intensify the process of masonry structure damage.
Formerly two types of mortar: lime mortar and cement mortar were in use. Sometimes lime mortar has cement added to it to increase its strength and hasten its setting. Using of modern types of masonry units, especially AAC blocks, calcium silica or high perforated clay hollow blocks shows that mortar should be selected more carefully, because in many causes the effect of using the typical kinds of mortar gives negative results. Therefore the problem of correct mortar selection for different types of masonry units is very important and now more and more significant.
The role of mortar as connector, pad and a barrier, and drain problems connected with strength and adhesion were presented and discussed. Moreover, the behaviour and physical, as well as mechanical properties of mortar and concrete were presented and commentated. Also, a wide discussion of influence of lime and cement content in mortar composition are presented. Finally, some general conclusions for correct mortar selection in correlation to given type of masonry units are formulated.

Streszczenie

Praktycznie rzecz biorąc, budynki zaraz po ich wzniesieniu są poddane działaniu przemieszczeń i deformacji związanych z osiadaniami oraz wpływów reologicznych, jak i termicznych oraz klimatycznych. W związku z powyższym, uszkodzenia konstrukcji murowych zależą od wielu czynników, z których jednym, zwykle traktowanym, jako mniej ważny, jest omawiany tu szerzej problem doboru rodzaju oraz własności zastosowanej zaprawy. Zaprawa, której parametry są dobrze dobrane do rodzaju elementów murowych w znacznym stopniu zabezpiecza ściany przed uszkodzeniami. Z drugiej strony, stosowanie zaprawy, której własności są nieodpowiednie może zintensyfikować proces rozwoju uszkodzeń konstrukcji.
Dawniej były głównie w użyciu dwa rodzaje zapraw: wapienna oraz cementowa. Czasem dodawano do zaprawy wapiennej dodatek cementu w celu podniesienia jej wytrzymałości oraz przyspieszenia jej wiązania. Stosowanie nowoczesnych typów elementów murowych, a w szczególności bloczków z betonu komórkowego, silikatów lub silnie drążonej ceramiki poryzowanej pokazuje, że dobór zaprawy powinien być ostrożniejszy, ponieważ w wielu przypadkach efekt użycia typowych mieszanek zapraw powoduje negatywne skutki. Stąd problem właściwego doboru rodzaju zaprawy do danego typu elementów murowych jest bardzo ważny i coraz bardziej istotny.
W artykule opisano i przedyskutowano rolę zaprawy, jako łącznika, bariery przeciwko wnikaniu mediów środowiskowych oraz problematykę związaną z jej wytrzymałością oraz adhezją. Ponadto, przedstawiono także i skomentowano zachowanie się oraz własności fizyczne i mechaniczne zaprawy oraz betonu. Zaprezentowano także szeroką dyskusję wpływu zawartości wapna oraz cementu, jako składników zaprawy. Na zakończenie sformułowano pewne ogólne wnioski i zalecenia dotyczące poprawnego doboru zaprawy do danego rodzaju elementów murowych.

Keywords: **Masonry mortar; Composition; Mechanical properties; Adhesion; Durability.**

1. INTRODUCTION

Buildings generally, just after erection and while in use, are subject to displacements and deformation due to settlement as well as rheological, thermal or climate influences. Whether this leads to masonry structure damage depends on a number of factors, one of which, and incidentally one of the main ones, shall be mentioned here: the type and properties of mortar used. Mortar whose parameters are well-matched to the type of masonry units will largely prevent wall damage. On the other hand, using mortar whose properties are inappropriate may intensify the process of masonry structure damage (see Freeman et al. [1], Parkinson *et al*. [2] or Schubert [3]). Using of modern types of masonry units, especially AAC blocks, calcium silica or high perforated clay hollow blocks shows that mortar should be selected more carefully, because in many cases the effect of using the typical kinds of mortar gives negative results.

