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Bibliography lime in mortars

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Content

1. Introduction

On behalf of the **European Lime Association** (EuLA) the Danish Technological Institute (DTI) has made a bibliographic study. The aim of this study is to provide an exhaustive overview of the internationally available scientific publications relating to the functionality which are in general devoted to lime containing mortars.

DTI has studied more than 200 articles, of which 4/5 of them have been delivered by EuLA, gathered amongst its members. The remaining articles have been selected by DTI.

EuLA also provided DTI with a list of functionalities to be assessed.

The background for the initiative is the competitive situation for the use of air lime in mortars. As the initiative is market related and mainly involving the masons and the building designer in the choice of mortars to be used, the functionalities have been grouped according to the interest of these two parties.

The lime industry may also have an interest of its own. For that reason functionalities in relation to that are also grouped.

Some of the articles are dealing with a combination of functionalities. These articles are grouped under the headline “Multi functionalities” but are also placed together with articles covering one specific functionality. The content of the articles is taken into account in the summary ending each head clause.

A few articles are dealing with other aspects of the function of lime than the functionalities listed. These articles are put together under the heading “Miscellaneous”.

Some articles are also considered “Out of purpose” and are grouped under that headline.

In Annex 1 a list of the functionalities and a summary for each is given.

Throughout this report, the articles are referred to by a reference number that corresponds to a number in Annex 2 where the full reference and information is listed.

2. Functionalities in relation to the interest of the Masons

2.1 General

The interests of the masons are that the mortar is:

- easy to handle,
- easy to mix,
- easy to use,
- easy to control and
- cheap.

The tendency is that the mason would like to have mortars delivered to the building site premixed or ready to use. The mixing of mortars on site requires less and less man power and less and less mixing time. It is only in relation to renovation works that individual mixes make it more appropriate to operate with flexible systems. The functionalities dealt with in the articles are the functionalities in relation to the interest "easy to use". In relation to the other interests no articles have been available.

2.2 Easy to use

2.2.1 Workability

Description
Workability is the sum of the application properties of a mortar which give its suitability. The special physical and chemical properties of lime make it the best plasticizer for mortar. A good mortar plasticizer requires the following four significant features:

1. it is made up of very small crystals,
2. the crystals should have the correct shape (plate-like),
3. there should be a sufficient film of liquid surrounding the crystal, and
4. the lubricating liquid should have a low surface tension (ref. no. 161).

Conclusions from articles
The general conclusion is that lime-based mortars have superior workability compared with cement mortars. The improved workability ensures a higher quality of the finished masonry, resulting in better bonding between mortar and bricks and thus better resistance against water penetration.
Workability is affected positively by ageing of the lime putty.
Recent research has focused on developing new analytic methods for characterizing workability instead of the traditional method where workability is appraised by measuring the amount by which a truncated cone shape of the examined mortar was lowered during a succession of 90 strokes on the flow-table device. With the rotoviscosimetric technique, the trend of the shear stress of flow versus time gives effective indications on the changes in internal friction of the dispersion of high content calcium hydroxide in water, and offers insight into the micro structural characteristics of the solid phase.

2.2.2 Water retention

Description
Water retention is the ability of a fresh hydraulic mortar to retain its mixing water when exposed to substrate suction.

Conclusions from articles
The results demonstrate the strong water retaining characteristics of lime, which enhances the workability, extends board life and ensures that adequate water is available to hydrate cementitious components of the mortar. Investigations also indicate that the use of aged lime putty is ideal because the material has higher plasticity and water retention capacity which results in mortars of higher strength that carbonate faster.

2.2.3 Air content

Description
The quantity of air included in a mortar.

Conclusions from articles
The main conclusions from investigation of the effect of air content on cement-lime mortar properties are that increasing air content has a minor effect on shrinkage and absorption properties, that it reduces water requirements and compressive strength and improves durability. Air content is substituting the use of lime in relation to establishing good workability and water retentivity. It is also important to have in mind that the investigation in relation to durability is done on mortar prisms and not on mortars taken from masonry joints.

2.3 Summary

For the mason the workability is the most important functionality of a mortar. Many articles demonstrate that the use of lime putty in mortars leads to a good workability of the mortar. The same is the case if the mixing time is extended (15-20 minutes) when using dry hydrated lime in the mortar. As the definition states, the workability is the sum of application properties. Different test methods have been used to determine the workability with different results. No articles have related the test method and test result to experience from application in practice e.g. the amount of energy needed for placing the units into the right position in the mortar, the time before mixing water is released from the mortar in the bowl (the need for remixing the mortar in the bowl) and how clean the mason can lay the masonry units. In the European masonry mortar standard only one method is specified for testing the workability of mortars (flow table method). A good workability of mortars is normally established by using wetted hydrated lime (lime putty or long mixing time for dry hydrated lime) and/or admixtures. Some mixing time is needed before dry hydrated lime is wetted in such a way that it can establish a good workability. The sand grading and the amount of filler also play a role as well as the use of binders with a high specific surface. With well graduated sand the amount of voids among the sand grains is smaller compared to sand where a great part of the grains have equal size.

The water retentivity is also an important functionality in relation to laying the masonry units. Especially when using high suction units, it is necessary that the mortar has a good water retentivity because otherwise the time, where correction of the unit is possible, is too short. When the correction is done anyway the adhesion between mortar and brick will be broken leading to masonry with a high risk of water penetration. A good water retentivity of mortars is established in the same way as workability.

Admixtures improving the workability are air-entraining/plasticizing admixtures. At the same time these admixtures allow water reduction, by incorporating during mixing a controlled quality of small, uniformly distributed air bubbles which remain after hardening. The air entraining/plasticizing admixtures improve thereby the durability of mortars in cold wet climates. The investigation on durability is mainly done with mortar cubes cast in steel moulds and not on mortars in the joints, which may lead to different results. The important case is the durability of the mortar in the joint. The same is the case for air content. The test result for determination of air content in fresh mortar and in the hardened mortar in the joint is not comparable. The water content in the fresh mortar and the suction of the bricks has an influence on the air content in the hardened mortar in the joint. Different admixtures have different grain sizes. The activation is depending upon the grain size. Fine grains are normally easier to activate than big grains. For that reason the activation of a specific admixture is depending on mixing time and mixing procedure. If the same mortar containing air-entraining admixtures is mixed in a quick mixer with a short mixing time and a pan mixer using ordinary mixing time of 5-15 minutes, then the air content of the 2 mixes will be quite different.

“Open time” or setting time is a functionality for fresh mortar and is not of real interest for pure lime mortars as the hardening process first is starting when part of the water is sucked away from the mortar when placed between the bricks. This functionality is dependent on hydraulic properties of the used binders.

The water demand can be of interest where the reduction of water leads to higher compressive strength of the mortar and this is taken into account in the design. Normally the water demand is fixed by the masons.

The functionalities: volume yield, sand carrying capacity, reduce vast and fresh mortar density are not investigated properly or not at all in the articles.

As mentioned the articles have not directly been dealing with aspects in relation to handling and mixing of mortars on site.

3. Functionalities in relation to the interest of the Designer

3.1 General

The designer has to take care of the interest of the end user as well as his own interests. It means that the interests of the designer are:

- the mechanical behaviour of the masonry,
- the physical behaviour of the masonry,
- durability aspects of the masonry and
- aesthetic aspects.

The functionalities covered in the articles are grouped in relation to the different interests.

3.2 Mechanical behaviour of the masonry

3.2.1 Compressive and flexural strength of the mortar

Description
The compressive strength is the maximum value of mortar failure determined by exerting a force in compression. The flexural strength is the failure stress of a mortar determined by exerting a force in flexure on three points.

Conclusions from articles
The main conclusion is that the inferior compressive strength of lime-based mortars compared with cement mortars is often more than compensated by the positive properties of lime-based mortars. These include better bonding between mortar and bricks and a more permeable pore structure. The strength development of lime-based mortars is dependent on curing time, binder-aggregate ratio and porosity.
With respect to curing time it is demonstrated that a vast increment of compressive and flexural strengths is seen for curing times between 28 and 365 days. This indicates that the standard test methods for cement of compressive strength after 28 days are not suitable for evaluating the mechanical properties of lime mortars.
With respect to binder-aggregate ratio, increasing binder content improves strength within a limit. For binder amounts beyond 2:1 the B/Ag ratio shows a strong strength reduction. The highest strength is attained with low binder/aggregate ratio (1:1.5, 1:2.5, 1:3) and sand aggregate in the fraction 0-4 mm. For coarser aggregate fractions, strong compaction of the mortars is necessary to reduce voids and increase the bond of lime paste with pebbles.
With respect to porosity, the increase due to the binder makes carbonation easier so mortar strength improves. However, in case of binder excess, the increase in voids leads to a strength reduction.

3.2.2 Compressive strength and flexural bond strength of the masonry

Description

The compressive strength of masonry is the strength in compression without the effect of loading restraint, slenderness or eccentricity of loading. The flexural bond strength of masonry is derived from the strength of small specimens tested to destruction under four point loading.

Conclusions from articles

High-lime mortars have excellent adhesion and bonding properties due to their high degree of workability, stickiness and water retention. Lime-based mortars are able to create continuous bonds with brick surfaces and completely fill spaces in brick surfaces. Optical inspections reveal that the adhesion between lime and brick is not always due to purely physical phenomena but also chemical reactions. Most important, the use of high strength cement mortars does not improve the masonry strength because of lack of bond strength and shrinkage of mortars when high absorption bricks are used.

3.2.3 Flexibility of the masonry

Description

Flexibility, defined as the elastic modulus, is the ability of mortars to accommodate stresses caused by building movements without excessive cracking (192).

Conclusions from articles

The main conclusion is that unlike cement mortars, lime-rich mortars are able to absorb a high degree of deformation before breakage (high flexibility). Deformable masonry structures have shown to be more durable than brittle ones when subjected to unforeseen imposed deformation due to differential settlements or earthquakes.

3.2.4 Carbonation

Description

Lime-based mortars exposed to CO_2 from the air results in carbonation. Carbonation involves five stages:

1. diffusion of gaseous CO_2 through the pores of the mortar,
2. dissolution of the CO_2 in the pore water,
3. dissolution of $Ca(OH)_2$ in the pore water,
4. chemical equilibrium of dissolved CO_2 in the pore water,
5. precipitation of $CaCO_3$. The amount of water and pore structure of the mortar are thus primary parameters for the carbonation process.

Conclusions from articles

The carbonation process has been investigated thoroughly with respect to different parameters. The most important parameters are pore structure, CO_2 concentration, water content and ageing.

The main conclusions for pore structure and porosity are that they change due to carbonation: Porosity decreases around 10% and pore size distribution shifts towards smaller pores. The degree of carbonation is much more pronounced with increasing lime content and porosity of the mortars, and the strength of the binder is controlled by the crystalline state and morphology of the carbonate rather than the conversion degree of $Ca(OH)_2$.
With respect to CO_2 concentration, the general interpretation is that the carbonation process is faster and more complete with high CO_2 concentration, and exposure of lime binders in high CO_2 concentrations leads to a modification in the habit, morphology and size of the calcite crystals. There are, however, different opinions on this matter. One investigation finds that reaction speed is not dependent upon CO_2 concentration but on a specific surface of the lime (ref. no. 44). Another investigation demonstrates that a correlation has been recorded between the uptake speed and the start of CO_2 concentration and a correlation has not been established between the maximum net uptake speed and the specific surface area of the lime (ref. no. 173).
The role of water is fundamental for the carbonation process as it provides the medium for the reactions to take place, but on the other hand hinders the gas diffusion process as diffusion in air is 0,139 cm^2/s and in water 10^4-10^5. The optimum water content for carbonation is the water content that corresponds to maximum absorption on the surface of the pores before capillary condensation. CO_2 diffusion still takes place at high water contents and is only prevented above the capillary water capacity. If the pore configuration permits the lime mortar to carbonate even at very humid environments, it equally assures the water vapour transfer inside masonry walls, which is not the case for cement mortars on masonry walls.
With respect to ageing, the use of aged lime putty is ideal, because the material, with higher plasticity and water retention capacity, results in mortars of higher strength that carbonate faster. Furthermore, it is shown that long-term aged putty mortars have the fastest and highest degree of carbonation.

3.3 Physical behaviour of the masonry

3.3.1 Vapour permeability

Description
The water vapour permeability indicates the potential for moisture in the masonry to evaporate through the mortar.

Conclusions from articles
The main conclusion is that lime mortars have higher water absorption coefficients, higher porosity and are more permeable than cement mortars.

3.3.2 Porosity and capillarity

Description

Porosity is the ratio between the volume of pores within the mortar and the total volume. Capillary porosity is defined as residual spaces occupied by original kneading water. When a capillary is in contact with a liquid, it creates a pressure difference reversely proportional to its radius, forcing the liquid to go inside the capillary. The capillary porosity as well as the pore structure of the binding materials plays an important role in moisture transport, which is related with durability, degradation and service life of the building materials (ref. no. 15).

Conclusions from articles

The most important parameters controlling porosity are the water-lime ratio, binder-aggregate ratio, and cement content. The binder-aggregate ratio and granulometry have a strong influence on the pore structure of hydrated lime mortars, and with increasing water-lime ratio the porosity and capillary coefficient increases (more uptake of water). When the cement content increases, the complexity of the microstructure and surface of the blended pastes increases whereas porosity, pore size and water vapour diffusivity are progressively reduced. Capillary porosity is controlled as porosity. The binder-aggregate ratio and granulometry have a strong influence on the pore structure of hydrated lime mortars, and with increasing water-lime ratio the porosity and capillary coefficient increases (more uptake of water).

3.4 Durability aspects of the masonry

3.4.1 Freeze-thaw resistance

Description

The freeze/thaw resistance of mortars is the resistance to winter climatic conditions which comprises its effective life.

Conclusions from articles

Only a few articles deal with freeze-thaw resistance of mortars and these ones almost entirely with hydraulic lime mortars. Only one article concludes that lime-based mortars are acceptably resistant to freeze-thaw damage because they are permeable (ref. 2).

3.4.2 Water penetration

Description

Water penetration is the resistance against water leakage through a masonry wall. Water penetration is determined with the ASTM method E 514, where water is sprayed against the masonry simulating near-hurricane wind and rainfall conditions.

Conclusions from articles

The main conclusion is that masonry walls constructed with lime-based mortars are more resistant to water leakage than those constructed with mortars containing no lime. This is mainly due to the better workability of lime-based mortars that ensures better bonding between mortar and bricks.

3.4.3 SO_2 (sulphate attack)

Description

Mortars exposed to SO_2 results in sulphate attacks where sulphate phases are formed causing expansion with cracks and fractures in the hardened mortar. In lime-based mortars gypsum is formed, and in hydraulic lime-based mortars gypsum, ettringite, syngenite. These compounds affect durability and microstructure.

Conclusions from articles

Lime-based and hydraulic mortars exposed to SO_2 results in sulphate attack by formation of gypsum as the primary damage product, through the reaction of SO_2 with free hydrated lime. Lime-based mortars are more resistant to acid rain attack due to the absence of free hydrated lime compared with cement mortars. Furthermore, cement mortars have higher tendency to form secondary damage products such as thaumasite ($CaSiO_3$, $CaCO_3$, $CaSO_4$, $15H_2O$) and ettringite ($Ca_3Al_2O_6$, $3CaSO_4$, $32H_2O$) because they are formed with reaction between gypsum and calcium-aluminium silicates from hydraulic mortars.

3.5 Aesthetic aspects of the masonry

3.5.1 Efflorescence

Description

Efflorescence of masonry, popularly called “building bloom”, is a white coating or scum that accumulates on the exterior walls of buildings, and is more common and visually evident on red brick buildings. The permanent form of efflorescence is composed primarily of soluble alkali salts that exude from the masonry interior as a solution and, upon drying, recrystallizes as a supersaturated solution on the masonry facade.

Conclusions from articles

The word efflorescence is also in the articles covering discoloration and lime staining. Efflorescence is caused by multiple factors. Efflorescence increases with increasing proportions of Portland cement, alkali salts, soft-burned highly absorptive brick, and high moisture content in masonry walls due to faulty design and construction practices. Thus, pure lime mortar generally has very low efflorescence potential compared to cement, mainly due to its extremely low content of soluble salts and sulphur.

3.6 Summary

The experience from some of the articles and from daily life shows that designers have the opinion that strong masonry is masonry with a high quality, and the compressive strength of the mortar is the only property of interest. For that reason there is a great focus upon mortars with a high compressive strength. Many articles deal with this property. The compressive strength of a mortar is tested by a standardized method developed for testing the quality of cement, which means that only the effect of hydraulic properties is tested. In the test method no account is taken of any influence of the suction behaviour of the masonry units. The W/C ratio used is determined by the mortar preparation. The W/C ratio plays a great role in the test value. It is possible to have a factor 3 between the lowest and the highest value, where the lowest value represents a high W/C ratio and the highest represents a low W/C ratio. The compressive strength of a cement-lime mortar is dependent upon the type of hydrated lime used. For the same composition the use of dry hydrated lime leads to a 2-3 times higher compressive strength compared to the use of lime putty. For a pure lime mortar the same difference is not seen. Some articles state that the use of an old lime putty leads to a higher compressive strength compared to the use of newly slaked limes. The quoted difference in the compressive strength is not observed in the masonry compressive strength. Lime mortars obtain their compressive strength slowly compared to cement based mortars but in the test method the same curing time has to be used for all mortars (28 days).

The compressive strength of the mortar is used together with the compressive strength of masonry units in equations to estimate the compressive strength of the masonry made of these products. Differences in the sucking behaviour between different types of units (clay-, calcium silicate-, concrete- and AAC-units) are taken into account in the equations by a factor.

The European masonry mortar standard gives the possibility for the manufacturer to declare the bond strength. That opportunity is not used very much. Designers are using national established data. These data does not always take into account the use of mortars with admixtures. Several articles state that the use of admixtures in mortars has a great implication upon the bond and the higher air content, the lower bond. The increase in thermal insulation requirement will result in more and more slender walls. That leads to a situation where the cross section of shear walls will go down. The only way to compensate for that is to use mortars giving higher shear strength of the masonry. Slender walls are also acting in bending. For that reason the need for a good masonry flexural strength will increase. Both aspects are linked to the bond, where the use of lime normally is an advantage.