At the beginning of the XX century, two types of mortar: lime mortar – composed of one part of lime to three pats of sand, and cement mortars with proportion from one part of Portland cement to one to four of sand were widely proposed (see Mitchell [4]) generally. Moreover, lime mortar sometimes has cement added to it to increase its strength and hasten its setting. Cement mortar use was recommended in cases of higher ultimate strength necessity achievement – just after masonry structures erecting. Nowadays, situation has changed. At the building market a lot of different cement-lime, cement or recommended for tin joins mortars are available. Especially in such a situation the problem of correct mortar selection for different types of masonry units is very important and now more and more significant. For example within a framework of CIB W23 Commission “Wall structures” activity was prepared and edited in 2007 a monographic work entitled “*Enclosure Masonry Wall Systems Worldwide*” [5], which contains a description of enclosure masonry wall systems being in use in different countries worldwide, as well as structural and material solutions, local experience and most characterised problems.

Masonry mortar is defined as a mixture of binder(s) (organic and non-organic), fillers and water, which harden as a result of chemical or physical reactions occurring with the binder. Sometimes, literature offers additional information that mortar serves the purpose of bonding masonry units into a stable masonry structure. This could be implied if mortar firmly joins two masonry units together, it is suitable for general use. Such approach may be the reason why the mortar market, particularly in Poland, is not very demanding. Quite possibly, the current state of affairs is also caused by the fact that for many decades (or even hundreds of years) the same or similar mortar has been used, which, due to its durability (as confirmed by preserved structures), testified to its suitability for use in the building industry. In the past, in typical design practice only prescribed mortars (according to notation accepted in Eurocode 6 – Part 1.1 [6] and Part 2 [7] and based on them new Polish Masonry Code PN-B-03002:2007 [8]) were usually in use, where designer had to specify the proportion of components by volume (cement : lime : sand). Such approach has a long tradition in most countries and in spite of considerably mechanical properties dispersion (connected e.g. with different sand amount in the range of the same strength class – see Table 1 with masonry types specified in American standard ASTM C270-08a “*Standard Specification for Mortar for Unit Masonry*” [9]) no significant problems connected with the use of this type of mortars were recorded.

The situation changed rapidly during last two decades, since introducing into building market (also in Poland) a designed, factory made types of mortars, especially when cement and subsequently chemical admixtures modifying its properties emerged on the market, and the pace and scale of works also increased by a number of times. Ready, factory made mortars are easy to use, both by designer and at the building site. Unfortunately, according to the authors, that sudden technological shift did not do a great favour to walls. Observation of masonry structures erected recently makes one arrive at the conclusion that they frequently become damaged (cracks and hairline cracks, mortar flaking) shortly after the building is put in use (within a few years). Building physics has not changed for centuries, and so have not the functions of mortar, which directly determine its properties.

Table 1.
Mortar specification given in American standard ASTM C270-07a

Mortar types (measured by volume)			
Designation	Cement	Hydrated Lime or Lime Putty	Sand
M	1	¼	3 – 3 ¾
S	1	½	4 – 4 ½
N	1	1	5 – 6
O	1	2	8 – 9
K	1	3	10 – 12
“L”	0	1	2 ¼ – 3

2. FUNCTIONS OF MORTAR

2.1. Mortar as a connector

Mortar serves the purpose of joining masonry units in such a way to create a durable and stable masonry structure. Due to the fact that characteristic strength of a wall depends on the strength grade (class) of masonry units more than on that of mortar, the weakest cement-lime mortar specified by the designer should be used. Unfortunately, there are not enough specific guidelines for mortar preparation and selection with some critical comments and description of problems, which can occur while using them. One of such guidelines is publication of British Masonry Society prepared by Edgell and Haseltine [10]. It is very useful publication but it does not analyse all aspects of correct mortar selection.

Also, mortars should be selected in such a way that their strength does not exceed the strength of masonry units used. That principle prevents walls from hairline cracking and masonry units from cracking. If mortar is subjected to destruction, the damage is relatively easy to remove. However, this is also an early warning that something bad is happening to the masonry structure, than perhaps load-bearing capacity limit states have been exceeded locally. Moreover, it is very important to select mortars in such a way as to ensure good adhesion to masonry units. Big problems with low adhesions were observed in case of AAC and Ca-Ci blocks using thin bed joint mortar, which is usually characterised by high strength class. Generally strong mortars (primarily cement mortars with air-entraining additives or plasticizers), which are characterized by poor adhesion to most types of masonry units, are used frequently. As a result, mortar flakes away from masonry units and moisture (water) penetrates the resultant cracks, which causes formation of various types of damage to masonry units – see Fig. 1.

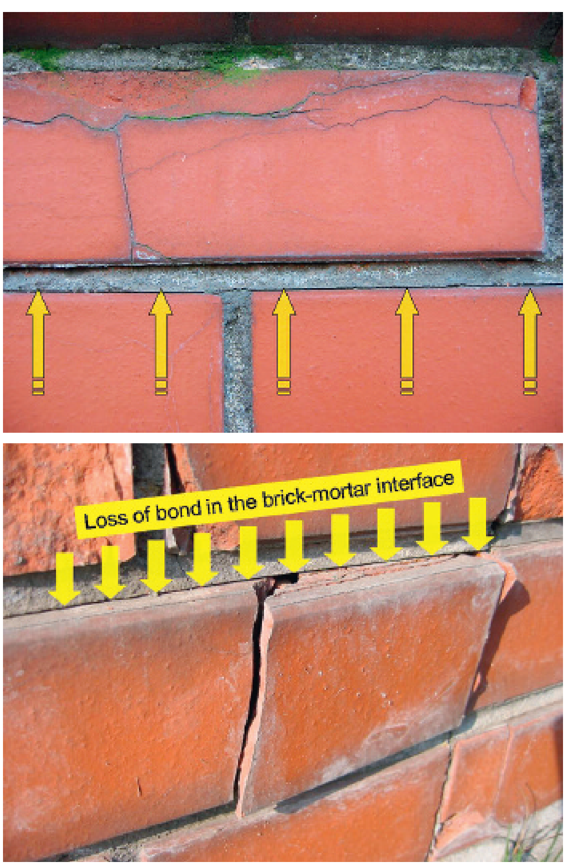

Figure 1.
Use of strong but poorly adhesive cement mortars with additives or plasticizer may cause serious damage to the masonry

2.2. Mortar as a pad

It is extremely important to alleviate in walls' stresses concentrations, especially in case of masonry structures built of masonry units characterised by low compressive strength and/or units with some (even small) surface irregularity. The state of stress in masonry is a result of the combination of many different factors, such as: loads pattern, thermal influences and moisture conditions. Generally, masonry should be treated as composite material, where in a flexible matrix (mortar) rigid elements are immersed (masonry units), and all wall components must remain in optimal relationship with each other in terms of appropriately selected strengths, modulus of elasticity, and permeability. It should be also borne in mind that some masonry units do not have perfectly even surfaces – in particular lower quality units. Therefore, local stress concentration caused by such imperfections should be levelled by deformations in elastic mortar layer.

2.3. Mortar as a barrier and drain

Wall protection against water penetration is equally important as the two other functions of mortar described hereinabove. The largest threat to masonry structures is water and moisture. Damp walls have a tendency to swell and degrade fast. They are easily affected by biological corrosion, which is shown below in Fig. 2. Water is also an agent responsible for the emergence of multicoloured patches of salt efflorescence, which in particular cases may lead to damage of masonry units, mortars, or plaster. Such damage commonly occurred, practically in each country (see Freeman *et al*. [1], Parkinson *et al*. [2] or Schubert [3]).