The articles generally indicate that the use of lime in mortars increase the flexibility of the masonry. The flexibility of masonry is not an aspect with a great focus. The values given in EC 6 do not reflect the advantage of using lime mortars in relation to the flexibility of masonry. Movements in masonry are very often handled by conservative rules-of-thumb valid for all types of masonry not taking the flexibility of the masonry into account.

With the great focus upon compressive strength of mortars it is natural that there is also a great focus upon carbonation. That focus is also in relation to porosity. Some articles have been dealing with ways to speed up the carbonation process.

It is important that the masonry is permeable in such a way that water within the masonry can easily evaporate and thereby keep the water content in the masonry low.

The porosity of lime based mortars is high and the vapour permeability good, which means that the physical behaviour of lime based mortar, masonry is good. A few articles indicate that this is the same for lime wash.

For the designer the durability aspect is of the same importance as the mechanical behaviour of masonry. Only a few articles deal with freeze-thaw resistance of mortars and one are concluding that the freeze-thaw resistance of lime based mortars seams to reach an acceptable level, but it shall not be recommended to use pure lime mortars in severe environment.

In relation to water penetration the main conclusion is that masonry walls constructed with lime-based mortars are more resistant to water leakage than those constructed with mortars not containing lime. This is mainly due to the better bond between mortar and bricks of lime-based mortars.

Lime-based mortars are more resistant to acid rain attack due to the absence of free hydrated lime compared with cement mortars.

Pure lime mortar generally has very low efflorescence potential compared to cement, mainly due to its extremely low content of soluble salts and sulphur.

5. Miscellaneous

Some of the articles have a function as a text book. In a good informative way the different types of lime are explained. The production and the use of lime and lime mortars are treated. It also covers natural hydraulic lime. A few articles deal with environmental aspects such as reaction between lime mortars and pollutants.

6. Conclusion

Lime and lime based mortars have much positive functionality.

For the mason the workability is the most important functionality of a mortar. Many articles demonstrate that the use of lime in mortars leads to good workability of the mortar. Good mortar workability can be established by using wetted hydrated lime (lime putty or dry hydrated lime using a long mixing time). A long mixing time is needed before dry hydrated lime is wetted in such a way that it can establish a good workability.

Air-entraining/plasticizing admixtures can also improve the workability and the durability of mortars in cold wet climates at the same time. The mixing time of the mortar can be rather short. The negative effect of the admixtures is the decrease in the bond compared to the bond of the same mortar without admixtures.

For the functionality water retentivity, a parallel situation appears to workability.

The challenge is to improve the workability function of dry hydrated lime in such a way that the lime can be used in a quick mixer to establish the needed workability. Another way is to develop a mixing system where a kind of lime slurry is used.

There is a great focus upon mortars with a high compressive strength. The reason is that designers are of the opinion that strong masonry is high quality masonry. The designer is not accustomed to take into account the flexibility of masonry, a property where the use of lime based mortars has an advantage. Movements in masonry are very often handled by conservative rules-of-thumb valid for all types of masonry not taking the flexibility of the masonry into account.

Compressive strength of a mortar is tested by a standardized method developed for testing the quality of cement, which means that only the effect of hydraulic properties is tested. It is a disadvantage for the use of lime in mortars to use that standardised test method.

Designers normally use nationally established data for masonry properties. These data do not always take into account the use of mortars with admixtures. Changes in the type of masonry constructions in the near future are calling for a greater focus upon the bond strength between mortar and bricks, where the use of lime is normally an advantage.

For the designer the durability aspect is of the same importance as the mechanical behaviour of masonry. Only a few articles deal with freeze-thaw resistance of mortars and these ones almost entirely with hydraulic lime mortars. Only one article concludes that lime-based mortars are acceptably resistant to freeze-thaw damage because they are permeable. It should nevertheless not be recommended to use pure lime mortars in severe environment. The frost-thaw resistance of masonry mortars in the joint is depending upon the mortar composition, the interaction between units and mortar and the tooling of the surface of the mortar joint. At the same time it has to be mentioned, that only limited research work has been done in relation to freeze-thaw resistance of hardened mortars in the joints. However a round robin test program has just been planned within CEN TC 125, Masonry Products, to deal with the freeze-thaw resistance of mortars, where the mortars are to be tested in a masonry panel together with clay bricks.

In relation to water penetration the main conclusion is that masonry walls constructed with lime-based mortars are more resistant to water leakage than those constructed with mortars not containing lime.

The challenge is to bring the advantages of the function of masonry in old buildings back on stage in a documented way. That function has lead to a very low maintenance cost for these buildings.

In relation to renovation the hydraulic properties of lime based mortars by using natural hydraulic lime as a binder or adding pozzolanic material to the mortar is of great interest. The background is that the strength developments of pure lime mortars in many cases are too slow and the compressive strength level is too low. On the other hand the experience has shown that the use of strong cement based mortars has resulted in damages; because historic buildings are very often built of soft materials. In relation to sustainability many good arguments seem to be available, when it will be a requirement to deal with environmental product declaration.

7. Proposals for further actions

It is in the mason's interest that a mortar is:
- easy to handle,
- easy to mix,
- easy to use,
- easy to control and
- cheap.

The functionalities dealt with in the articles are the functionalities in relation to the interest "easy to use". In relation to the other interests no articles have been available, but it is of the same or bigger importance that the mortar is easy to handle, easy to mix and easy to control.

The mason would like to have mortars delivered to the building site premixed or ready to use. The mixing of mortars on site should require less and less man power and less and less mixing time.

Cement based mortars are nowadays delivered on site premixed or ready to use in a silo connected to a quick mixer or in a container and are as such fulfilling the "easy to handle and easy to mix" interest. These mortars fulfil the "easy to use" interest of the mason by using admixtures, and the mortar producer is taking care of the control of the mortar.

Cement based mortars are as such fulfilling the interest of the masons. The challenge for the lime based mortars is to do the same.

For that reason the development of a logistic system for handling and mixing of lime based mortars is recommended. In that respect it is needed using a dry mortar concept to make it possible for dry air lime to be wetted very quickly when in contact with mixing water or to operate with a lime slurry, otherwise the air lime will not establish the desirable workability for the lime based mortar quick enough. To wet the dry air lime in a dry mortar during mixing to act as workability improving agent takes 10 – 15 minutes mixing time.

It is also recommended to optimize the workability in relation to the wish of the mason and not in relation to a test method. The existing test methods are functioning well when the need is for mortar to keep a constant quality from one mix to another, but they are not dealing with all the workability aspects for a mortar.

The interest of the designer is:
- the mechanical behaviour of the masonry,
- the physical behaviour of the masonry,
- durability aspects of the masonry and
- aesthetic aspects.

The mechanical behaviour of the masonry

Designers are of the opinion that strong masonry is high quality masonry, and the compressive strength of the mortar is the only property of interest. That opinion is not favourable for the use of lime based mortars. The test method for testing the compressive strength of mortars is not favourable either. It is recommended to try to change that opinion by demonstrating the advantage of flexible masonry in relation to stability. It can also be recommended to develop dry air lime with very effective pozzolanic material added and at the same time improve the ability of the air lime to establishing a good workability of the mortar mix of such a binder.

The flexibility of masonry is not an aspect with a great focus. The values given in EC 6 do not reflect the advantage of using lime mortars in relation to the flexibility of masonry. Movements in masonry are very often handled by conservative rules of thumb valid for all types of masonry not taking into account the flexibility of the masonry. It is recommended to demonstrate the advantage of flexible masonry in relation to movements in masonry.

The flexural and shear strength of masonry, where the use of lime based mortars generally leads to higher values compared to cement based mortars with admixtures, is not an area where the strength data is optimized. Designers are using national established data. These data do not always take into account the use of mortars with admixtures. The need in the future for using slender walls will demand mortars with good bond strength. It is recommended to demonstrate the advantage of lime based mortars in relation to masonry's flexural and shear strength. It is recommended to demonstrate the advantage of lime based mortars in relation to bond strength.

Durability aspects of the masonry

For the designer the durability aspect is of the same importance as the mechanical behaviour of masonry. A few articles indicate that the porosity of lime based mortars seems to make the mortar so permeable that the freeze-thaw resistance seams to reach an acceptable level, but it shall not be recommended to use pure lime mortars in severe environment. When the durability of the mortar is of that great importance, it is recommended that the freeze-thaw resistance of lime based mortars is investigated using masonry panels.

In relation to water penetration the main conclusion is that masonry walls constructed with lime-based mortars are more resistant to water leakage than those constructed with mortars not containing lime. It is recommended to market that information together with information about the bond strength as they are linked together.

The physical behaviour of the masonry and the aesthetic aspects

The physical behaviour of the masonry and the aesthetic aspects will partly be dealt with when dealing with durability and as such do not need the same attention.

The conclusion for further actions

The conclusion for further actions can be summarized as follows:

On behalf of mortar in fresh condition

- For the mason a test method for workability, which is more related to practice is wanted
- Development of dry air lime, which can be wetted very quickly so that the lime based mortar can obtain their workability during quick mixing

On behalf of engineering

- Development of slender masonry structures taking into account the positive effect that lime containing mortars have upon shear strength and flexural strength of masonry
- Documentation of the advantage of flexible structures

On behalf of durability

- Development of freeze-thaw resistance test for mortars using masonry panels and investigate the durability of lime based mortars
- Documentation of the relationship between a good bond and water penetration

O**n behalf of proper modelling**

- Development of proper test method taking into account the end use condition of mortars

Aarhus, 17 June 2010
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List and summery of articles

Functionalities

<u>Workability</u>

24: Functionality: **Workability**, rheology
Applications: Mortars
Scientific notion (1-3): 2
Summary: The laboratory Vane test has been compared with the cone penetration test and the flow table. The result of the study is that the vane test gives similar results as the cone penetration test and the flow table. With stiff mortars the results differs a bit.

83: Functionality: **Workability** and bond
Applications: High calcium lime and dolomitic lime
Scientific notion (1-3): 3
Summary: SEM has been used to identify differences in the micro structure of high calcium lime and dolomitic lime depending on e.g. firing temperature. SEM has also been used to identify differences in the bond between a cement-lime mortar and a cement mortar with the same amount of cement, where the workability has been established by air entraining agent. The comparison shows a lot better bond for the cement-lime mortar.

91: Functionality: Water retention, **workability**, (ageing)
Applications: Conservation of architectural features, lime putty and mortar
Scientific notion (1-3): 2
Summary: Investigation of the effects of ageing on lime putty. The portlandite crystals undergo significant particle size reduction and morphological changes upon ageing. The effect of crystal evolution on the "quality" of the putty was tested, using both ASTM tests for consistency, water retention and plasticity. The main conclusion is that water retention, consistency and flow tests suggest that much of the water in the 2-year putty is removable by mechanical action and not strongly adsorbed onto the particles. In contrast, more of the water in the 16-year putty is strongly adsorbed onto portlandite crystals, and is not easily removed from the putty. The test result suggest limitations in the use of the flow test as an indicator of the amount of water necessary for producing both a mortar with good workability and a hardened mortar with desired properties.

107: Functionality: **Workability**
Applications: hydraulic lime-based mortars
Scientific notion (1-3): 3
Summary: The study is dealing with the effect of using different additives to the mortar on the workability. Water retaining agent promoted an increase of torque and slump values. Air entraining agent induced a typical thinning or fluid like behaviour and the torque values decrease. Super plasticizer promoted a decrease of torque values and an increase of slump values.

114: Functionality: **Workability**
Applications: Masonry in general, cement-lime mortar (type S hydrated lime).
Scientific notion (1-3): 2
Summary: Investigation of the effects of ageing lime putty and lime-sand slurries on the workability, microstructure and strength of Portland cement mortars. The main conclusion is that the amount of hydration products is more important to the workability and hardened properties of the mortar than the crystal morphology. The increase in surface area of the lime hydration products resulting from small, lightly packed calcium hydroxide crystals in thick coatings on the aggregates is the primary influence on workability, water retentivity and bond. The ageing process contributed more to the thickness and porosity of the coating than it did to changing crystal formations.

136: Functionality: **Workability**
Applications: Masonry in general, lime putty and mortars
Scientific notion (1-3): 2
Summary: Re-evaluation of the rotoviscosimetric technique for the characterization of lime putties compared to the recent European standards on building limes, which only in partial terms face the issue of the workability of mortars. With this method, the workability is appraised by measuring the amount by which a truncated cone shape of the examined mortar was lowered during a succession of 90 strokes on the flow-table device. With the rotoviscosimetric technique, the trend of the shear stress of flow versus time gives effective indications on the changes in internal friction of the dispersion of high content calcium hydroxide in water, and offers insight into the microstructural characteristics of the solid phase.

167: Functionality: **Workability**
Applications: Masonry in general, lime, hydraulic lime, and lime-cement mortars
Scientific notion (1-3): 1
Summary: Investigation of a procedure for mixture optimization of mortars using Farris model is demonstrated for the case of a trimodal mortar. Through the concept of intrinsic viscosity, rheological measurements can be used to evaluate the shape of binder particles and vice versa: Differences between suspensions of dry hydrated lime powder and wet slaked lime putty are demonstrated.

168: Functionality: **Workability**, water retention
Applications: Restoration and general purposes, lime, hydraulic lime, and lime-cement mortars as well as cement with admixtures.
Scientific notion (1-3): 2
Summary: Investigation of test methods for assessing workability of different lime-based mortars and cement mortars with additives. The test methods are yield stress and desorptivity to quantify water retention.
Notes: Development of new test methods.

169: Functionality: **Workability**, water retention
Applications: Masonry in general, lime, hydraulic lime, and lime-cement mortars as well as cement with admixtures.
Scientific notion (1-3): 2 (proceedings)

Summary: Same work as in 168. Investigation of yield stress, water retention, density and air content to characterize workability of different lime-based mortars and cement mortars with additives. The main conclusions are that specific surface area is an important characteristic of the binder, where a higher value gives higher water/binder ratio, water retention and yield stress. With respect to differences between lime-based and cement-based mortars, it is concluded that the performance of cement is improved by replacing 1/3 by lime or by adding admixtures. Another problem with ordinary Portland cement is that the subjective optimum binder/aggregate ratio for masons is too high.

170: Functionality: **Workability**, compressive and flexural strength, flexibility
Applications: Masonry in general, lime, hydraulic lime, and lime-cement mortars as well as cement with admixtures.
Scientific notion (1-3): 2 (proceedings)
Summary: Same work as in 168. Investigation of the influence of water/binder ratio of fresh mortar on workability and strength of masonry of different lime-based mortars and cement mortars with additives. The main conclusions are that the lime mortars show an influence of anisotropy due to the process of carbonation, while the hydraulic mortars show a decrease of strength with increasing water/binder ratio. The amount of air voids plays an equally important role.

171: Functionality: **Workability**
Applications: Masonry in general, lime, hydraulic lime, and lime-cement mortars.
Scientific notion (1-3): 1
Summary: Investigation of vane test for clayey soil and the direct shear test for rock and soil for measuring yield stress of lime, hydraulic lime, and lime-cement mortars as an alternative classical rheological technique. The main finding is that the maximum stress in an undrained mortar is not a material constant, but shows important variations depending on the rate of stress increase and the normal stress applied.
Notes: Interesting with alternative method that allows assessing yield stress of fresh mortars as a dynamic parameter.

186: Functionality: **Workability**
Applications: New build, cement-lime mortar type N
Scientific notion (1-3): 1 (proceedings)
Summary: Review article on cement-lime mortar type N. The main statement is that masons would select a type N mortar because of the workability, board life, yield, and cleaning.

220: Functionality: Compressive and flexural strength of masonry, **workability**, water retentivity, water penetration
Applications: Masonry mortars
Scientific notion (1-3): 3
Summary: Masonry build of cement - lime mortars mixed 1:2:9 provide adequate wall strength for nearly all uses of masonry construction. The high lime content in the mortar contributes to other important characteristics such as improved workability and water retentivity leading to a good bond between units and mortar

and thereby watertight joints. Cement in the mortar is mainly used to provide high early strength so that the construction work can proceed rapidly.

Water retention

3: Functionality: **General characterization of lime-based mortars (bond strength, compressive strength, flexural strength, efflorescence, vapour permeability, water retention, porosity, flexibility)**
Applications: Conservation of historic buildings, traditional lime-based and "ready to use" renders
Scientific notion (1-3): 1-2
Summary: Investigation of the performances of a new generation of cement-based mortars, so-called "ready to use", compared with the traditional lime-based mortars used nowadays in the field of ancient masonries. It is stated that some of the factory made renders ("ready to use") are still too waterproof and have too high mechanical performances while others have evolved towards performances much more compatible with ancient masonries. The result is that some of these renders are easier to use than the traditional mortars and thus can represent an interesting alternative to traditional mortars in restoration operations.
Notes: Not very convincing data, and also a lot of different French test methods.

8: Functionality: **Water retention**
Applications: Masonry in general, cement mortar
Scientific notion (1-3): 2
Summary: Investigation of methods to measure water retentivity of cement mortars. The traditional British and European standard tests are compared with a capillary suction technique and pressure cell technique. The main conclusion is that it is possible to measure a well defined and reproducible property – the desorptivity – which characterizes the water retentivity of a cement mortar. It is better to use the pressure cell technique, which could become a valuable standard test method.

10: Functionality: Water penetration, **water retention**, air content, compressive strength
Applications: cement-lime and cement-lime replacement mortar
Scientific notion (1-3): 3
Summary: The cement-lime replacement mortars have different properties compared to cement-lime mortar. The cement-lime replacement mortars have lower water/binder ratios, lower water retention, greater air content and lower compressive strength. In addition masonry walls constructed using cement-lime replacement mortars are less resistant to moisture penetration compared to masonry walls constructed using cement-lime mortars.

55: Functionality: **Water retention**
Applications: Masonry in general, cement-lime mortar
Scientific notion (1-3): 2
Summary: Investigation of a measurement technique using a simple pressure filtration cell to determine the desorptivity, and thus water retention, of cement-lime mortars. The results demonstrate the strong water-retaining characteristics of lime.

91: Functionality: **Water retention**, workability, (ageing)
Applications: Conservation of architectural features, lime putty and mortar
Scientific notion (1-3): 2
Summary: Investigation of the effects of ageing on lime putty. The portlandite crystals undergo significant particle size reduction and morphological changes upon ageing. The effect of crystal evolution on the “quality” of the putty was tested, using both ASTM tests for consistency, water retention and plasticity. The main conclusion is that water retention, consistency and flow tests suggest that much of the water in the 2-year putty is removable by mechanical action and not strongly adsorbed onto the particles. In contrast, more of the water in the 16-year putty is strongly adsorbed onto portlandite crystals, and is not easily removed from the putty. The test result suggests limitations in the use of the flow test as an indicator of the amount of water necessary for producing both a mortar with good workability and a hardened mortar with desired properties.

111: Functionality: **water retention, sand carrying capacity, self healing, tensile bond and flexibility**
Applications: Masonry mortars
Scientific notion (1-3): 1
Summary: The use of hydrated lime increases the water retention as a hydroxide particle is 1/500 the size of a typical Portland cement particle. Consequently hydroxide particles have all together a very high total surface area which increases water retentivity. Because the lime particles are large in number and small in size they can coat every sand particle, which means a good sand carrying effect. When lime slowly gains strength over time in a masonry wall the lime can act as a self healer if a hairline crack develops between the masonry unit and the mortar. The fine particle size of the lime also play a role in establishing a strong mortar unit bond by having the lime particles deeply penetrating into the microscopic openings in the masonry units.

127: Functionality: Carbonation, **water retention**,
Applications: Conservation of historic buildings, lime mortars
Scientific notion (1-3): 2
Summary: Review article on lime mortar technology, including burning, slaking, ageing and carbonation of lime for conservation of historic buildings. The main conclusion is that the use of aged lime putty is recommended because the material has higher plasticity and water retention capacity which results in mortars of higher strength that carbonate faster.

161: Functionality: **General characterization of lime-based mortars (water retention, bond strength, efflorescence, self-healing, vapour permeability, carbonation, compressive strength, flexural strength).**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2
Summary: Review article on the difference between lime and cement mortars. Lime-based mortars produce tight, durable, mortar bond, and hence watertight walls where cement mortars generally exhibit high bond strengths but have poor extent of bond and also lack durable bonds due to a tendency to develop separation cracking. The

principal reasons for the superiority of lime over Portland cement are its higher degree of plasticity and water retention and its greater fineness and inherent stickiness, which permit joints to be filled more readily and completely. The subject of durability in mortars comprises consideration of autogenous healing and efflorescence. The main causes of efflorescence are malconstruction and design, mortar material especially cement with alkali content, environmental conditions with high rainfall. The positive role of lime in combating the efflorescence of masonry is attributed first to the fact that it hinders water penetration but mainly to its extremely low content of soluble salts and sulphur.
Notes: Good review article

168: Functionality: Workability, **water retention**, yield stress
Applications: Restoration and general purposes, lime, hydraulic lime, and lime-cement mortars as well as cement with admixtures.
Scientific notion (1-3): 2
Summary: Investigation of test methods for assessing workability of different lime-based mortars and cement mortars with additives. The test methods are yield stress and desorptivity to quantify water retention.
Notes: Development of new test methods.

169: Functionality: Workability, **water retention**, yield stress
Applications: Masonry in general, lime, hydraulic lime, and lime-cement mortars as well as cement with admixtures.
Scientific notion (1-3): 2 (proceedings)
Summary: Same work as in 168. Investigation of yield stress, water retention, density and air content to characterize workability of different lime-based mortars and cement mortars with additives. The main conclusions are that specific surface area is an important characteristic of the binder, where a higher value gives higher water/binder ratio, water retention and yield stress. With respect to differences between lime-based and cement-based mortars, it is concluded that the performance of cement is improved by replacing 1/3 by lime or by adding admixtures. Another problem with ordinary Portland cement is that the subjective optimum binder/aggregate ratio for masons is too high.

185: Functionality: Hydraulic properties, Compressive strength, sand carrying capacity, board life (open time), mortar yield, air content, sand bulking, **water retention**
Applications: Masonry in general, lime-pozzolan and high cement content mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Comparison of lime-pozzolan and high cement content mortar based on field and laboratory tests. The motivation for the investigation is Mexican masons' problems with Portland cement-admixture, because of the excessive compressive strength that is incompatible with relatively soft masonry units. The main conclusions are that lime-pozzolan mortars have superior workability, higher yield, longer board life, higher water retention and moderate compressive strength. Lime-pozzolan mortars are also less energy-intensive because mine waste is used as pozzolan material.

Notes: No specification of lime and cement mortars (local mortars from Mexico). Interesting perspectives and many arguments for the superiority of lime-pozzolan mortars compared to cement-based mortars.

189: Functionality: Air content, **water retention**, flexural bond strength
Applications: New build, cement-lime and cement/air entrained lime mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of the effect of air-entrained lime (type SA) on the properties of cement/lime mortars. The main conclusion is that cement/lime and cement/air-entrained lime mortars showed no significant differences in water retention and flexural bond strength of mortar when combined with standard concrete masonry units.

212: Functionality: **Water retention, water demand, compressive strength, masonry strength**
Applications: Cement-lime mortar 50/50/750
Scientific notion (1-3): 3
Summary: A cement-lime mortar is mixed using different technologies, cement + sand + dry hydrated lime, cement + sand + slaked quick lime, cement + sand + lime putty (3 months old), cement + sand + lime putty (9 years old), cement + sand + carbide lime, cement + sand + quick lime slaked in the moist sand, cement + sand + hydrated lime premixed with the cement and cement + sand + hydrated lime as a retarded mortar. Generally speaking, the longer time the lime has been in contact with water, the better is the water retention, the lower is the bleeding effect and the higher is the water demand. The longer the lime has been in contact with water, the lower is the compressive strength. The effect coming from the lower compressive strength upon the masonry strength is limited.

220: Functionality: Compressive and flexural strength of masonry, workability, **water retentivity**, water penetration
Applications: Masonry mortars
Scientific notion (1-3): 3
Summary: Masonry build of cement - lime mortars mixed 1:2:9 provide adequate wall strength for nearly all uses of masonry construction. The high lime content in the mortar contributes to other important characteristics such as improved workability and water retentivity leading to a good bond between units and mortar and thereby watertight joints. Cement in the mortar is mainly used to provide high early strength so that the construction work can proceed rapidly.

<u>Air content</u>

10: Functionality: Water penetration, water retention, **air content**, compressive strength
Applications: cement-lime and cement-lime replacement mortar
Scientific notion (1-3): 3
Summary: The cement-lime replacement mortars have different properties compared to cement-lime mortar. The cement-lime replacement mortars have lower water/binder ratios, lower water retention, greater air content and lower compressive

strength. In addition masonry walls constructed using cement-lime replacement mortars are less resistant to moisture penetration compared to masonry walls constructed using cement-lime mortars.

84: Functionality: **Air content**
Applications: Masonry in general, cement-lime mortars with air-entraining agents.
Scientific notion (1-3): 2
Summary: Investigation of the effect of air content on the durability of cement-lime mortars. The objective was to obtain data that might indicate the air content levels that are beneficial in cement-lime mortars. The properties measured included shrinkage of mortar bars, dry density, absorption, compressive strength, and resistance to freeze-thaw cycling of mortar cubes. The main conclusions are that increasing air content has a minor effect on shrinkage and absorption properties, reduces water requirements and compressive strength, and improves durability.

189: Functionality: **Air content**, water retention, flexural bond strength
Applications: New build, cement-lime and cement/air entrained lime mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of the effect of air-entrained lime (type SA) on the properties of cement-lime mortars. The main conclusion is that cement/lime and cement-air-entrained lime mortars showed no significant differences in water retention and flexural bond strength of mortar when combined with standard concrete masonry units.

185: Functionality: Hydraulic properties, Compressive strength, sand carrying capacity, board life (open time), mortar yield, **air content**, sand bulking, water retention
Applications: Masonry in general, lime-pozzolan and high cement content mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Comparison of lime-pozzolan and high cement content mortar based on field and laboratory tests. The motivation for the investigation is Mexican masons' problems with Portland cement-admixture, because of the excessive compressive strength that is incompatible with relatively soft masonry units. The main conclusions are that lime-pozzolan mortars have superior workability, higher yield, longer board life, higher water retention and moderate compressive strength. Lime-pozzolan mortars are also less energy-intensive because mine waste is used as pozzolan material.
Notes: No specification of lime and cement mortars (local mortars from Mexico). Interesting perspectives and many arguments for the superiority of lime-pozzolan mortars compared to cement-based mortars.

216: Functionality: **Air content,** Flexural strength of masonry
Applications: Masonry mortars
Scientific notion (1-3): 3
Summary: The study is dealing with the influence of the air content in the mortar upon the flexural strength of the masonry. The study is showing that there is a great influence. With an air content about 20 % the flexural strength can easily be half or less compared to the flexural strength for the same mortar with an air content below 10 %. The more the mortar is cement based the greater the influence is.

<u>Water demand</u>

132: Functionality: Workability, **water demand**
Applications: Masonry in general, cement-lime mortars
Scientific notion (1-3): 1
Notes: Low quality work.

212: Functionality: **Water retention, water demand, compressive strength, masonry strength**
Applications: Cement - lime mortar 50/50/750
Scientific notion (1-3): 3
Summary: A cement-lime mortar is mixed using different technologies, cement + sand + dry hydrated lime, cement + sand + slaked quick lime, cement + sand + lime putty (3 months old), cement + sand + lime putty (9 years old), cement + sand + carbide lime, cement + sand + quick lime slaked in the moist sand, cement + sand + hydrated lime premixed with the cement and cement + sand + hydrated lime as a retarded mortar. Generally speaking, the longer time the lime has been in contact with water, the better is the water retention, the lower is the bleeding effect and the higher is the water demand. The longer the lime has been in contact with water, the lower is the compressive strength. The effect coming from the lower compressive strength upon the masonry strength is limited.

Open time

Compressive and flexural strength of mortars

3: Functionality: **General characterization of lime-based mortars (bond strength, compressive strength, flexural strength, efflorescence, vapour permeability, water retention, porosity, flexibility)**
Applications: Conservation of historic buildings, traditional lime-based and "ready to use" renders
Scientific notion (1-3): 1-2
Summary: Investigation of the performances of a new generation of cement-based mortars, so-called "ready to use", compared with the traditional lime-based mortars used nowadays in the field of ancient masonries. It is stated that some of the factory made renders ("ready to use") are still too waterproof and have too high mechanical performances while others have evolved towards performances much more compatible with ancient masonries. The result is that some of these renders are easier to use than the traditional mortars and thus can represent an interesting alternative to traditional mortars in restoration operations.
Notes: Not very convincing data, and also a lot of different French test methods.

10: Functionality: Water penetration, water retention, air content, **compressive strength**
Applications: cement-lime and cement-lime replacement mortar
Scientific notion (1-3): 3
Summary: The cement-lime replacement mortars have different properties compared to cement-lime mortar. The cement-lime replacement mortars have lower water/binder ratios, lower water retention, greater air content and lower compressive strength. In addition masonry walls constructed using cement-lime replacement mortars are less resistant to moisture penetration compared to masonry walls constructed using cement-lime mortars.

23: Functionality: **Compressive strength**
Applications: Restoration work and new build, lime, natural hydraulic and lime-cement mortars
Scientific notion (1-3):
Summary: Review article focusing on compressive strength but also describing the positive properties of lime mortars.

32: Functionality: Porosity**, compressive strength**
Applications: Repair mortars for ancient masonry and concrete industry (admixture), slaked lime-metakaolin mortar
Scientific notion (1-3): 2
Summary: Investigation of the effect of different slaked lime-metakaolin mortar mixes on porosity and compressive strength. The main findings of the statistical analysis of the results are that increasing SL + MK/sand ratio increases the strength, porosity and amount of binder formed. The next factor in order of importance is the presence of super plasticizer admixture, where the presence of super plasticizer increases strength, raises the calcite content and reduces porosity. However, curing

or natural carbonation time does not seem to have any significant effect on composition or porosity. The SL-MK mortars are promising as repair mortars.
Notes: Not that relevant because it is a special mortar with MK and admixture.

33: Functionality: **Compressive and flexural strength**, porosity, capillary porosity
Applications: Repair of monuments and manufacture of renderings and plasters, lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the role of aggregates on the strength, porosity and capillary porosity of lime mortars. The main findings are that the highest strength is attained with low binder/aggregate ratio (1:1.5, 1:2.5, 1:3) and sand aggregate in the fraction 0-4 mm. For coarser aggregate fractions, strong compaction of the mortars is necessary to reduce voids and increase the bond of lime paste with pebbles. Compaction also reduces water penetration.

34: Functionality: Carbonation, **compressive strength**
Applications: Masonry in general, hydrated lime paste
Scientific notion (1-3): 2
Summary: Investigation of reaction kinetics, strength and microstructure of carbonate binders by varying CO_2 gas pressure, exposure time and initial degree of compaction of the raw material. The main conclusion is that the strength of the binder is controlled by the crystalline state and morphology of the carbonate rather than the conversion degree of $Ca(OH)_2$.

35: Functionality: **Compressive and flexural strength**, flexural bond strength of masonry, flexibility, hydraulic property
Applications: Restoration work, lime and hydraulic lime mortars
Scientific notion (1-3): 2
Summary: Investigation of strength development and lime reaction in time for several mixtures of lime and hydraulic lime mortars. The main conclusions are that all the examined mortars present very slow rates of hardening, with the exception of hydraulic lime mortar and mortar with lime putty-natural pozzolanic addition. The best mechanical behaviour was observed in mortars with lime powder and lime powder-artificial pozzolanic addition. These materials present also a low ratio of compressive to flexural strength.
Notes: Interesting because of extremely long curing times.

37: Functionality: Flexibility**, compressive and flexural strength,** porosity
Applications: Restoration work, cement-lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour of lime-cement mortars in the full range of compositions 0-100% cement. The main conclusion is that lime-rich mortars are able to absorb a high degree of deformation before breakage (high flexibility), and thus have great potential as materials for restoration work as they can accommodate the movements of ancient buildings. Further, with increasing cement content, the surface fractal dimension (indicator of complexity of the pore system) and mechanical strength increases.

47: Functionality: **Porosity, compressive and flexural strength, flexibility (elastic modulus)**
Applications: Restoration work, mortars of aerial lime, hydraulic lime, cement and other pozzolanic materials.
Scientific notion (1-3): 3
Summary: Characterization of several mortar types to improve knowledge that will facilitate the further choice of suitable material to replace any old mortar. The mortars are characterized with respect to chemical and mineralogical compositions and physical properties (density, porosity, strength and elastic modulus).
Notes: Not really conclusive but instead knowledge matrix for future comparison.

48: Functionality: **Compressive and flexural strength**
Applications: Restoration work, lime-based mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour of different new aerial lime mortars in long-term tests, especially the influence of curing time, B/Ag ratio, type of aggregate (nature, grain size distribution and shape) and porosity on mechanical strength. The main conclusions are that a vast increment of compressive and flexural strengths is seen for curing times between 28 and 365 days. Increasing binder content improves strength within a limit. For binder amounts beyond 2:1 the B/Ag ratio shows a strong strength reduction. The porosity increase due to the binder makes carbonation easier so mortar strength improves. However, in case of binder excess, the increase in voids leads to a strength reduction.
Notes: Excellent work but no reference to standard methods! Strength reduction after 182 and 391 days for B/Ag < 1:2 (1:3 normally cited as the optimal ratio!).

59: Functionality: **Durability (Porosity, compressive and flexural strength, SO_2, freeze-thaw resistance)**
Applications: Restoration work, aerial and hydraulic mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour in hardened repair lime-based mortars (aerial and hydraulic) subjected to different environments: Outside exposure, weathering cycles (in a climatic chamber), SO_2-rich environment (in a SO_2 chamber), freeze-thaw cycles and indoor exposure (laboratory conditions). This allows evaluating and comparing the durability of the repair lime-based mortars. The main conclusion is that aerial lime mortars exposed to SO_2-rich environment, results in the formation of gypsum that causes a strength drop.

61: Functionality: Porosity, **compressive and flexural strength**, (binder/aggregate ratio and aggregate psd and chemistry)
Applications: Restoration works, natural hydraulic lime-based mortars.
Scientific notion (1-3): 2
Summary: Investigation of the factors affecting the mechanical behaviour in different NHL-based mortars. The influence of curing time, binder/aggregate ratio, nature and particle size distributions of the aggregates, and porosity has been studied. The main conclusions are that specimens with more binder content show the highest compressive and flexural strengths. With respect to aggregate, a suitable grain size distribution, angle-shape and limestone composition give the highest strengths. High porosity, due to large binder amount, results in increased strength as well.

73: Functionality: Capillary porosity, vapour permeability, **compressive and flexural strength,** hydraulic properties
Applications: Conservation of historic buildings, lime and lime-pozzolan plaster
Scientific notion (1-3): 1-2
Summary: Investigation of basic, mechanical, thermal and hygric properties of lime-pozzolan plaster mixtures with metakaolin, grinded brick and grinded enamel glass as the pozzolan material are analyzed. The main conclusions are that a significant increase of both compressive and bending strength of the studied plasters was achieved. Most thermal and hygric properties of lime-pozzolan plasters were found to be either comparable or even better than the respective properties of classical lime plaster. The only exception was the linear hygric expansion coefficient that was higher than for the common lime plaster.

89: Functionality: **Compressive and flexural strength,** flexibility
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 1-2
Summary: Investigation of the triaxial behaviour of mortar in masonry structures in order to elucidate the origin of the deformability of masonry. The main conclusions are that the mechanical behaviour of mortar changes from a brittle material under simple uniaxial compression to an elasto-plastic structure under triaxial compression. There is a corresponding change of failure mechanism from diagonal shear bands to a pore collapse of the internal structure. Lime mortar is more likely to deform plastically and, thus, to contribute to the overall deformability of masonry structure. Deformable masonry structures have shown to be more durable than brittle ones when subjected to unforeseen imposed deformation due to differential settlements or earthquakes.
Notes: Interesting new testing method for compressive strength that maybe gives more information of the material properties? No description of mortar material and preparation.

104: Functionality: Hydraulic properties, porosity, **compressive strength**
Applications: Masonry in general, lime-pozzolan mortars.
Scientific notion (1-3): 2
Summary: Investigation of the effect of lime content on the water requirement, initial porosity, strength development, pozzolanic reaction rate, and microstructure of lime-natural-pozzolan mixtures. Also, the effect of quicklime and hydrated lime on the strength development and pozzolanic reaction. The main conclusions are that an increase of lime over a critical value results in an increase in water requirement and initial porosity, and the strength of the lime-pozzolan pastes decreases. A mixture of 20% hydrated lime and 80% natural pozzolan is regarded as an optimum mixture.