From building physics point of view, mortar joint should regulate moisture in a wall by driving it out. The level of moisture in walls is never equal to zero. One of the sources of moisture may be precipitation water, which enters masonry structure through damaged roof, faulty gutters, eaves or outer sills. Groundwater should not be forgotten either as it will penetrate masonry structure if foundations insulation was executed incorrectly or has been damaged. Moisture should escape from walls outside the building through mortar joints and not through masonry units. The mortar used in a wall should have higher permeability than the surrounding masonry units. If that rule is not observed, bricks become eroded and the mortar itself remains undamaged. This is particularly important when using mortars to repair historic walls. Inappropriately selected mortars may cause even greater damage – as is shown in Fig. 3. Such situation is not acceptable from both engineering and economical point of view.

Figure 2.
View of the typical damage: compact, tight and rigid mortars quickly destroy masonry

Figure 3.
Medieval castle in Olsztyn (Poland). Damaged wall as a result of using wrong mortar for the given type of brick

3. MORTAR SELECTIONS

3.1. Universal mortar?

Taking into account the fact that individual types of masonry units (e.g. ceramic bricks and hollow blocks, aerated autoclaved concrete (AAC) blocks, calcium-silica bricks and blocks) are significantly different in terms of their physical parameters (see Table 2 and Table 3), thus mortars should also be different and selected according to the properties of joined bricks. Therefore, universal mortar does not exist.

For every type of masonry units, mortar having carefully selected properties should be used. When selecting mortar components it should be taken into account that mortar has also other functions apart from binding masonry units together into a stable masonry structure. Absorbability of the background (masonry units) is particularly important as it determines proper behaviour of mortar, which is shown in Table 4 below.

Due to the reasons listed above, mortar selection according to the nature of works and the type of masonry units used has far-reaching consequences. When selecting mortar, all aspects related to the building being designed should be taken into account. When actually constructing, it becomes a sort of compromise between the required mechanical and physical properties and economy.

3.2. Strength or adhesion?

In Europe, the basis for selection of mortars is their durability, which was reflected in Eurocode 6 – Part 1.1 [6] and Part 2 [7]. According to American standard ASTM C270-08a "*Standard Specification for Unit Masonry*" [9] the most important hardened mortar parameter is its adhesion to the background. What is more important then: compressive strength or adhesion? Nowadays very often one can see walls, which are a few years old and are seriously damaged as a result of mortar losing its adhesion to the brick. Improving of the cement mortar workability by adding air-entraining agents, so-called plasticizers, causes this situation. Thus, using durable frost-resistant mortar, which at the same time does not adhere to the background, does not ensure durability of a

Table 2.
Selected physical properties of masonry units and mortars

Material	ρ [kg/m³]	λ [W/m×K]	S_{24} [W/m²×K]	μ	f_b [N/mm²]
Calcium-silica bricks	1000-2200	1.10	11.53	20	7.5-20.0
Clay bricks	1800	0.77	10.26	15	5.0-20.0
AAC blocks	300-1000	0.20	2.34	10	2.0 -7.5
Lime mortar	1700	0.80	9.09	7	0.3-4
Cement-lime mortar	1850	0.90	10.05	19	1-20
Cement mortar	2000	1.20	13.09	25	1-30

ρ – dry density;
λ – coefficient of heat transmission (in medium wet conditions);
S_{24} – coefficient of heat assimilation (gives the material ability to assimilation or giving up the heat in accordance to surface temperature variation) in 24 hours cycle;
μ – the diffusion resistance coefficient of material;
f_b – compressive strength.