108: Functionality: **Compressive strength**
Applications: Masonry in general, lime-pozzolan mortars
Scientific notion (1-3): 2
Summary: Investigation of the hydration products and compressive strength with curing age up to 365 days for lime-pozzolan mortars.
Notes: This work does not contribute with new knowledge – with increasing lime/pozzolan ratio, the formation of CSH gets slower.

111: Functionality: **water retention, sand carrying capacity, self healing, tensile bond and flexibility**
Applications: Masonry mortars
Scientific notion (1-3): 1
Summary: The use of hydrated lime increases the water retention as a hydroxide particle is 1/500 the size of a typical Portland cement particle. Consequently hydroxide particles have all together a very high total surface area which increases water retentivity. Because the lime particles are large in number and small in size they can coat every sand particle, which means a good sand carrying effect. When lime slowly gains strength over time in a masonry wall the lime can act as a self healer if a hairline crack develops between the masonry unit and the mortar. The fine particle size of the lime also plays a role in establishing a strong mortar unit bond by having the lime particles deeply penetrating into the microscopic openings in the masonry units.

161: Functionality: **General characterization of lime-based mortars (water retention, bond strength, efflorescence, self-healing, vapour permeability, carbonation, compressive strength, flexural strength).**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2
Summary: Review article on the difference between lime and cement mortars. Lime-based mortars produce tight, durable, mortar bond, and hence watertight walls where cement mortars generally exhibit high bond strengths but have poor extent of bond and also lack durable bonds due to a tendency to develop separation cracking. The principal reasons for the superiority of lime over Portland cement are its higher degree of plasticity and water retention and its greater fineness and inherent stickiness, which permit joints to be filled more readily and completely. The subject of durability in mortars comprises consideration of autogenous healing and efflorescence. The main causes of efflorescence are malconstruction and design, mortar material especially cement with alkali content, environmental conditions with high rainfall. The positive role of lime in combating the efflorescence of masonry is attributed first to the fact that it hinders water penetration but mainly to its extremely low content of soluble salts and sulphur.
Notes: Good review article

170: Functionality: Workability, **compressive and flexural strength**, flexibility
Applications: Masonry in general, lime, hydraulic lime, and lime-cement mortars as well as cement with admixtures.
Scientific notion (1-3): 2 (proceedings)
Summary: Same work as in 168. Investigation of the influence of water/binder ratio of fresh mortar on workability and strength of masonry of different lime-based mortars and cement mortars with additives. The main conclusions are that the lime mortars show an influence of anisotropy due to the process of carbonation, while the hydraulic mortars show a decrease of strength with increasing water/binder ratio. The amount of air voids plays an equally important role.

178: Functionality: Carbonation, **compressive and flexural strength**, porosity, flexibility
Applications: Conservation of historic buildings, cement-lime mortars
Scientific notion (1-3): 3
Summary: Investigation of the hardening reactions and their influence on strength development, porosity and microstructure of cement-lime mortars using lime hydrate and lime putty as partial replacement of cement in varying ratios. The main conclusions are that the degree of carbonation is much more pronounced with increasing lime content and porosity of the mortars. Unlike the reference cement mortar, the cement-lime mortars exhibit an elastic-plastic deformation which enables them to adapt to differential settlements and more deformation under critical stresses in the masonry.

174 + 177 + 179: Functionality: Carbonation, **compressive and flexural strength**, porosity
Applications: Masonry in general, lime, hydraulic and lime-pozzolan mortars
Scientific notion (1-3): 2
Summary: Investigation of the influence of rice husk ash and lime on the hardening and strength development of cement mortars. The main conclusions are that the effect of the pozzolanic reaction on the early strength gain of the RHA-cement was not clear while it seemed to contribute to their long-term strength development. Carbonation reaction was favoured at the later stage due to the higher porosity of the RHA-cement mortars and yielded lower strength values compared with the reference cement. However, strength reduction was recorded in the very early stage of the mortars when cement in low content (10%-wt) was used in combination with RHA and lime.

185: Functionality: Hydraulic properties, **Compressive strength**, sand carrying capacity, board life (open time), mortar yield, air content, sand bulking, water retention
Applications: Masonry in general, lime-pozzolan and high cement content mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Comparison of lime-pozzolan and high cement content mortar based on field and laboratory tests. The motivation for the investigation is Mexican masons' problems with Portland cement-admixture, because of the excessive compressive strength that is incompatible with relatively soft masonry units. The main conclusions are that lime-pozzolan mortars have superior workability, higher yield, longer board life, higher water retention and moderate compressive strength. Lime-pozzolan mortars are also less energy-intensive because mine waste is used as pozzolan material.
Notes: No specification of lime and cement mortars (local mortars from Mexico). Interesting perspectives and many arguments for the superiority of lime-pozzolan mortars compared to cement-based mortars.

203: Functionality: **Compressive and flexural strength**, compressive and flexural bond strength, flexibility (modulus of elasticity)
Applications: Masonry in general, lime-pozzolanic, cement-lime and cement mortars
Scientific notion (1-3): 1 (proceedings)

Summary: Investigation of mechanical behaviour of brick masonries derived from unit and mortar characteristics. The aim is to set up a simple mathematical model of the mechanical behaviour of brickwork from which the value of value of strength and deformability parameters can be obtained. The main conclusions are that it is possible to obtain reliable information on the carrying capacity of masonry when the mechanical properties of bricks and mortars are known. Also, the use of high strength cement mortars does not improve the masonry strength because of lack of bond strength and shrinkage of mortars when high absorption bricks are used.
Notes: Interesting to look at masonry and not just bricks and mortars as individual entities. The point that the overall strength of the masonry is not dependent on mortar strength alone is a central topic that could be the focus of future research.

209: Functionality: **Compressive strength and flexural strength**
Applications: Cement-lime mortars
Scientific notion (1-3): 3
Summary: The study is showing that the strength of the mortar is depending very much upon the V/C ratio. If no water is sucked away from the mortar (a high V/C ratio) the compressive strength is about 2-3 times lower compared to a natural V/C ratio (the mortar placed between normally sucking clay bricks). For cement based mortars placed between high sucking clay bricks the V/C ratio can be so low that there is not water enough for the hydration of the cement.

211: Functionality: **Compressive strength**
Applications: Different lime, cement-lime, masonry cement and cement mortars
Scientific notion (1-3): 3
Summary: The casting procedures and curing conditions have a great influence on the tested compressive strength. If the casting procedure and the curing condition allows the lime to carbonate the strength is tested higher compared to a situation where the lime cannot carbonate especially for the lime based mortars. If the casting procedure and the curing condition are resulting in a lower V/C ratio than the one valid when the mortar is mixed then the compressive strength of the mortar is higher compared to the strength of the mortar with a high V/C ratio. The strength of a cement-lime mortar with the low V/C ratio can be 3 times higher than the strength of the same mix with the high V/C ratio.

212: Functionality: **Water retention, water demand, compressive strength, masonry strength**
Applications: Cement-lime mortar 50/50/750
Scientific notion (1-3): 3
Summary: A cement-lime mortar is mixed using different technologies, cement + sand + dry hydrated lime, cement + sand + slaked quick lime, cement + sand + lime putty (3 months old), cement + sand + lime putty (9 years old), cement + sand + carbide lime, cement + sand + quick lime slaked in the moist sand, cement + sand + hydrated lime premixed with the cement and cement + sand + hydrated lime as a retarded mortar. Generally speaking, the longer time the lime has been in contact with water, the better is the water retention, the lower is the bleeding effect and the higher is the water demand. The longer the lime has been in contact with water, the lower is the compressive strength. The effect coming from the lower compressive strength upon the masonry strength is limited.

213: Functionality: **Compressive strength**
Applications: Cement-lime mortars
Scientific notion (1-3): 3
Summary: The suction of the masonry units has a great influence upon the compressive strength of the mortar between the bricks. The mortar between light weight concrete units and AAC unit obtains the same strength as the in the mortar compressive strength test method. The mortar between clay units with different sucking behaviour obtains nearly the double strength compared to the test method.

214: Functionality: **Compressive strength**
Applications: masonry mortars
Scientific notion (1-3): 2
Summary: If the mixing time on site increases 15 minutes the compressive strength of the mortar will go down. After 1 hour's mixing the strength will only be half.

Compressive and flexural bond strength of masonry

3: Functionality: **General characterization of lime-based mortars (bond strength, compressive strength, flexural strength, efflorescence, vapour permeability, water retention, porosity, flexibility)**
Applications: Conservation of historic buildings, traditional lime-based and "ready to use" renders
Scientific notion (1-3): 1-2
Summary: Investigation of the performances of a new generation of cement-based mortars, so-called "ready to use", compared with the traditional lime-based mortars used nowadays in the field of ancient masonries. It is stated that some of the factory made renders ("ready to use") are still too waterproof and have too high mechanical performances while others have evolved towards performances much more compatible with ancient masonries. The result is that some of these renders are easier to use than the traditional mortars and thus can represent an interesting alternative to traditional mortars in restoration operations.
Notes: Not very convincing data, and also a lot of different French test methods.

5: Functionality: **Masonry compressive strength,** flexibility
Applications: Masonry mortars
Scientific notion (1-3): 2
Summary: The study is showing that it is possible to test the compressive strength and modulus of elasticity of masonry using model bricks 1:4. The correlation is quite good.

9: Functionality: **Flexural bond strength,** water penetration
Applications: Masonry in general, cement-lime and polymer-modified mortars
Scientific notion (1-3): 2
Summary: Investigation of bond strength between cement-lime mortar and polymer-modified mortar and shale brick. The main conclusions are that cement-lime mortars, but not polymer-modified mortars, are able to create continuous bonds with brick surfaces and completely fill spaces in brick surfaces. Although the bond strength of CL mortars cannot reach the high value of PL mortars, a good CL mortar bond

allows little or no water to enter or penetrate between the mortar and brick during service.

35: Functionality: Compressive and flexural strength, **flexural bond strength of masonry**, flexibility, hydraulic property
Applications: Restoration work, lime and hydraulic lime mortars
Scientific notion (1-3): 2
Summary: Investigation of strength development and lime reaction in time for several mixtures of lime and hydraulic lime mortars. The main conclusions are that all the examined mortars present very slow rates of hardening, with the exception of hydraulic lime mortar and mortar with lime putty-natural pozzolanic addition. The best mechanical behaviour was observed in mortars with lime powder and lime powder-artificial pozzolanic addition. These materials also present a low ratio of compressive to flexural strength.
Notes: Interesting because of extremely long curing times.

77: Functionality: **Compressive and flexural bond strength,** hydraulic properties
Applications: Historic mortars
Scientific notion (1-3): 3
Summary: The investigated historic mortar presents high tensile strengths in comparison with other traditional mortars. The cementitious character of the historic mortar could be attributed to hot lime technology and the addition of montmorillonitic clay dust to the lime.

83: Functionality: Workability and **bond**
Applications: High calcium lime and dolomitic lime
Scientific notion (1-3): 3
Summary: SEM has been used to identify differences in the micro structure of high calcium lime and dolomitic lime depending on e.g. firing temperature. SEM has also been used to identify differences in the bond between a cement-lime mortar and a cement mortar with the same amount of cement, where the workability has been established by air entraining agents. The comparison shows a lot better bond for the cement-lime mortar.

112: Functionality: **Bond strength**
Applications: Masonry in general
Scientific notion (1-3): 1-2
Summary: Investigation of tensile strength of one specific fired clay brick unit and British Standard designation (iii) mortar as well as two commercially available dense aggregate concrete blocks. All three materials showed more or less decreasing strength with increasing moisture content.
Notes: Not really relevant as there is no specification of the mortar type.

161: Functionality: **General characterization of lime-based mortars (water retention, bond strength, efflorescence, self-healing, vapour permeability, carbonation, compressive strength, flexural strength).**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2

Summary: Review article on the difference between lime and cement mortars. Lime-based mortars produce tight, durable, mortar bond, and hence watertight walls where cement mortars generally exhibit high bond strengths but have poor extent of bond and also lack durable bonds due to a tendency to develop separation cracking. The principal reasons for the superiority of lime over Portland cement are its higher degree of plasticity and water retention and its greater fineness and inherent stickiness, which permit joints to be filled more readily and completely. The subject of durability in mortars comprises consideration of autogenous healing and efflorescence. The main causes of efflorescence are malconstruction and design, mortar material especially cement with alkali content, environmental conditions with high rainfall. The positive role of lime in combating the efflorescence of masonry is attributed first to the fact that it hinders water penetration but mainly to its extremely low content of soluble salts and sulphur.
Notes: Good review article

180: Functionality: Water penetration**, bond strength**
Applications: Masonry in general, lime type S
Scientific notion (1-3): Review
Summary: Review of water penetration of masonry composed of lime type S mortar compared with ordinary cement. The main conclusion is that masonry walls constructed with mortars containing type S lime are more resistant to water leakage than those constructed with mortars containing no lime.
Notes: Resistance against water penetration due to better bonding -> (bond strength)

189: Functionality: Air content, water retention, **flexural bond strength**
Applications: New build, cement-lime and cement/air entrained lime mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of the effect of air-entrained lime (type SA) on the properties of cement/lime mortars. The main conclusion is that cement/lime and cement/air-entrained lime mortars showed no significant differences in water retention and flexural bond strength of mortar when combined with standard concrete masonry units.

194: Functionality: **Bond strength**
Applications: Restoration, lime mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of the interface between bricks and mortar to understand the adhesion phenomenon and bond strength between the two materials.
Notes: Interesting subject but no major conclusions.

197: Functionality: Adhesion (**flexural bond strength**)
Applications: Ancient lime mortars
Scientific notion (1-3): 1-2
Summary: Investigation of adhesion between binder and aggregate and the resulting mortar and brick in ancient mortars from Milan. The main conclusion from numerous optical inspections is that the adhesion between lime and brick is not always due to purely physical phenomena but also chemical reactions.
Notes: Interesting subject but no new conclusions.

203: Functionality: Compressive and flexural strength, c**ompressive and flexural bond strength**, flexibility (modulus of elasticity)
Applications: Masonry in general, lime-pozzolanic, cement-lime and cement mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of mechanical behaviour of brick masonries derived from unit and mortar characteristics. The aim is to set up a simple mathematical model of the mechanical behaviour of brickwork from which the value of value of strength and deformability parameters can be obtained. The main conclusions are that it is possible to obtain reliable information on the carrying capacity of masonry when the mechanical properties of bricks and mortars are known. Also, the use of high strength cement mortars does not improve the masonry strength because of lack of bond strength and shrinkage of mortars when high absorption bricks are used.
Notes: Interesting to look at masonry and not just bricks and mortars as individual entities. The point that the overall strength of the masonry is not dependent on mortar strength alone is a central topic that could be the focus of future research.

210: Functionality: **Adhesion**
Applications: Rendering mortars
Scientific notion (1-3): 2
Summary: The adhesion is lower when the thin render is applied on smooth bricks compared to rough bricks. Efflorescence of gypsum does not affect the adhesion. Wetting of high sucking bricks has a positive effect on the adhesion.

212: Functionality: **Water retention, water demand, compressive strength, masonry strength**
Applications: Cement - lime mortar 50/50/750
Scientific notion (1-3): 3
Summary: A cement-lime mortar is mixed using different technologies, cement + sand + dry hydrated lime, cement + sand + slaked quick lime, cement + sand + lime putty (3 months old), cement + sand + lime putty (9 years old), cement + sand + carbide lime, cement + sand + quick lime slaked in the moist sand, cement + sand + hydrated lime premixed with the cement and cement + sand + hydrated lime as a retarded mortar. Generally speaking, the longer time the lime has been in contact with water, the better is the water retention, the lower is the bleeding effect and the higher is the water demand. The longer the lime has been in contact with water, the lower is the compressive strength. The effect coming from the lower compressive strength upon the masonry strength is limited.

215: Functionality: **Masonry compressive strength and flexural strength**
Applications: Masonry mortar, cement-lime mortar 50/50/750
Scientific notion (1-3): 3
Summary: The study is looking upon the influence of the sand grading upon the masonry strength. The study is showing that mortars with sand grading giving bad water retention are obtaining a slightly lower masonry compressive strength but absolutely the best masonry flexural strength.

216: Functionality: Air content**, Flexural strength of masonry**
Applications: Masonry mortars
Scientific notion (1-3): 3
Summary: The study is dealing with the influence of air content in mortar upon the flexural strength of the masonry. The study is showing that there is a great influence. With an air content about 20 % the flexural strength can easily be half or less compared to the flexural strength for the same mortar with an air content below 10 %. The more the mortar is cement based the greater the influence is.

220: Functionality: **Compressive and flexural strength of masonry,** workability, water retentivity, water penetration
Applications: Masonry mortars
Scientific notion (1-3): 3
Summary: Masonry build of cement - lime mortars mixed 1:2:9 provide adequate wall strength for nearly all uses of masonry construction. The high lime content in the mortar contributes to other important characteristics such as improved workability and water retentivity leading to a good bond between units and mortar and thereby watertight joints. Cement in the mortar is mainly used to provide high early strength so that the construction work can proceed rapidly.

223: Functionality: **Bond strength**
Applications: Masonry mortars
Scientific notion (1-3): 2
Summary: The two must important factors affecting the bond strength are the type of mortar characterized by its water retention, air content and strength and the type of units characterized by its suction. Generally high bond strength is obtained through the use of mortar having high water retention, high strength and a low air content and units having a moderate suction and roughened surfaces.

Flexibility

3: Functionality: **General characterization of lime-based mortars (bond strength, compressive strength, flexural strength, efflorescence, vapour permeability, water retention, porosity, flexibility)**
Applications: Conservation of historic buildings, traditional lime-based and "ready to use" renders
Scientific notion (1-3): 1-2
Summary: Investigation of the performances of a new generation of cement-based mortars, so-called "ready to use", compared with the traditional lime-based mortars used nowadays in the field of ancient masonries. It is stated that some of the factory made renders ("ready to use") are still too waterproof and have too high mechanical performances while others have evolved towards performances much more compatible with ancient masonries. The result is that some of these renders are easier to use than traditional mortars and thus can represent an interesting alternative to traditional mortars in restoration operations.
Notes: Not very convincing data, and also a lot of different French test methods.