Table 3.
Range of long term moisture expansion or shrinkage and coefficient of thermal expansion for different masonry units (according to Polish Standard PN-B-03002:2007)

Type of masonry unit	$\varepsilon_{s,\infty}$		α_T	
	Recommended	Range of values	Recommended	Range of values
	mm/m		10^{-6}/K	
Clay	- 0.2	-0.2 ÷ +0.4	6	5 ÷ 7
Calcium Silicate	- 0.4	-0.1 ÷ -0.4	9	7 ÷ 9
Dense aggregate concrete	- 0.6	-0.2 ÷ -0.6	10	8 ÷ 12
Lightweight aggregate concrete	- 1.0	-0.1 ÷ -1.0	10	8 ÷ 12
Autoclaved aerated concrete	- 0.4	-0.2 ÷ -0.4	8	7 ÷ 9

Table 4.
Mortar behaviour in accordance with background absorption

Low absorbable background – mortar with high retention of water	High absorbable background – mortar with low retention of water
1. Mixture is too loose. 2. Structure is not homogenous, separation of components occurs. 3. High shrinkage occurs. 4. Compressive strength is reduced. 5. Mortar cracks. 6. Mortar becomes poorly resistant to water	1. Mortar dries quickly, in extreme cases it "burns". 2. Mortar maintains working properties for a shorter period of time. 3. Consistency becomes too thick and thus: – workability of mortar is diminished, – adhesion of mortar to the base is reduced, in particular in case of thin bed mortars.

masonry structure (see Fig. 1). Therefore, when selecting mortar, particular attention should be paid to its adhesiveness. Mortar adhesiveness is one of the most difficult mortar parameters to measure. Assessment of adhesion of mortar to brick involves three aspects: range, durability, and strength. Range – the larger the masonry unit-mortar contact area, the better. Durability – how long the optimal bond between mortar and brick will last. Strength – nowadays it is estimated on the basis of characteristic shear strength of the mortar joint. How the mortar binds with the brick depends on many factors. They can be classified into three areas. These are factors related to the mortar itself, the type of background, and the brickwork quality.

3.3. Mortar or concrete?

It is wrongly believed that because concrete and mortar have similar components: cement – aggregate (sand) – water, the same methods are used when developing and producing these two materials. Mortars differ from concrete in terms of working consistency, methods of laying, and curing. Concrete is an independent structural material. The reverse is true in case of mortars. Mortar should serve protective function with respect to masonry units the wall is constructed of. Concrete is laid in timber or steel formworks, which maximally reduce water escape from the fresh concrete into the ground. Mortar is laid between masonry units, being sometimes highly absorbable, which causes more or less rapid escape of water from mortar into the background. In extreme cases, it may turn out that there is not enough water in the mortar for proper binding to occur, especially in case of masonry structures built of AAC bocks and cement or cement-lime general purpose mortar and common joints with thickness between 10 mm and 15 mm. Rapid loss of water by the mortar results in decreased workability. This causes worsening of the quality of a mortar joint (brick-mortar).

The basic parameter characterizing concrete is compressive strength. In case of mortars, it is only one of many parameters, and not at all the most important. Using air-entraining additives and admixtures in case of concrete is highly recommended (frost-resistance is achieved); however, in case of mortars excess of air-entraining admixture may contribute to loss of the mortar-brick adhesion, which consequently leads to masonry erosion.

3.4. Cement or Lime?

Both lime and cement are made as a result of limestone burning in special furnaces. If limestone has high content and purity of calcium carbonate, the outcome of the burning process is lime. In order to obtain Portland clinker, which after grinding becomes cement, apart from calcium carbonate the limestone has to contain, apart from other things, silica.

Lime is an aerial binding material. In the process of lime mortar binding an important role is played by carbon dioxide presented in the atmosphere. By combining with calcium hydroxide present in lime mortar, it forms calcium carbonate. Because water is not required for lime bonding, it is added to lime mortar only to improve its workability. After it has been embedded, water contained in the mortar gradually evaporates. As a result the porous structure of lime mortar is formed, owing to which it is more permeable to water and gases than cement mortar. Lime mortar also differs from cement mortar in the sense that it is more elastic (compare values of modulus of elasticity of mortars specified in Table 5), and usually has better than cement mortars, adhesion to different types of masonry units – see Zhou *et al*. [11], which has a positive influence on masonry condition.

From Hilsdorf's theory of behaviour of masonry walls under axially compression point of view it is advisable to use mortars and masonry units with similar values of modulus of elasticity, because the failure is strongly dependent on differences between deformability of both of these components. Significant differences of elasticity modulus caused decrease of the main (from design point of view) mechanical parameter of masonry: compressive strength. But for the sake of ability to local concentrated stresses alleviation and adhesion improvement, masonry mortars should be characterised by lower values of modulus of elasticity. This is the main contradiction in process of mortar selection during designing process.

Table 5.
Comparison of modulus of elasticity of mortars with lime contents

Lime content in mortar (sum of binders to sand as 1:3)	Modulus of elasticity E_m [N/mm^2]
0%	37.5
20%	35.0
40%	23.0
60%	17.5
80%	11.0
100%	8.0

Cement is a hydraulic binding material, which means that it needs water in order to bind. The products of cement hydration are responsible for forming a durable, rigid and tight mortar structure. Cement mortar is poorly permeable to water and gases. The more cement in the mortar, the faster mortar binding is. Cement mortars are characterized by high thermal expansion, comparable to concrete, which shall be considered a serious flaw. Moreover, shortcomings of cement mortars include high brittleness, i.e. cracking, practically without prior deformation. As a result, cement mortars poorly compensate for stresses occurring in the wall. Figure 3 above compares the main features of cement and lime mortars.

The other very important problem is the resistance of masonry constructions (especially walls) against cracks (see Freeman *et al*. [1] or Schubert [3])). This property is strongly connected with lime content in masonry mortar. In Fig.4 the scheme of the characteristic properties of mortar depending on the type of binding material is presented. The level of the cement or lime content in mortar strongly depends on the behaviour and mechanical properties of the mortar and finished masonry construction, as well. During designing process the suitable balance between these two components should be taken into account.

The influence of mortar type (cement or cement-lime) on in-plane deformations of masonry walls based on the test data is presented in Table 6, where the values of in-plane deformability parameters of a vertically sheared (e.g. as a result on building of the irregular settlement) masonry wallettes built using cement mortar (1:3) and cement-lime mortar (1:1:6), determined by Kubica [12] are shown.

Interesting is much higher values of the shear strains (non-dilatational strain angles) of specimens built using cement-lime mortar, especially in the phase directly before failure. That means that masonry made with cement-lime mortar is more resistant to cracks. Moreover, an advantage of mortars with high lime content is also the fact that they are characterized by thermal expansion coefficient comparable to the analogous coefficient of calcium-silica bricks and blocks, ceramic masonry units or autoclaved aerated concrete blocks.

Comparison of the properties of these two types of mortar clearly shows that cement mortar is in opposition to lime mortar. Therefore, the question which binder to use: cement or lime shall be answered in the following way: it is best to use cement-lime or lime-cement (the two mortars are not equivalent). By mixing different proportions of cement with lime and sand, one obtains a whole range of mortars whose parameters differ significantly (see Fig. 4). If the share of cement is increased, the mortar becomes more durable, less absorbable, and faster binding. At the same time, cement stiffens mortar structure, due to which it has lower deformation capacity and is more susceptible to cracking. If, on the other hand, the amount of lime is increased, the mortar becomes more elastic, permeable, and binding time is increased. Also, thermal expansion of the mortar is reduced. That variable nature of cement-lime mortars allows us to precisely select the appropriate

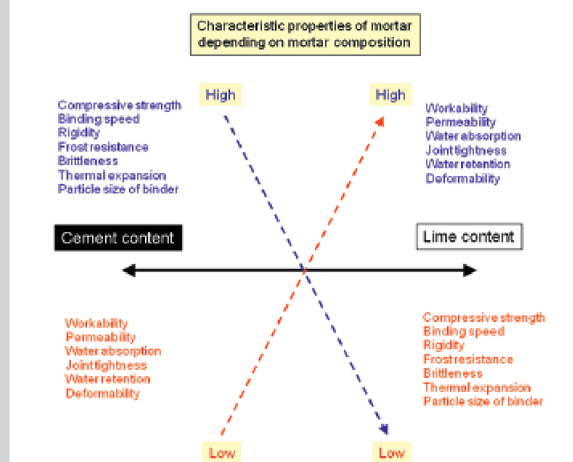

Figure 4.
Scheme of main characteristic properties of cement and lime mortar

Table 6.
Comparison of shear strains for vertically sheared masonry walls made of cement and cement-lime mortar – according to Kubica [12]