5: Functionality: Masonry compressive strength**, flexibility**

Applications: Masonry mortars
Scientific notion (1-3): 2
Summary: The study is showing that it is possible to test the compressive strength and modulus of elasticity of masonry using model bricks 1:4. The correlation is quite good.

35: Functionality: Compressive and flexural strength, flexural bond strength of masonry, **flexibility**, hydraulic property
Applications: Restoration work, lime and hydraulic lime mortars
Scientific notion (1-3): 2
Summary: Investigation of strength development and lime reaction in time for several mixtures of lime and hydraulic lime mortars. The main conclusions are that all the examined mortars present very slow rates of hardening, with the exception of hydraulic lime mortar and mortar with lime putty-natural pozzolanic addition. The best mechanical behaviour was observed in mortars with lime powder and lime powder-artificial pozzolanic addition. These materials present also a low ratio of compressive to flexural strength.
Notes: Interesting because of extremely long curing times.

37: Functionality: **Flexibility,** compressive and flexural strength, porosity
Applications: Restoration work, cement-lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour of lime-cement mortars in the full range of compositions 0-100% cement. The main conclusion is that lime-rich mortars are able to absorb a high degree of deformation before breakage (high flexibility), and thus have great potential as materials for restoration work as they can accommodate the movements of ancient buildings. Further, with increasing cement content, the surface fractal dimension (indicator of complexity of the pore system) and mechanical strength increases.

47: Functionality: **Porosity, compressive and flexural strength, flexibility (elastic modulus)**
Applications: Restoration work, mortars of aerial lime, hydraulic lime, cement and other pozzolanic materials.
Scientific notion (1-3): 3
Summary: Characterization of several mortar types to improve knowledge that will facilitate the further choice of suitable material to replace any old mortar. The mortars are characterized with respect to chemical and mineralogical compositions and physical properties (density, porosity, strength and elastic modulus).
Notes: Not really conclusive but instead knowledge matrix for future comparison.

85: Functionality: **Flexibility**
Applications: Masonry mortar
Scientific notion (1-3): 3
Summary: Lime sand mortars are highly deformable and exhibit behaviour characteristic of hardening plasticity in compression. A lime-sand mortar jointed masonry arch is tolerant of significant yielding within the joints.

89: Functionality: Compressive and flexural strength**, flexibility**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 1-2
Summary: Investigation of the triaxial behaviour of mortar in masonry structures in order to elucidate the origin of the deformability of masonry. The main conclusions are that the mechanical behaviour of mortar changes from a brittle material under simple uniaxial compression to an elasto-plastic structure under triaxial compression. There is a corresponding change of failure mechanism from diagonal shear bands to a pore collapse of the internal structure. Lime mortar is more likely to deform plastically and, thus, to contribute to the overall deformability of masonry structure. Deformable masonry structures have shown to be more durable than brittle ones when subjected to unforeseen imposed deformation due to differential settlements or earthquakes.
Notes: Interesting new testing method for compressive strength that may be gives more information of the material properties? No description of mortar material and preparation.

111: Functionality: **water retention, sand carrying capacity, self healing, tensile bond and flexibility**
Applications: Masonry mortars
Scientific notion (1-3): 1
Summary: The use of hydrated lime increases the water retention as a hydroxide particle is 1/500 the size of a typical Portland cement particle. Consequently hydroxide particles have all together a very high total surface area which increases water retentivity. Because the lime particles are large in number and small in size they can coat every sand particle, which means a good sand carrying effect. When lime slowly gains strength over time in a masonry wall the lime can act as a self healer if a hairline crack develops between the masonry unit and the mortar. The fine particle size of the lime also play a role in establishing a strong mortar unit bond by having the lime particles deeply penetrating into the microscopic openings in the masonry units.

128: Functionality: **Flexibility**
Applications: Lime mortars
Scientific notion (1-3): 1
Summary: By using lime mortars the masonry will be less rigid and brittle leading to avoiding the use of movement joints. In areas where foundations are expensive to establish to avoid foundation movements the return to an inherently flexible form of construction is to be welcomed. The problem for the use of lime mortars are the product and design standards. The masonry is designed based on strength and not on elasticity and plasticity.

170: Functionality: Workability, compressive and flexural strength, **flexibility**
Applications: Masonry in general, lime, hydraulic lime, and lime-cement mortars as well as cement with admixtures.
Scientific notion (1-3): 2 (proceedings)
Summary: Same work as in 168. Investigation of the influence of water/binder ratio of fresh mortar on workability and strength of masonry of different lime-based mortars and cement mortars with additives. The main conclusions are that the lime mortars show an influence of anisotropy due to the process of carbonation, while the hydraulic mortars show a decrease of strength with increasing water/binder ratio. The amount of air voids plays an equally important role.

178: Functionality: Carbonation, compressive and flexural strength, porosity, **flexibility**
Applications: Conservation of historic buildings, cement-lime mortars
Scientific notion (1-3): 3
Summary: Investigation of the hardening reactions and their influence on strength development, porosity and microstructure of cement-lime mortars using lime hydrate and lime putty as partial replacement of cement in varying ratios. The main conclusions are that the degree of carbonation is much more pronounced with increasing lime content and porosity of the mortars. Unlike the reference cement mortar, the cement-lime mortars exhibit an elastic-plastic deformation which enables them to adapt to differential settlements and more deformation under critical stresses in the masonry.

203: Functionality: Compressive and flexural strength, **flexibility** (modulus of elasticity)
Applications: Masonry in general, lime-pozzolanic, cement-lime and cement mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of mechanical behaviour of brick masonries derived from unit and mortar characteristics. The aim is to set up a simple mathematical model of the mechanical behaviour of brickwork from which the value of value of strength and deformability parameters can be obtained. The main conclusions are that it is possible to obtain reliable information on the carrying capacity of masonry when the mechanical properties of bricks and mortars are known. Also, the use of high strength cement mortars does not improve the masonry strength because of lack of bond strength and shrinkage of mortars when high absorption bricks are used.
Notes: Interesting to look at masonry and not just bricks and mortars as individual entities. The point that the overall strength of the masonry is not dependent on mortar strength alone is a central topic that could be the focus of future research.

Carbonation

14: Functionality: **Carbonation**, porosity
Applications: Masonry in general, lime and lime-cement pastes
Scientific notion (1-3): 3
Summary: Investigation of variation of microstructure with carbonation of lime and blended pastes. The main conclusion is that porosity and pore structure changes due to carbonation: Porosity decreases around 10% and pore size distribution shifts towards smaller pores.

34: Functionality: **Carbonation**, compressive strength
Applications: Masonry in general, hydrated lime paste
Scientific notion (1-3): 2
Summary: Investigation of reaction kinetics, strength and microstructure of carbonate binders by varying CO_2 gas pressure, exposure time and initial degree of compaction of the raw material. The main conclusion is that the strength of the binder is controlled by the crystalline state and morphology of the carbonate rather than the conversion degree of $Ca(OH)_2$.

39: Functionality: **Carbonation**
Applications: Masonry in general, non-hydraulic lime and lime-pozzolan mortars with and without air-entraining agent, restoration
Scientific notion (1-3): 2
Summary: Investigation of forced and natural carbonation of lime-based mortars with and without additives. The main conclusions are that the carbonation process is faster and more complete with high CO_2 concentration but not affected by additives.

44: Functionality: **Carbonation**
Applications: Masonry in general, lime putty
Scientific notion (1-3): 2
Summary: Investigation of reaction kinetics of carbonation in lime putty. The main conclusion is that reaction speed is not dependent upon CO_2 concentration but on specific surface of the lime.

45: Functionality: **Carbonation**, porosity
Applications: Conservation and restoration of historic structures, non-hydraulic lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the effect of carbonation on pore structure of non-hydraulic lime mortars with mercury intrusion porisometry. The main conclusion is that during carbonation there is an increase in pore volume in the ~0.1 µm pore diameter range across all mortar types which is attributed to the transformation of portlandite to calcite. There is also a monotonic increase in the volumes of pores with diameters below 0.03 µm, most likely due to attachment of calcite crystals to the surface of aggregate particles and in some cases to the surface of portlandite crystals.

92: Functionality: **Carbonation**
Applications: Conservation of historic buildings, lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the effects of lime putty ageing on traditional lime mortar carbonation evolution. The main conclusion is that long-term aged putty mortars have the fastest and highest degree of carbonation and result in significant improvement of mortar quality of increased mortar paste plasticity, workability, and water retention.

123: Functionality: **Carbonation**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the influence of moisture content on the diffusion coefficient of CO_2. The main conclusions are that CO2 diffusion still takes place at high water contents and is only prohibited above the capillary water content. If the pore configuration permits the lime mortar to carbonate even at very humid environments, it equally assures water vapour transfer inside the masonry wall, which is not the case for cement mortars on masonry walls.

127: Functionality: **Carbonation**, water retention,
Applications: Conservation of historic buildings, lime mortars
Scientific notion (1-3): 2
Summary: Review article on lime mortar technology, including burning, slaking, ageing and carbonation of lime for conservation of historic buildings. The main conclusion is that the use of aged lime putty is recommended because the material has higher plasticity and water retention capacity which results in mortars of higher strength that carbonate faster.

130: Functionality: **Carbonation**
Applications: Conservation and restoration of historic buildings, lime mortars
Scientific notion (1-3): 2
Summary: Investigation of carbonation profiles in non-hydraulic lime mortars with thermo gravimetric analysis. The main conclusions are that the carbonation front does not progress linearly through the mortar, it oscillates with Liesegang patterns, carbonation occurs at the core ahead of the carbonation front, and after carbonation there is still a significant amount of uncarbonated lime.

135: Functionality: **Carbonation**
Applications: lime mortars
Scientific notion (1-3): 3
Summary: Non hydraulic lime mortars owe their strength to the mineral calcite. In the presence of atmospheric carbon dioxide this process takes place at a moisture content of the mortar of about 0,8 to 4 %.

161: Functionality: **General characterization of lime-based mortars (water retention, bond strength, efflorescence, self-healing, vapour permeability, carbonation, compressive strength, flexural strength).**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2
Summary: Review article on the difference between lime and cement mortars. Lime-based mortars produce tight, durable mortar bond, and hence watertight walls where cement mortars generally exhibit high bond strengths but have poor extent of bond and also lack durable bonds due to a tendency to develop separation cracking. The principal reasons for the superiority of lime over Portland cement are its higher degree of plasticity and water retention and its greater fineness and inherent stickiness, which permit joints to be filled more readily and completely. The subject of durability in mortars comprises consideration of autogenous healing and efflorescence. The main causes of efflorescence are malconstruction and design, mortar material especially cement with alkali content, environmental conditions with high rainfall. The positive role of lime in combating the efflorescence of masonry is attributed first to the fact that it hinders water penetration but mainly to its extremely low content of soluble salts and sulphur.
Notes: Good review article

172: Functionality: **Carbonation**
Applications: Masonry in general, lime pastes
Scientific notion (1-3): 2
Summary: Investigation of carbonation reaction kinetics of lime pastes with different water content using in-situ XRD. The main conclusion is that higher reaction rates were recorded for the samples with a higher content of water due to an increase in the amount of dissolved CO_2.
Notes: Interesting analytical technique with in-situ XRD and CO_2 atmosphere. No new results.

173: Functionality: **Carbonation**
Applications: Masonry in general, lime, hydraulic and lime-pozzolan mortars
Scientific notion (1-3): 2
Summary: Investigation of carbonation reaction kinetics of lime, hydraulic and lime-pozzolan pastes. The dependence of the reaction rate on CO_2 concentration and specific surface area of the lime hydrate have been investigated. The main conclusions are that a correlation has been recorded between the uptake speed and the start of CO_2 concentration and a correlation has not been established between the maximum net uptake speed and the specific surface area of the lime. The amount of total calcium hydroxide that remained uncarbonated is 9-12%.

175: Functionality: **Carbonation**
Applications: Masonry in general, lime pastes
Scientific notion (1-3): 2
Summary: Same material as in #172. Investigation of the influence of high CO_2 concentration on the polymorph and size of calcium carbonate crystals precipitated during carbonation of lime binders. The main conclusion is that exposure of lime binders in high CO_2 concentrations leads to a modification in the habit, morphology and size of the calcite crystals.
Notes: Important as most investigations of carbonation is through accelerated tests.

178: Functionality: **Carbonation**, compressive and flexural strength, porosity, flexibility
Applications: Conservation of historic buildings, cement-lime mortars
Scientific notion (1-3): 3
Summary: Investigation of the hardening reactions and their influence on strength development, porosity and microstructure of cement-lime mortars using lime hydrate and lime putty as partial replacement of cement in varying ratios. The main conclusions are that the degree of carbonation is much more pronounced with increasing lime content and porosity of the mortars. Unlike the reference cement mortar, the cement-lime mortars exhibit an elastic-plastic deformation which enables them to adapt to differential settlements and more deformation under critical stresses in the masonry.

174 + 177 + 179: Functionality: **Carbonation**, compressive and flexural strength, porosity
Applications: Masonry in general, lime, hydraulic and lime-pozzolan mortars
Scientific notion (1-3): 2
Summary: Investigation of the influence of rice husk ash and lime on the hardening and strength development of cement mortars. The main conclusions are that the effect of the pozzolanic reaction on the early strength gain of the RHA-cement was not clear while it seemed to contribute to their long-term strength development. Carbonation reaction was favoured at the later stage due to the higher porosity of the RHA-cement mortars and yielded lower strength values compared with the reference cement. However, strength reduction was recorded in the very early stage of the mortars when cement in low content (10%-wt) was used in combination with RHA and lime.

Vapour permeability

38: Functionality: Porosity**, vapour permeability**
Applications: Restoration of historic buildings, air-hardening lime mortars partially replaced with cement and hydraulic lime
Scientific notion (1-3): 3
Summary: Investigation of the effect of cement addition on the pore structure of air-hardening lime mortars. A second target is to establish correlation between microstructure and water vapour transport. The main conclusions are that porosity, pore size and water vapour diffusivity are progressively reduced as the cement content increases. With respect to restoration, aerial lime mortars with low cement content as agglomerate are more suitable than those containing hydraulic lime as binder. Further, the addition of cement in the proportions used in this study generates more permeable mixes than the typical masonry of historic buildings.

65: Functionality: Porosity, water penetration, **vapour permeability**
Applications: Restoration and conservation, repair and maintenance, hydraulic lime (NHL), lime and cement mortars
Scientific notion (1-3): 2
Summary: Investigation of waterproof historic masonry with hydraulic lime mortars with siloxane impregnation. The main conclusions are that by comparison with the cement mortars which obstruct water vapour transmission, the lime mortar proved to be the most permeable material. The impregnated mortars show less water vapour permeability; nevertheless, the transportation of water vapour through the surface has not been impeded by the application of the resin. Part of the study includes the difference between cement and lime mortars demonstrating that lime mortars have lower water absorption coefficients, higher porosity and are more permeable than cement mortars.
Notes: Interesting perspectives for future lime mortars

73: Functionality: Capillary porosity, **vapour permeability**, compressive and flexural strength**,** hydraulic properties
Applications: Conservation of historic buildings, lime and lime-pozzolan plaster
Scientific notion (1-3): 1-2
Summary: Investigation of basic, mechanical, thermal and hygric properties of lime-pozzolan plaster mixtures with metakaolin, grinded brick and grinded enamel glass as the pozzolan material is analyzed. The main conclusions are that a significant increase of both compressive and bending strength of the studied plasters was achieved. Most thermal and hygric properties of lime-pozzolan plasters were found to be either comparable or even better than the respective properties of classical lime plaster. The only exception was the linear hygric expansion coefficient that was higher than for the common lime plaster.

161: Functionality: **General characterization of lime-based mortars (water retention, bond strength, efflorescence, self-healing, vapour permeability, carbonation, compressive strength, flexural strength).**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2

Summary: Review article on the difference between lime and cement mortars. Lime-based mortars produce tight, durable, mortar bond, and hence watertight walls where cement mortars generally exhibit high bond strengths but have poor extent of bond and also lack durable bonds due to a tendency to develop separation cracking. The principal reasons for the superiority of lime over Portland cement are its higher degree of plasticity and water retention and its greater fineness and inherent stickiness, which permit joints to be filled more readily and completely. The subject of durability in mortars comprises consideration of autogenous healing and efflorescence. The main causes of efflorescence are malconstruction and design, mortar material especially cement with alkali content, environmental conditions with high rainfall. The positive role of lime in combating the efflorescence of masonry is attributed first to the fact that it hinders water penetration but mainly to its extremely low content of soluble salts and sulphur.
Notes: Good review article

190: Functionality: Vapour permeability
Applications: Masonry in general, lime wash
Scientific notion (1-3): 1 (proceedings)
Summary: Discussion of lime wash as a proven, versatile and beautiful material to protect and maintain a wide range of building facades. The main statements are that it is materially inexpensive, easy to apply, and durable. Lime wash can beneficially consolidate damaged substrates and is vapour-permeable, allowing a building to breathe.

208: Functionality: Vapour permeability
Applications: Surface treatment of masonry with thin layer of mortar, paint and lime wash
Scientific notion (1-3): 2
Summary: The vapour permeability is lower for masonry with an applied thin layer of mortar and paint compared to the not treated masonry, while the vapour permeability of the masonry with an applied layer of lime wash seems to be a little bit better than the non treated masonry.

Porosity, capillary porosity

3: Functionality: **General characterization of lime-based mortars (bond strength, compressive strength, flexural strength, efflorescence, vapour permeability, water retention, porosity, flexibility)**
Applications: Conservation of historic buildings, traditional lime-based and “ready to use” renders
Scientific notion (1-3): 1-2
Summary: Investigation of the performances of a new generation of cement-based mortars, so-called “ready to use”, compared with the traditional lime-based mortars used nowadays in the field of ancient masonries. It is stated that some of the factory made renders (“ready to use”) are still too waterproof and have too high mechanical performances while others have evolved towards performances much more compatible with ancient masonries. The result is that some of these renders are easier

to use than the traditional mortars and thus can represent an interesting alternative to traditional mortars in restoration operations.
Notes: Not very convincing data, and also a lot of different French test methods.