Level of precompression (vertical compressive stresses)	In-plane deformations (shear strains – non-dilatational strain angles)	
σ_c [N/mm^2]	at first crack appearance Θ_{cr} [mm/m]	at failure Θ_u [mm/m]
Clay brick masonry made with cement mortar (1 : 3; cement : sand proportion by volume)		
0	0.33	0.37
0.2	0.51	1.21
0.4	0.63	1.18
0.6	0.76	1.40
Clay brick masonry made with cement-lime mortar (1 : 1 : 6; cement : lime : sand – proportion by volume)		
0	0.47	0.52
0.2	0.71	1.33
0.4	1.05	3.16
0.6	3.42	9.18

mortar to majority of currently produced and used masonry units while taking into account the location and function of the wall. Only in a few cases can pure cement mortars be used, for example when laying very strong, low-absorbable stones (e.g. granite). On the other hand, using pure lime mortars should be limited to special cases in which very soft and porous stones are laid or if the environment where the wall is to be located is highly loaded with salts.

3.5 Thin joints mortars

Thin bed mortars are a special case of masonry mortars. They are used for aerated autoclaved concrete (AAC) blocks and also for calcium-silica bricks and blocks and for a few ceramic hollow blocks. After over ten years of using that type of mortars certain conclusions can be made with respect to their usability in the building industry. On the one hand, reducing the thickness of a joint to 1-3 mm entails elimination of cold bridges, which are created when using mortar joints with thickness between 10 mm to 15 mm. On the other hand, however, the thin joint is completely devoid of many positive properties characteristic of thick joints. Namely, in case of thin joints the mortar does not fulfil the function of a "pad" and "drain". If we add the fact that thin joints are produced on the basis of cement binders, and thus are characterized by high strength (usually of over 10 N/mm^2), then maladjustment (lack of pad, too high strength) results in easy wall cracking, especially in the area below windows and places where there are joined materials characterised by different physical properties – see Fig. 5.

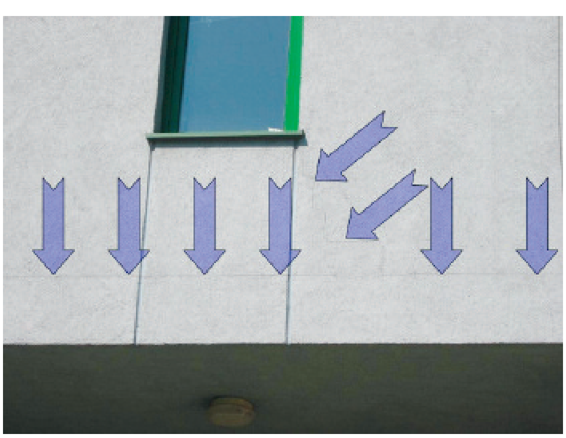

Figure 5.
Cracked building façade. Thin bed mortar and thin external plastering

4. SUMMARY

Summarising, it is a paradox that due to gradual tightening mortar becomes stronger, frost-resistant and waterproof, but at the same time the durability of masonry structure decreases. In case of masonry structures it is not about the mortar being like concrete – compact, tight, rigid, and non-permeable to water. These are exactly the properties, which are less useful, and in many cases harmful, which can be witnessed by looking at buildings that after a few years of being in use require renovation work. And this is not just a result of bad workmanship and haste, but to a large extent of the quality and properties of materials, as well as design solutions and details.