13: Functionality: **Porosity, capillary porosity**
Applications: Restoration works of cultural heritage, lime-based and blended pastes
Scientific notion (1-3): 3
Summary: Investigation of the effect of different cement content on pore structure and capillary porosity. The results show that when the cement content increases, the complexity of the microstructure and surface of the blended pastes increases and the porosity and capillary coefficient decreases. The main conclusion is that in order to choose a binding material for restoration works, high cement mixes would have a great durability in front of the moisture?

14: Functionality: Carbonation, **porosity**
Applications: Masonry in general, lime and lime-cement pastes
Scientific notion (1-3): 3
Summary: Investigation of variation of microstructure with carbonation of lime and blended pastes. The main conclusion is that porosity and pore structure changes due to carbonation: Porosity decreases around 10% and pore size distribution shifts towards smaller pores.

15: Functionality: **Porosity, capillary porosity**
Applications: Masonry in general and restoration works of cultural heritage, lime-based pastes
Scientific notion (1-3): 3
Summary: Investigation of the effect of different W/L ratio on pore structures and capillary porosity. The results show that when the W/L ratio increases, the porosity and capillary coefficient increases (more uptake of water). The conclusion is that kneading water is only responsible for a swelling of the structure, but does not change the pore surface.

32: Functionality: **Porosity,** compressive strength
Applications: Repair mortars for ancient masonry and concrete industry (admixture), slaked lime – metakaolin mortar
Scientific notion (1-3): 2
Summary: Investigation of the effect of different slaked lime-metakaolin mortar mixes on porosity and compressive strength. The main findings of the statistical analysis of the results are that increasing SL + MK/sand ratio increases the strength, porosity and amount of binder formed. The next factor in order of importance is the presence of super plasticizer admixture, where the presence of super plasticizer increases strength, raises the calcite content and reduces porosity. However, curing or natural carbonation time does not seem to have any significant effect on composition or porosity. The SL-MK mortars are promising as repair mortars.
Notes: Not that relevant because it is a special mortar with MK and admixture.

33: Functionality: Compressive and flexural strength, **porosity, capillary porosity**
Applications: Repair of monuments and manufacture of renderings and plasters, lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the role of aggregates on the strength, porosity and capillary porosity of lime mortars. The main findings are that the highest strength is attained with low binder/aggregate ratio (1:1.5, 1:2.5, 1:3) and sand aggregate in the fraction 0-4 mm. For coarser aggregate fractions, strong compaction of the mortars is necessary to reduce voids and increase the bond of lime paste with pebbles. Compaction also reduces water penetration.

37: Functionality: Flexibility, compressive and flexural strength, **porosity**
Applications: Restoration work, cement-lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour of lime-cement mortars in the full range of compositions 0-100% cement. The main conclusion is that lime-rich mortars are able to absorb a high degree of deformation before breakage (high flexibility), and thus have great potential as materials for restoration work as they can accommodate the movements of ancient buildings. Further, with increasing cement content, the surface fractal dimension (indicator of complexity of the pore system) and mechanical strength increases.

38: Functionality: **Porosity,** vapour permeability
Applications: Restoration of historic buildings, air-hardening lime mortars partially replaced with cement and hydraulic lime
Scientific notion (1-3): 3
Summary: Investigation of the effect of cement addition on the pore structure of air-hardening lime mortars. A second target is to establish correlation between microstructure and water vapour transport. The main conclusions are that porosity, pore size and water vapour diffusivity are progressively reduced as the cement content increases. With respect to restoration, aerial lime mortars with low cement content as agglomerate are more suitable than those containing hydraulic lime as binder. Further, the addition of cement in the proportions used in this study generates more permeable mixes than the typical masonry of historic buildings.

45: Functionality: Carbonation, **porosity**
Applications: Conservation and restoration of historic structures, non-hydraulic lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the effect of carbonation on pore structures of non-hydraulic lime mortars with mercury intrusion porisometry. The main conclusion is that during carbonation there is an increase in pore volume in the ~0.1 µm pore diameter range across all mortar types which is attributed to the transformation of portlandite to calcite. There is also a monotonic increase in the volumes of pores with diameters below 0.03 µm, most likely due to attachment of calcite crystals to the surface of aggregate particles and in some cases to the surface of portlandite crystals.

47: Functionality: **Porosity, compressive and flexural strength, flexibility (elastic modulus)**
Applications: Restoration work, mortars of aerial lime, hydraulic lime, cement and other pozzolanic materials.
Scientific notion (1-3): 3
Summary: Characterization of several mortar types to improve knowledge that will facilitate the further choice of suitable material to replace any old mortar. The mortars are characterized with respect to chemical and mineralogical compositions and physical properties (density, porosity, strength and elastic modulus).
Notes: Not really conclusive but instead knowledge matrix for future comparison.

59: Functionality: **Durability (Porosity, compressive and flexural strength, SO_2, freeze-thaw resistance)**
Applications: Restoration work, aerial and hydraulic mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour in hardened repair lime-based mortars (aerial and hydraulic) subjected to different environments: Outside exposure, weathering cycles (in a climatic chamber), SO_2-rich environment (in a SO_2 chamber), freeze-thaw cycles and indoor exposure (laboratory conditions). This allows evaluating and comparing the durability of the repair lime-based mortars. The main conclusion is that aerial lime mortars exposed to SO_2-rich environment, results in the formation of gypsum that causes a strength drop.

61: Functionality: **Porosity**, compressive and flexural strength, (binder/aggregate ratio and aggregate psd and chemistry)
Applications: Restoration works, natural hydraulic lime-based mortars.
Scientific notion (1-3): 2
Summary: Investigation of the factors affecting the mechanical behaviour in different NHL-based mortars. The influence of curing time, binder/aggregate ratio, nature and particle size distributions of the aggregates, and porosity has been studied. The main conclusions are that specimens with more binder content show the highest compressive and flexural strengths. With respect to aggregate, a suitable grain size distribution, angle-shape and limestone composition give the highest strengths. High porosity, due to large binder amount, results in increased strength as well.

65: Functionality: **Porosity**, water penetration, vapour permeability
Applications: Restoration and conservation, repair and maintenance, hydraulic lime (NHL), lime and cement mortars
Scientific notion (1-3): 2
Summary: Investigation of waterproof historic masonry with hydraulic lime mortars with siloxane impregnation. The main conclusions are that by comparison with the cement mortars which obstruct water vapour transmission, the lime mortar proved to be the most permeable material. The impregnated mortars show less water vapour permeability; nevertheless, the transportation of water vapour through the surface has not been impeded by the application of the resin. Part of the study includes the difference between cement and lime mortars demonstrating that lime mortars have lower water absorption coefficients, higher porosity and are more permeable than cement mortars.
Notes: Interesting perspectives for future lime mortars

73: Functionality: **Capillary porosity**, vapour permeability, compressive and flexural strength**,** hydraulic properties
Applications: Conservation of historic buildings, lime and lime-pozzolan plaster
Scientific notion (1-3): 1-2
Summary: Investigation of basic, mechanical, thermal and hygric properties of lime-pozzolan plaster mixtures with metakaolin, grinded brick and grinded enamel glass as the pozzolan material is analyzed. The main conclusions are that a significant increase of both compressive and bending strength of the studied plasters was achieved. Most thermal and hygric properties of lime-pozzolan plasters were found to be either comparable or even better than the respective properties of classical lime plaster. The only exception was the linear hygric expansion coefficient that was higher than for the common lime plaster.

80: Functionality: **Porosity**
Applications: Repair works, lime pozzolan mortars
Scientific notion (1-3): 2
Summary: Investigation of the strength-porosity relationships in lime-pozzolan mortars to find the effect of water/binder ratio, the aggregate volume content, the evolution of porosity with time. The main conclusion is that the water/binder ratio is the most important parameter in controlling the porosity.

104: Functionality: Hydraulic properties, **porosity**, compressive strength
Applications: Masonry in general, lime-pozzolan mortars.
Scientific notion (1-3): 2
Summary: Investigation of the effect of lime content on the water requirement, initial porosity, strength development, pozzolanic reaction rate, and microstructure of lime-natural-pozzolan mixtures. Also, the effect of quicklime and hydrated lime on the strength development and pozzolanic reaction. The main conclusions are that an increase of lime over a critical value results in an increase in water requirement and initial porosity, and the strength of the lime-pozzolan pastes decreases. A mixture of 20% hydrated lime and 80% natural pozzolan is regarded as an optimum mixture.

117: Functionality: SO_2, salt crystallization, **porosity**
Applications: Masonry in general, cement and lime-pozzolan mortars, degradation of concrete
Scientific notion (1-3): 2
Summary: Investigation of acid rain degradation of cement and lime-pozzolan mortars. Lime-pozzolan mortars are more resistant to acid rain attack than cement mortars due to the absence of free hydrated lime. Cement mortars with higher porosity (w/c ratio) retain more soluble salts from the acid rain solution.

120: Functionality: Durability (efflorescence, salt crystallization, water penetration, freeze-thaw resistance, **porosity**)
Applications: Repair of historic buildings, fat and feebly lab lime binder
Scientific notion (1-3): 2
Summary: Investigation of the durability and long-term behaviour of lime putty and feebly-hydraulic lime mortar. The tests consisted of both thermal and salt crystallization cycles, as well as water absorption, capillary suction and porosity. The main findings are that thermal cycling had no effect on mortars whereas salt

crystallization cycles were too aggressive to the samples. Feebly-hydraulic mortar possesses the highest porosity, overall capillary suction and water absorption, being capable of holding the greatest amount of moisture. These suggest that the feebly-hydraulic lime mortar is the most susceptible to failure by water dissolution and expansion. The tests governing moisture movement suggest that mortars fabricated with fat (non-hydraulic) lime are more durable than feebly-hydraulic lime mortars.

124: Functionality: P**orosity, capillary porosity**
Applications: Restoration of cultural built heritage, lime mortars
Scientific notion (1-3): 2
Summary: Investigation of the influence of mortar composition and curing circumstances for different hydrated lime mortars on the physical properties. Variation in slaking method, type of aggregate, binder/aggregate ratio and physical properties of carbonation depth, total porosity, pore size distribution, capillary water absorption. The main conclusion is that binder/aggregate ratio and granulometry have the strongest influence on the pore structure of the hydrated lime mortars.

178: Functionality: Carbonation, compressive and flexural strength, **porosity**, flexibility
Applications: Conservation of historic buildings, cement-lime mortars
Scientific notion (1-3): 3
Summary: Investigation of the hardening reactions and their influence on strength development, porosity and microstructure of cement-lime mortars using lime hydrate and lime putty as partial replacement of cement in varying ratios. The main conclusions are that the degree of carbonation is much more pronounced with increasing lime content and porosity of the mortars. Unlike the reference cement mortar, cement-lime mortars exhibit an elastic-plastic deformation which enable them to adapt to differential settlements and more deformation under critical stresses in masonry.

174 + 177 + 179: Functionality: Carbonation, compressive and flexural strength, **porosity**
Applications: Masonry in general, lime, hydraulic and lime-pozzolan mortars
Scientific notion (1-3): 2
Summary: Investigation of the influence of rice husk ash and lime on the hardening and strength development of cement mortars. The main conclusions are that the effect of the pozzolanic reaction on the early strength gain of the RHA-cement was not clear while it seemed to contribute to their long-term strength development. Carbonation reaction was favoured at the later stage due to the higher porosity of the RHA-cement mortars and yielded lower strength values compared with the reference cement. However, strength reduction was recorded in the very early stage of the mortars when cement in low content (10%-wt) was used in combination with RHA and lime.

Freeze-thaw resistance

2: Functionality: **Freeze-thaw resistance**, durability
Applications: New build, lime mortar and hydraulic lime mortar used as render
Scientific notion (1-3): 1-2
Summary: Investigation of durability of lime-based mortars in a severe climate based on field and artificial ageing tests. The main conclusions are that only minor deterioration occurred after one year exposure on field stations, and pure air-lime mortars had similar weather resistance as hydraulic lime mortar.

59: Functionality: **Durability (Porosity, compressive and flexural strength, SO_2, freeze-thaw resistance)**
Applications: Restoration work, aerial and hydraulic mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour in hardened repair lime-based mortars (aerial and hydraulic) subjected to different environments: Outside exposure, weathering cycles (in a climatic chamber), SO_2-rich environment (in a SO_2 chamber), freeze-thaw cycles and indoor exposure (laboratory conditions). This allows evaluating and comparing the durability of the repair lime-based mortars. The main conclusion is that aerial lime mortars exposed to SO_2-rich environment result in the formation of gypsum that causes a strength drop.

68: Functionality: **Freeze-thaw**, hydraulic properties
Applications: Repair mortar for restoration of ancient buildings, lime mortars with aggregates of crushed ceramics and volcanics
Scientific notion (1-3): 2
Summary: Experimental study of ancient mortars from Sagalassos to design a suitable repair mortar for restoration and conservation purposes, focusing on durability against frost damage. Lime together with crushed ceramics, volcanic and a combination of the two were tested. The main conclusion is that mortars prepared with limestone and volcanic aggregates have the best freeze-thaw resistance, probably due to an appropriate pore structure and sufficient mechanical strength.

120: Functionality: Durability (efflorescence, salt crystallization, water penetration, **freeze-thaw resistance**, porosity)
Applications: Repair of historic buildings, fat and feebly lab lime binder
Scientific notion (1-3): 2
Summary: Investigation of the durability and long-term behaviour of lime putty and feebly-hydraulic lime mortar. The tests consisted of both thermal and salt crystallization cycles, as well as water absorption, capillary suction and porosity. The main findings are that thermal cycling had no effect on mortars whereas salt crystallization cycles were too aggressive to the samples. Feebly-hydraulic mortar possesses the highest porosity, overall capillary suction and water absorption, being capable of holding the greatest amount of moisture. These suggest that the feebly-hydraulic lime mortar is the most susceptible to failure by water dissolution and expansion. The tests governing moisture movement suggest that mortars fabricated with fat (non-hydraulic) lime are more durable than feebly-hydraulic lime mortars.

222: Functionality: **Durability**
Applications: Masonry mortars
Scientific notion (1-3): 2
Summary: The article is a study of what appears to be the most significant research in the mortar field in relation to durability of mortars. Based on the extensive background it is concluded that the use of lime in mortars contributes to water tight walls and durable masonry structures.

Water penetration

9: Functionality: Flexural bond strength**, water penetration**
Applications: Masonry in general, cement-lime and polymer-modified mortars
Scientific notion (1-3): 2
Summary: Investigation of bond strength between cement-lime mortar and polymer-modified mortar and shale brick. The main conclusions are that cement-lime mortars, but not polymer-modified mortars, are able to create continuous bonds with brick surfaces and completely fill spaces in brick surfaces. Although the bond strength of CL mortars cannot reach the high value of PL mortars, a good CL mortar bond allows little or no water to enter or penetrate between the mortar and brick during service.

10: Functionality: **Water penetration**, water retention, air content, compressive strength
Applications: cement-lime and cement-lime replacement mortar
Scientific notion (1-3): 3
Summary: The cement-lime replacement mortars have different properties compared to cement-lime mortar. The cement-lime replacement mortars have lower water/binder ratios, lower water retention, greater air content and lower compressive strength. In addition masonry walls constructed using cement-lime replacement mortars are less resistant to moisture penetration compared to masonry walls constructed using cement-lime mortars.

19: Functionality: **Water penetration**
Applications: Lime renders
Scientific notion (1-3): 1
Summary: An investigation of the climate and the use of lime rendering mortars in Germany shows that in wet coastal climate the use is not so widespread compared to areas with continental climate, where in former times all houses were rendered with lime render. In areas with coastal climate the durability of lime mortar has been obtained by special technique.

65: Functionality: Porosity, **water penetration**, vapour permeability
Applications: Restoration and conservation, repair and maintenance, hydraulic lime (NHL), lime and cement mortars
Scientific notion (1-3): 2
Summary: Investigation of waterproof historic masonry with hydraulic lime mortars with siloxane impregnation. The main conclusions are that by comparison with the cement mortars which obstruct water vapour transmission, the lime mortar proved to

be the most permeable material. The impregnated mortars show less water vapour permeability; nevertheless, the transportation of water vapour through the surface has not been impeded by the application of the resin. Part of the study includes the difference between cement and lime mortars demonstrating that lime mortars have lower water absorption coefficients, higher porosity and are more permeable than cement mortars.
Notes: Interesting perspectives for future lime mortars

120: Functionality: Durability (efflorescence, salt crystallization, **water penetration**, freeze-thaw resistance, porosity)
Applications: Repair of historic buildings, fat and feebly lab lime binder
Scientific notion (1-3): 2
Summary: Investigation of the durability and long-term behaviour of lime putty and feebly-hydraulic lime mortar. The tests consisted of both thermal and salt crystallization cycles, as well as water absorption, capillary suction and porosity. The main findings are that thermal cycling had no effect on mortars whereas salt crystallization cycles were too aggressive to the samples. Feebly-hydraulic mortar possesses the highest porosity, overall capillary suction and water absorption, being capable of holding the greatest amount of moisture. These suggest that the feebly-hydraulic lime mortar is the most susceptible to failure by water dissolution and expansion. The tests governing moisture movement suggest that mortars fabricated with fat (non-hydraulic) lime are more durable than feebly-hydraulic lime mortars.

180: Functionality: **Water penetration,** bond strength
Applications: Masonry in general, lime type S
Scientific notion (1-3): Review
Summary: Review of water penetration of masonry composed of lime type S mortar compared with ordinary cement. The main conclusion is that masonry walls constructed with mortars containing type S lime are more resistant to water leakage than those constructed with mortars containing no lime.
Notes: Resistance against water penetration due to better bonding -> (bond strength)

220: Functionality: Compressive and flexural strength of masonry, workability, water retentivity, **water penetration**
Applications: Masonry mortars
Scientific notion (1-3): 3
Summary: Masonry build of cement - lime mortars mixed 1:2:9 provide adequate wall strength for nearly all uses of masonry construction. The high lime content in the mortar contributes to other important characteristics such as improved workability and water retentivity leading to a good bond between units and mortar and thereby watertight joints. Cement in the mortar is mainly used to provide high early strength so that the construction work can proceed rapidly.

221: Functionality: **Water penetration**
Applications: Masonry mortars
Scientific notion (1-3): 3
Summary: Masonry test panels made of cement-lime mortars and masonry cement mortars is tested for water permeance. The panels made of cement-lime mortars reduce the water leakage up to ten times compared to the panels made by masonry

cement mortars. An explanation is the higher air content of masonry cement mortars leading to a lower bond between units and mortar. The self-healing aspects of lime in mortars explain the increased moisture resistance tested after six months of outdoor curing.

Salt crystallization

40: Functionality: **Salt crystallization**
Applications: Masonry in general, lime-cement mortar
Scientific notion (1-3): 3
Summary: Investigation of the effect of NaCl on lime-cement mortar. The main findings are that NaCl is able to modify the hydric and hygric behaviour and the related dilation of material completely, resulting in an irreversible dilation during the drying phase when the salt crystallizes.

100: Functionality: **Salt content**
Applications: Red ceramic bricks and lime mortars
Scientific notion (1-3): 3
Summary: The research is carried out in order to test the applicability of the hygroscopic moisture content method to determine the salt content in lime mortars and ceramic bricks. For most of the salts there seems to be a good correlation. For sodium sulphate the correlation seems good when the content is 2 % or less whereas some uncertainties seem to appear with a higher content. For potassium and calcium sulphate the methods cannot be used.

117: Functionality: SO_2, **salt crystallization**, porosity
Applications: Masonry in general, cement and lime-pozzolan mortars, degradation of concrete
Scientific notion (1-3): 2
Summary: Investigation of acid rain degradation of cement and lime-pozzolan mortars. Lime-pozzolan mortars are more resistant to acid rain attack than cement mortars due to the absence of free hydrated lime. Cement mortars with higher porosity (w/c ratio) retain more soluble salts from the acid rain solution.

120: Functionality: Durability (efflorescence, **salt crystallization**, water penetration, freeze-thaw resistance, porosity)
Applications: Repair of historic buildings, fat and feebly lab lime binder
Scientific notion (1-3): 2
Summary: Investigation of the durability and long-term behaviour of lime putty and feebly-hydraulic lime mortar. The tests consisted of both thermal and salt crystallization cycles, as well as water absorption, capillary suction and porosity. The main findings are that thermal cycling had no effect on mortars whereas salt crystallization cycles were too aggressive to the samples. Feebly-hydraulic mortar possesses the highest porosity, overall capillary suction and water absorption, being capable of holding the greatest amount of moisture. These suggest that the feebly-hydraulic lime mortar is the most susceptible to failure by water dissolution and expansion. The tests governing moisture movement suggest that mortars fabricated with fat (non-hydraulic) lime are more durable than feebly-hydraulic lime mortars.

SO_2 (sulphate attack)

18: Functionality: **SO_2**
Applications: Masonry in general, ancient and modern hydraulic mortars, cement and hydraulic lime-based mortars.
Scientific notion (1-3): 3
Summary: Investigation of collected ancient and recent hydraulic mortars demonstrates that deterioration takes place by sulphate attack by gypsum formation on the external surface of the sample. Secondary damaging product of ettringite occurs in deeper areas of the sample by reaction between gypsum/pollutant SO_2 and calcium aluminate hydrates from the binder. Ettringite is unstable in atmospheric CO_2.

31: Functionality: **SO_2**
Applications: Masonry in general, cement and hydraulic lime-based mortars.
Scientific notion (1-3): 3
Summary: Investigation of thaumasite formation in cement and lime-based mortars demonstrates that gypsum is first formed by interaction of hydraulic mortar with SO2. Subsequently gypsum reacts with calcium carbonate and C-S-H gel to form thaumasite. The primary conclusion is that cement mortars have higher tendency to form thaumasite than hydraulic lime.

59: Functionality: **Durability (Porosity, compressive and flexural strength, SO_2, freeze-thaw resistance)**
Applications: Restoration work, aerial and hydraulic mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour in hardened repair lime-based mortars (aerial and hydraulic) subjected to different environments: Outside exposure, weathering cycles (in a climatic chamber), SO_2-rich environment (in a SO_2 chamber), freeze-thaw cycles and indoor exposure (laboratory conditions). This allows evaluating and comparing the durability of the repair lime-based mortars. The main conclusion is that aerial lime mortars exposed to SO_2-rich environment result in the formation of gypsum that causes a strength drop.

109: Functionality: **SO_2**
Applications: Modern and ancient hydraulic mortars
Scientific notion (1-3): 2
Summary: Investigation of modern and ancient hydraulic mortars for damage caused by SO_2 pollution. The main effect of air pollution of hydraulic mortars is gypsum formation and secondary damaging products ettringite and thaumasite. Hydraulic mortars are the most sensitive building materials because of both primary and secondary damage products.

117: Functionality: **SO_2**, salt crystallization, porosity
Applications: Masonry in general, cement and lime-pozzolan mortars, degradation of concrete
Scientific notion (1-3): 2
Summary: Investigation of acid rain degradation of cement and lime-pozzolan mortars. Lime-pozzolan mortars are more resistant to acid rain attack than cement mortars due to the absence of free hydrated lime. Cement mortars with higher porosity (w/c ratio) retain more soluble salts from the acid rain solution.

129: Functionality: **SO_2**
Applications: Restoration of historic buildings, aerial and hydraulic lime-based mortars
Scientific notion (1-3): 3
Summary: Aerial and hydraulic lime-based mortars exposed to different environmental conditions – outside, SO_2, climatic. Lab controlled testing. SO_2 exposure results in sulphate attacks on the surface with gypsum in aerial mortars and gypsum and syngenite in hydraulic lime-based mortars.

<u>Self-healing</u>

<u>Efflorescence</u>

3: Functionality: **General characterization of lime-based mortars (bond strength, compressive strength, flexural strength, efflorescence, vapour permeability, water retention, porosity, flexibility)**

Applications: Conservation of historic buildings, traditional lime-based and “ready to use” renders
Scientific notion (1-3): 1-2
Summary: Investigation of the performances of a new generation of cement-based mortars, so-called “ready to use”, compared with the traditional lime-based mortars used nowadays in the field of ancient masonries. It is stated that some of the factory made renders (“ready to use”) are still too waterproof and have too high mechanical performances while others have evolved towards performances much more compatible with ancient masonries. The result is that some of these renders are easier to use than traditional mortars and thus can represent an interesting alternative to traditional mortars in restoration operations.
Notes: Not very convincing data, and also a lot of different French test methods.

101: Functionality: **Efflorescence**
Applications: Historical buildings, hydraulic lime-based plaster (in-field experiments)
Scientific notion (1-3): 2
Summary: Investigation of new macro porous hydraulic lime-based plaster (Antol Risan Calce) designated to resist salt crystallization from rising damp and the durability of the plaster. Many factors affect the formation of efflorescence such as salt solubility, amount of water present in the brick wall and brick pore structure. Compared to the traditional hydraulic lime-based plaster, new plaster does not show either presence of efflorescence or of crypto-florescence.
Notes: Not really relevant

120: Functionality: Durability (**efflorescence**, salt crystallization, water penetration, freeze-thaw resistance, porosity)
Applications: Repair of historic buildings, fat and feebly lab lime binder
Scientific notion (1-3): 2
Summary: Investigation of the durability and long-term behaviour of lime putty and feebly-hydraulic lime mortar. The tests consisted of both thermal and salt crystallization cycles, as well as water absorption, capillary suction and porosity. The main findings are that thermal cycling had no effect on mortars whereas salt crystallization cycles were too aggressive to the samples. Feebly-hydraulic mortar possesses the highest porosity, overall capillary suction and water absorption, being capable of holding the greatest amount of moisture. These suggest that the feebly-hydraulic lime mortar is the most susceptible to failure by water dissolution and expansion. The tests governing moisture movement suggest that mortars fabricated with fat (non-hydraulic) lime are more durable than feebly-hydraulic lime mortars.

161: Functionality: **General characterization of lime-based mortars (water retention, bond strength, efflorescence, self-healing, vapour permeability, carbonation, compressive strength, flexural strength).**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2
Summary: Review article on the difference between lime and cement mortars. Lime-based mortars produce tight, durable mortar bond, and hence watertight walls where cement mortars generally exhibit high bond strengths but have poor extent of bond and also lack durable bonds due to a tendency to develop separation cracking. The

principal reasons for the superiority of lime over Portland cement are its higher degree of plasticity and water retention and its greater fineness and inherent stickiness, which permit joints to be filled more readily and completely. The subject of durability in mortars comprises consideration of autogenous healing and efflorescence. The main causes of efflorescence are malconstruction and design, mortar material especially cement with alkali content, environmental conditions with high rainfall. The positive role of lime in combating the efflorescence of masonry is attributed first to the fact that it hinders water penetration but mainly to its extremely low content of soluble salts and sulphur.
Notes: Good review article

165: Functionality: **Efflorescence**
Applications: Masonry in general, lime, hydraulic and cement mortars
Scientific notion (1-3): 2
Summary: Review of efflorescence in masonry. The conclusion is that efflorescence is caused by multiple factors. Efflorescence increases with increasing proportions of Portland cement, alkali salts, soft-burned highly absorptive bricks, and high moisture content in masonry walls due to faulty design and construction practices. Thus, pure lime mortar generally has very low efflorescence potential compared to cement.

166: Functionality: **Efflorescence**, salt crystallization
Applications: Masonry in general
Scientific notion (1-3):
Summary: Review with definition of efflorescence and salt crystallization. No clear distinction. Efflorescence is white deposits on the surface of concrete or masonry, by migration of soluble salt and deposition by evaporation. This is mainly calcium hydroxide originating from the hydrated cement paste. Sodium or calcium sulphates often originate from the outside of the given concrete element from the groundwater in contact with the concrete element.

Hydraulic properties

11: Functionality: **Hydraulic properties**
Applications: “coccipesto” mortars
Scientific notion (1-3): 3
Summary: The hydraulic properties of the mortar are the best when lime is mixed with crossed clay burned at a temperature of 500-600 °C

35: Functionality: Compressive and flexural strength, flexural bond strength of masonry, flexibility, **hydraulic property**
Applications: Restoration work, lime and hydraulic lime mortars
Scientific notion (1-3): 2
Summary: Investigation of strength development and lime reaction in time for several mixtures of lime and hydraulic lime mortars. The main conclusions are that all the examined mortars present very slow rates of hardening, with the exception of hydraulic lime mortar and mortar with lime putty-natural pozzolanic addition. The best mechanical behaviour was observed in mortars with lime powder and lime

powder-artificial pozzolanic addition. These materials present also a low ratio of compressive to flexural strength.
Notes: Interesting because of extremely long curing times.

66: Functionality: **Hydraulic properties**
Applications: Historic mortars
Scientific notion (1-3): 3
Summary: Brick powder used as aggregates in mortars and plasters have good pozzolanicity mainly derived from their amorphous clay mineral dissociation products. All the bricks used were little vitrified and did not contain high temperature products like mullite. They have been fired at a low temperature. The results may indicate that the pozzolanic bricks were particularly chosen for the manufacturing of hydraulic mortars and plasters.

68: Functionality: Freeze-thaw, **hydraulic properties**
Applications: Repair mortar for restoration of ancient buildings, lime mortars with aggregates of crushed ceramics and volcanics
Scientific notion (1-3): 2
Summary: Experimental study of ancient mortars from Sagalassos to design a suitable repair mortar for restoration and conservation purposes, focusing on durability against frost damage. Lime together with crushed ceramics, volcanics and a combination of the two were tested. The main conclusion is that mortars prepared with limestone and volcanic aggregates have the best freeze-thaw resistance, probably due to an appropriate pore structure and sufficient mechanical strength.

73: Functionality: Capillary porosity, vapour permeability, compressive and flexural strength**, hydraulic properties**
Applications: Conservation of historic buildings, lime and lime-pozzolan plaster
Scientific notion (1-3): 1-2
Summary: Investigation of basic, mechanical, thermal and hygric properties of lime-pozzolan plaster mixtures with metakaolin, grinded brick and grinded enamel glass as the pozzolan material is analyzed. The main conclusions are that a significant increase of both compressive and bending strength of the studied plasters was achieved. Most thermal and hygric properties of lime-pozzolan plasters were found to be either comparable or even better than the respective properties of classical lime plaster. The only exception was the linear hygric expansion coefficient that was higher than for the common lime plaster.

77: Functionality: Compressive and flexural bond strength**, hydraulic properties**
Applications: Historic mortars
Scientific notion (1-3): 3
Summary: The investigated historic mortar presents high tensile strengths in comparison with other traditional mortars. The cementitious character of the historic mortar could be attributed to hot lime technology and the addition of montmorillonitic clay dust to the lime.

79: Functionality: **Hydraulic properties**
Applications: Crushed brick/lime mortar (Hagia Sophia)
Scientific notion (1-3): 3
Summary: The aim of the study is to find out what the mortar mixes have been used in the different periods of the building of Hagia Sophia. It has also been studied in what ways the use of crushed bricks are improving the bond in the interface between bricks and mortars.

99: Functionality: **Hydraulic properties**
Applications: lime mortars
Scientific notion (1-3): 1
Summary: The article discusses the use of pozzolans in lime mortars. There is a wish to have standardized pozzolans available on the market with clear guidance how to use them on site.

104: Functionality: **Hydraulic properties**, porosity, compressive strength
Applications: Masonry in general, lime-pozzolan mortars.
Scientific notion (1-3): 2
Summary: Investigation of the effect of lime content on the water requirement, initial porosity, strength development, pozzolanic reaction rate, and microstructure of lime-natural-pozzolan mixtures. Also, the effect of quicklime and hydrated lime on the strength development and pozzolanic reaction. The main conclusions are that an increase of lime over a critical value results in an increase in water requirement and initial porosity, and the strength of the lime-pozzolan pastes decreases. A mixture of 20% hydrated lime and 80% natural pozzolan is regarded as an optimum mixture.

131: Functionality: **Hydraulic properties**
Applications: Lime mixed with natural and artificial pozzolans
Scientific notion (1-3): 3
Summary: The reacted $Ca(OH)_2$ determined by DTA/TG analysis in pastes of lime/pozzolan systems could be an indicative factor for pozzolan reactivity evaluation. The lime/metakaolin pastes reacted much quicker with $Ca(OH)_2$ compared with lime/natural pozzolan (earth of Milos) and lime/ceramic powder pastes. The result of DTA/TG analysis should be correlated with mechanical strength and X-ray diffraction data.

185: Functionality: **Hydraulic properties**, Compressive strength, sand carrying capacity, board life (open time), mortar yield, air content, sand bulking, water retention
Applications: Masonry in general, lime-pozzolan and high cement content mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Comparison of lime-pozzolan and high cement content mortar based on field and laboratory tests. The motivation for the investigation is Mexican masons' problems with Portland cement-admixture, because of the excessive compressive strength that is incompatible with relatively soft masonry units. The main conclusions are that lime-pozzolan mortars have superior workability, higher yield, longer board life, higher water retention and moderate compressive strength. Lime-pozzolan mortars are also less energy-intensive because mine waste is used as pozzolan material.

Notes: No specification of lime and cement mortars (local mortars from Mexico). Interesting perspectives and many arguments for the superiority of lime-pozzolan mortars compared to cement-based mortars.

Sustainability

71: Functionality: **Sustainability**
Applications: Restoration and new build
Scientific notion (1-3):
Summary: Good review article listing the benefits of lime compared with cement mortars. Bricks from lime mortars can be reused and production of lime requires lower burning temperature than cement production, which means that the use of lime has less impact on the climate.

86: Functionality: Lime mortar functionalities**, sustainability**
Applications: Lime versus cement mortars
Scientific notion (1-3): 1
Summary: Lime mortars are more flexible compared to cement mortars. Lime mortars are more permeable and allow evaporation of damp from within the wall. The same applies to lime renders. From an environmental point of view buildings constructed with lime mortars can be altered easily, and the bricks can be reused. Indeed the masonry can be reclaimed entirely if a building has completed its useful life. The firing temperature for lime is much lower than for cement.

156: Functionality: **Sustainability**
Applications: Restoration and new build
Scientific notion (1-3): Review article
Summary: Review of the benefits of lime mortars compared with cement mortars. Lime mortars are more energy efficient and could be a viable economic solution for new build in the future.

183: Functionality: **Sustainability**, indoor climate
Applications: New build, lime mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Historical review article of cement and lime mortars. The main point stated is that lime is considered to be the future binder of choice because of its positive properties relating to sustainability, material re-use and conservation, energy conservation and healthy buildings.
Notes: Interesting because it describes lime as the future binder

184: Functionality: **Sustainability**
Applications: Architectural conservation, lime mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Review of book on the past and present use of lime as a binder in masonry and pointing mortar. The purpose of the book was to disseminate knowledge on lime mortar to professionals in the field of architectural conservation. The most interesting aspect is life cycle analysis, where the main point stated is that the greatest apparent

difference between lime-based mortars and others was the possibility to reuse the bricks in new construction after demolition.

187: Functionality: **Sustainability**
Applications: New build and repair and maintenance
Scientific notion (1-3): 1 (proceedings)
Summary: Review article on lime as a sustainable "green" building product. The main statements are that lime is sustainable from a limestone raw material and energy perspective. Lime serves as an important ingredient in obtaining points in the Leadership in Energy and Environmental Design (LEED) Green Building rating system.
Notes: Interesting for further research in order to quantify the sustainable and green properties of lime mortars.

Multi-functionalities

3: Functionality: **General characterization of lime-based mortars (bond strength, compressive strength, flexural strength, efflorescence, vapour permeability, water retention, porosity, flexibility)**
Applications: Conservation of historic buildings, traditional lime-based and "ready to use" renders
Scientific notion (1-3): 1-2
Summary: Investigation of the performances of a new generation of cement-based mortars, so-called "ready to use", compared with the traditional lime-based mortars used nowadays in the field of ancient masonries. It is stated that some of the factory made renders ("ready to use") are still too waterproof and have too high mechanical performances while others have evolved towards performances much more compatible with ancient masonries. The result is that some of these renders are easier to use than traditional mortars and thus can represent an interesting alternative to traditional mortars in restoration operations.
Notes: Not very convincing data, and also a lot of different French test methods.

4: Functionality: **Lime plaster properties**
Applications: Plasters
Scientific notion (1-3): 3
Summary: Various lime mortars were examined in regard to their technological and hygric characteristics as well as to their pore structure. The influence of the specific modification of certain parameters such as binder, binder/aggregate value, water/binder value, aggregate, and the kind of storage onto the mortars' properties was examined.