European standard EN 1996-2:2006 [7] recommends that producers and contractors should profit from local and national experience, as well as traditions. And the European tradition is to build using lime and cement-lime mortars.

On the basis of the solutions and analyses presented above, the following general conclusions can be formulated:

1. The basic criterion for mortar selection should be its adhesiveness to the given type of masonry units and elastic properties (modulus of elasticity). The closer the values of modulus of elasticity of masonry units and mortar, the better their cooperation will be, and consequently the masonry mechanical parameters.
2. Lime is not only an independent binding material, but it is also an essential component of mortars, which in a favourable way modifies their properties. It gives them elasticity, vapour permeability, increases the mortar's ability to absorb moisture from the wall, maximally reduces the occurrence of salt efflorescence, and protects walls and plasters to biological corrosion.
3. Mortars with higher content of lime show optimal adhesion to various types of backgrounds (masonry units) and create highly masonry joints density. They also allow one to increase the distance between vertical expansion joints.
4. In general building engineering, it seems that simple cement-lime combinations are best. Complicating the composition of mortar by excessive use of admixtures and additives may result in a positive modification of the mortar itself (e.g. it becomes tighter), however, at the same time, the modification may turn out to be destructive to the masonry wall as a whole.

5. It is necessary from designer's point of view to elaborate the general guidelines and requirements concerning correct mortar selection state the recommended combinations of masonry units and types of mortars with short description of behaviour and properties of masonry made of these materials. Such document could be very helpful and should eliminate majority of mistakes made in this field.

REFERENCES

[1] *Freeman, T. J., Littlejon, G.S. Driscoll R.M.C.*; Has your house got cracks? A guide to subsidence and heave of buildings on clay. Thomas Telford Publishing, London, 1994

[2] *Parkinson, G., Shaw, G., Beck, J.K. Knowles, D.*; Appraisal & repair of masonry, Thomas Telford Publishing. London, 1996

[3] *Schubert P.*; Mauerwerk. Risse vermeiden und Instandsetzung, (Masonry walls. Preventing and repairing of cracks). Fraunhofer IRB Verlag, Stuttgart, 2004

[4] *Mitchell Ch. F.*; Brickwork And Masonry – A Practical Text Book For Students, And Those Engaged In The Design And Execution Of Structures In Brick And Stone. Regent Street Polytechnic, London, W., 1904. An imprint, 23 October 2009, Breinigsville, PA USA

[5] *Enclosure Masonry Wall Systems Worldwide*. CIB Publication. Editor; S. Pompeu Santos. BALKEMA, Taylor & Francis Group plc, London, Great Britain. 2007

[6] EN 1996-1-1;2005 Design of masonry structures – Part 1-1; General rules for reinforced and unreinforced masonry structures. CEN, 2005

[7] EN 1996-2;2006 Design of masonry structures – Part 2; Design considerations, selection of materials and execution of masonry. CEN, 2006

[8] PN-B-03002;2007, Masonry structures. Design and calculations. Polski Komitet Normalizacyjny, Warsaw, 2007

[9] ASTM C270-08a Standard Specification for Mortar for Unit Masonry. ASTM International, West Conshohocken, PA, USA

[10] *Edgell, G. and Haseltine, B. A.*; Building mortar for low rise housing. Recommendations, problems and solutions. British Masonry Society Publishing, London, 2006

[11] *Zhou Z., Walker P., D'Ayala D.*; Influence of Materials on Mortar and Bond Strength of Hydraulic Lime Mortared Brickwork, Proceedings of the 8th International Seminar on Structural Masonry, Istanbul, 2008, p.89-95

[12] *Kubica, J.*; Unreinforced masonry walls subjected to non-dilatational strains produced by irregular vertical ground displacements (Niezbrojone ściany murowe poddane odkształceniom postaciowym wywołanym nierównomiernymi pionowymi przemieszczeniami podłoża). Wydawnictwo Politechniki Śląskiej, Gliwice, 2003 (in Polish)