10: Functionality: **The influence of using lime replacements**
Applications: cement-lime and cement-lime replacement mortar
Scientific notion (1-3): 3
Summary: The cement-lime replacement mortars have different properties compared to cement-lime mortar. The cement-lime replacement mortars have lower water/binder ratios, lower water retention, greater air content and lower compressive strength. In addition masonry walls constructed using cement-lime replacement

mortars are less resistant to moisture penetration compared to masonry walls constructed using cement-lime mortars.

26: Functionality: **Experimental methods**
Applications: Repair mortars
Scientific notion (1-3): 1
Summary: The study has tried to summarize a basic schema of experimental methods that may be followed in order within the repairing process of the masonry mortar and renders and plasters.

47: Functionality: **Porosity, compressive and flexural strength, flexibility (elastic modulus)**
Applications: Restoration work, mortars of aerial lime, hydraulic lime, cement and other pozzolanic materials.
Scientific notion (1-3): 3
Summary: Characterization of several mortar types to improve knowledge that will facilitate the further choice of suitable material to replace any old mortar. The mortars are characterized with respect to chemical and mineralogical compositions and physical properties (density, porosity, strength and elastic modulus).
Notes: Not really conclusive but instead knowledge matrix for future comparison.

53: Functionality: **Medieval mortar technology**
Applications: Ancient masonry mortars
Scientific notion (1-3): 3
Summary: The examination of ancient mortar provided useful information about a medieval mortar technology regarding their raw material properties and durability characteristics based on the basic physical and mechanical properties.
Notes: A durability index for stones has been used for mortars

59: Functionality: **Durability (Porosity, compressive and flexural strength, SO_2, freeze-thaw resistance)**
Applications: Restoration work, aerial and hydraulic mortars
Scientific notion (1-3): 2
Summary: Investigation of the mechanical behaviour in hardened repair lime-based mortars (aerial and hydraulic) subjected to different environments: Outside exposure, weathering cycles (in a climatic chamber), SO_2-rich environment (in a SO_2 chamber), freeze-thaw cycles and indoor exposure (laboratory conditions). This allows evaluating and comparing the durability of the repair lime-based mortars. The main conclusion is that aerial lime mortars exposed to SO_2-rich environment, results in the formation of gypsum that causes a strength drop.

62: Functionality: **Capillary suction (water absorption), porosity, compressive strength**
Applications: General characterization of natural hydraulic lime mortars for restoration works
Scientific notion (1-3): 2
Summary: Physicochemical characterization of original mortars and plasters and evaluation of repair ones prepared with natural hydraulic lime. Mortars were

analyzed for mineralogical composition, water absorption by capillarity, compressive strength, modulus of elasticity, porosity and pore size distribution.
Notes: Not really relevant.

72: Functionality: **Porosity, freeze-thaw resistance, salt crystallization, capillary suction, (flexural bond strength)**
Applications: Conservation of ancient buildings, lime mortar, lime mortar + air-entraining agent, lime mortar + pozzolan, lime mortar + air-entraining agent + pozzolan.
Scientific notion (1-3): 2
Summary: Investigation of the compatibility of a selected representative set of building materials (bricks and calcarenite) and lime-based conservation mortars (hydraulic and/or non-hydraulic) by focusing on the study of their physical-chemical properties. The properties are porosity, water absorption, desorption, capillarity, ageing (salt crystallization + freeze-thaw). The main conclusion is that calcarenite has proved to be a material that behaves better than brick (in the freeze-thaw test), and creates a stronger, more continuous degree of adherence to lime mortars.
Notes: Not so conclusive, but interesting that the entire masonry is evaluated (brick/calcarenite + mortar).

86: Functionality: **Lime mortar functionalities,** sustainability
Applications: Lime versus cement mortars
Scientific notion (1-3): 1
Summary: Lime mortars are more flexible compared to cement mortars. Lime mortars are more permeable and allow evaporation of damp from within the wall. The same applies to lime renders. From an environmental point of view buildings constructed with lime mortars can be altered easily, and the bricks can be reused. Indeed the masonry can be reclaimed entirely if a building has completed its useful life. The firing temperature for lime is much lower than for cement.

90: Functionality: **Text book**
Applications: Lime based renders and plasters
Scientific notion (1-3): 1
Summary: An explanation about the content of a WTA recommendation dealing Building lime and their processes of setting, criteria for the use of lime renderings, conditions for application, application, documentation, hints for prevention of damage, literature and an appendix dealing with basics and definitions. (Kind of a text book)

94: Functionality: **General characterization of lime-based mortars (salt crystallization, vapour permeability, freeze-thaw resistance, porosity, carbonation, compressive strength, flexural strength).**
Applications: Conservation of historic buildings, high calcium lime, and hydraulic lime mortars with and without set-additives.
Scientific notion (1-3): 2
Summary: Comprehensive field and laboratory investigation of lime-based mortars. Too many results to be summarized shortly.

111: Functionality: **water retention, sand carrying capacity, self healing, tensile bond and flexibility**
Applications: Masonry mortars
Scientific notion (1-3): 1
Summary: The use of hydrated lime increases the water retention as a hydroxide particle is 1/500 the size of a typical Portland cement particle. Consequently hydroxide particles have all together a very high total surface area which increases water retentivity. Because lime particles are large in number and small in size they can coat every sand particle, which means a good sand carrying effect. When lime slowly gains strength over time in a masonry wall the lime can act as a self healer if a hairline crack develops between the masonry unit and the mortar. The fine particle size of lime also plays a role in establishing a strong mortar unit bond by having the lime particles deeply penetrating into the microscopic openings in the masonry units.

118: Functionality: **Multifunctionalities – water extraction from mortar to brick**
Applications: Masonry in general, lime-cement and air-entrained cement mortars
Scientific notion (1-3): 2
Summary: Investigation of the composition of lime-cement and air-entrained cement as a function of distance to the brick-mortar interface. The main conclusion is that in air-entrained cement mortars the water retentivity is low and as a result of enrichment of cement near the brick-mortar interface, at this interface the cement may not be fully hydrated and may cause poor bonding of the mortar with the brick.

119: Functionality: **Clay fine additive (water retention, flexibility (dynamic modulus of elasticity), flexural and compressive strength, capillary porosity, vapour permeability, porosity, freeze-thaw resistance, and sulphate attack.**
Applications: Restoration of historic buildings, lime, hydraulic lime and lime-cement mortars.
Scientific notion (1-3): 2
Summary: Investigation of the influence of loam and clay contents in a quartz aggregate on the properties of fresh and hardened lime and lime-cement mortars. The mortars and pastes were tested for water requirement, water retention capacity, dynamic modulus of elasticity, flexural and compressive strength, shrinkage, water absorption coefficient, total capillary water absorption, water desorption, water vapour diffusion, porosity and pore size distribution, freeze-thaw resistance, and sulphate attack. The main conclusion is that clay fines in aggregates result in an increase of the water demand for a constant mortar consistency, and the higher water/binder ratio causes a strong decrease of the mortar quality with respect to mechanical, hygral and durability properties. Further, with increasing amount of clay in the aggregate a decrease in dynamic modulus of elasticity, flexural and compressive strength is found. The reduction in E-modulus and strength can be up to 50% and is related to the increase of the water/binder ratio. Further, the clay fines in aggregates result in an increase in the water retention capacity. Clay minerals lead to a higher water requirement for a given consistency, thus improving workability. The increase of the amount of mixing water does not lead to a decrease of the water retention capacity. Therefore, the clay fines improve fresh mortar characteristics.

161: Functionality: **General characterization of lime-based mortars (water retention, bond strength, efflorescence, self-healing, vapour permeability, carbonation, compressive strength, flexural strength).**
Applications: Masonry in general, lime mortars
Scientific notion (1-3): 2
Summary: Review article on the difference between lime and cement mortars. Lime-based mortars produce tight, durable mortar bond, and hence watertight walls where cement mortars generally exhibit high bond strengths but have poor extent of bond and also lack durable bonds due to a tendency to develop separation cracking. The principal reasons for the superiority of lime over Portland cement are its higher degree of plasticity and water retention and its greater fineness and inherent stickiness, which permit joints to be filled more readily and completely. The subject of durability in mortars comprises consideration of autogenous healing and efflorescence. The main causes of efflorescence are malconstruction and design, mortar material especially cement with alkali content, environmental conditions with high rainfall. The positive role of lime in combating the efflorescence of masonry is attributed first to the fact that it hinders water penetration but mainly to its extremely low content of soluble salts and sulphur.
Notes: Good review article

192: Functionality: **General characterization**
Applications: Masonry in general
Scientific notion (1-3): 1 (proceedings)
Summary: Review article on the most important properties of cement-lime mortars.
Notes: Good review article.

204: Functionality: **Characterization of masonry**
Applications: Restoration of historic buildings and masonry in general, lime mortar
Scientific notion (1-3): 1-2
Summary: Characterization of mortars and plasters from ancient monuments of Milan. The main conclusion is that good adhesion between mortar and brick is achieved by means of materials whose physical and mechanical properties are compatible.
Notes: The statement of compatibility is an important argument for lime mortar, which should be followed in future research.

212: Functionality: **Water retention, water demand, compressive strength, masonry strength**
Applications: Cement-lime mortar 50/50/750
Scientific notion (1-3): 3
Summary: A cement-lime mortar is mixed using different technologies, cement + sand + dry hydrated lime, cement + sand + slaked quick lime, cement + sand + lime putty (3 months old), cement + sand + lime putty (9 years old), cement + sand + carbide lime, cement + sand + quick lime slaked in the moist sand, cement + sand + hydrated lime premixed with the cement and cement + sand + hydrated lime as a retarded mortar. Generally speaking, the longer time the lime has been in contact with water, the better is the water retention, the lower is the bleeding effect and the higher is the water demand. The longer the lime has been in contact with water, the

lower is the compressive strength. The effect coming from the lower compressive strength upon the masonry strength is limited.

Miscellaneous

51: Functionality: **Capillary rise of water**
Applications: cement-lime mortars
Scientific notion (1-3): 3
Summary: The water soaking of porous stones joined by lime-cement mortars determines an interaction between bricks and mortar able to block the capillary rise of water. Such a phenomenon takes place for stones able to release alkali by interaction with the mortar. Owing to such an interaction, an impermeable layer of precipitating lime forms at the stone-mortar interface.

57: Functionality: **Biocide properties**
Applications: Repair lime mortars with biocide properties
Scientific notion (1-3): 3
Summary: There is a tendency that mortars with biocide properties are more resistance to H_2SO_4 media and acid rain compared to the same mortar without biocide properties, especially if sepiolite (clay) has been added. The biocide properties have been obtained by pentachlorophenol.

60 and 63: Functionality: **Resistance to pollutant**
Applications: Lime mortars and lime mortars with sepiolite
Scientific notion (1-3): 3
Summary: The reaction between lime mortars and NO pollutant is low. NO_2 pollutant has lower reactivity than NO. Using sepiolite in the lime mortar makes no different. The presence of water and ozone increases SO_2 pollutant the gas reaction with the lime mortar.

69: Functionality: **Fungicial effect of organic tin**
Applications: Cement and lime plasters
Scientific notion (1-3):
Summary: The study shows that the fungicial effect of organic tin (tributyl tin acetate) is reliable even in small concentrations.

75: Functionality: **Calculation method, composition of hardened mortars**
Applications: Cement lime mortars
Scientific notion (1-3): 2
Summary: An optimization of calculation method for determination of composition of hardened mortars of Portland cement and hydrated lime has been worked out. The method seems to be more accurate compared to the traditional ones.

93: Functionality: **Text book**
Applications: Hydraulic lime mortars
Scientific notion (1-3): 1
Summary: Text book about what natural hydraulic lime is and the application.

95: Functionality: **Text book**
Applications: Lime mortars
Scientific notion (1-3): 1
Summary: Text book about the different types of lime and the preparation of lime mortars.

97 and 98: Functionality: **Text book**
Applications: Lime mortars
Scientific notion (1-3): 1
Summary: Text book about the production of lime and the use of lime and lime mortars.

163: Functionality: **Text book**
Applications:
Scientific notion (1-3):
Summary: Text book dealing with materials and compositions of various mixtures used during the course of centuries.

188: Functionality: **Standards**
Applications:
Scientific notion (1-3):
Summary: Overview of standards related to building lime.

191: Functionality: **Replacement of grouts in reinforced masonry**
Applications: Reinforced masonry, grout and cement-lime mortars
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of the use of cement-lime based mortar as an alternative grout in reinforced masonry. The main conclusions from the preliminary test are that type S mortar fill has the potential to be an acceptable alternative to masonry grout for modified low-lift applications of reinforced masonry.
Notes: Demonstrates alternative use of cement-lime mortars. It would be beneficial if lime-based mortars can be used in other types of constructions. Could be subject for further research.

Out of purpose

7: Functionality:
Applications:
Scientific notion (1-3): 3
Summary: Investigation of reaction of SO_2 with $Ca(OH)_2$ for spray drying as an alternative to wet scrubbing of SO_2-containing flue gas.
Notes: Out of purpose

12: Functionality: Workability
Notes: Out of purpose (too fuzzy!)

16: Functionality: Miscellaneous
Applications: Sand-lime mortars
Scientific notion (1-3): 2
Summary:
Notes: Out of purpose

20: Functionality: Miscellaneous
Applications: Calcium silicate masonry
Scientific notion (1-3):
Summary:
Out of purpose

21: Functionality: Efflorescence
Applications: Concrete and asbestos cement
Scientific notion (1-3):
Summary:
Out of purpose

25: Functionality: Miscellaneous
Applications: Clay bricks
Scientific notion (1-3):
Summary:
Notes: Out of purpose

27: Functionality: Compressive strength, water absorption
Applications: Plaster in rural areas, cement-lime and cement-termite hill mortars
Scientific notion (1-3): 1
Summary: Investigation of compressive strength and water absorption capacity of cement-lime and cement-termite hill mortars. The main objective is to encourage the use of less-fancied natural products as construction materials especially in low cost housings.
Notes: Not good work – no reference to standard methods and no description of lime type used. ASTM C1403 - 06 Standard Test Method for Rate of Water Absorption of Masonry Mortars. Out of purpose.

29: Functionality: Workability
Applications: Cement-lime mortars
Scientific notion (1-3): 1
Summary: Lime putty gives better workability than dry hydrated lime
Notes: Out of purpose

36: Functionality: SO_2, salt crystallization
Applications: Masonry in general, cement mortars.
Scientific notion (1-3): 3
Summary: Investigation of thaumasite formation in cement mortars. No reference to lime-based mortars.
Notes: Out of purpose

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41: Functionality:
Applications: Cement
Scientific notion (1-3): 3
Summary:
Notes: out of purpose

42: Functionality: Compressive strength
Applications: Cement mortars
Scientific notion (1-3): 3
Summary:
Notes: Out of purpose

43: Functionality: Porosity
Applications: Transport Cement mortars
Scientific notion (1-3): 2
Summary:
Notes: Out of purpose

46: Functionality: Hydration
Applications: Cement
Scientific notion (1-3): 3
Summary: The temperature has a great effect upon the hydration rate. From 20 to 60 °C the hydration rate raised 5 times.
Notes: Out of purpose

50: Functionality: Carbonation
Applications: Lime mortar
Scientific notion (1-3): 2
Summary: Use of micro Raman spectroscopy to distinguish between calcite, aragonite, vaterite.
Notes: Out of purpose

52: Functionality: Frost-thaw resistance
Applications: Cement mortars
Scientific notion (1-3): 2
Summary:
Notes: Out of purpose

56: Functionality:
Applications: Different types of lime based mortars
Scientific notion (1-3): 1
Summary:
Notes: out of purpose

58: Functionality:
Applications: New build, pozzolanic pastes
Scientific notion (1-3): 2
Summary: Investigation of the pozzolanic reaction and comparison with historic pozzolanic mortars.

Notes: Out of purpose

64: Functionality: Porosity, Tensile strength
Applications: Historical mortars
Scientific notion (1-3): 2
Summary:
Notes: Out of purpose

70: Functionality: Porosity, compressive strength
Applications: Masonry in general, cement and lime-cement mortars
Scientific notion (1-3): 1-2
Summary: Investigation of the effect of warm and dry curing on the pore structure of cement and cement-lime mortars. The parameters are temperature and curing conditions (air, wet, 33% humidity). The main conclusion is that the ageing process in cement-lime mortars, which increases the volume of pores smaller than 50 nm diameter at the expense of macro porosity, promotes the development of compressive strength with increasing temperature, relative humidity and period of curing.
Notes: Not that relevant as the results mainly apply to warm and dry climate. Out of purpose.

74: Functionality: Degradation
Applications: External renders
Scientific notion (1-3): 2
Summary:
Notes: Out of purpose

78: Functionality: Water demand?, mortar consistency
Applications: Masonry in general, cement-lime pastes
Scientific notion (1-3): 1
Summary: Investigation of viscosity of cement paste in which the cement has been substituted by different types of lime in varying proportions. The aim is to determine the water/binder ratios that allow working with mortars of the same consistency. The main conclusions are that regardless of the type of lime used, the substitution of a certain percentage of cement by lime requires a higher percentage of water during mortar production.
Notes: Not new and no viscosity data presented! Out of purpose

81: Functionality: Porosity
Applications: Aerated concrete
Scientific notion (1-3):
Summary:
Notes: Out of purpose

82: Functionality: Strengthening of masonry
Applications:
Scientific notion (1-3):
Summary:
Notes: Out of purpose

87: Functionality: Porosity, vapour permeability
Applications: Masonry in general
Scientific notion (1-3): 1-2
Summary: Modelling of the porous structure of a cement and lime mortar and to investigate the influence of this model on the simulation of moisture retention and transfer. The main conclusion is that numerical values of isothermal mass diffusivity were shown to have a strong dependence on the particular model used to represent the fissures.
Notes: Out of purpose

88: Functionality: Miscellaneous
Applications: CL 1/1/10 by weight plastering mortar
Scientific notion (1-3): 3
Summary: An accelerated laboratory test to evaluate the bio receptivity of plastering mortars to fungal growth has been developed.
Notes: Out of purpose

102: Functionality: Compressive strength
Applications: Sand lime mortar
Scientific notion (1-3): 2
Summary: Model based on experimental data for the hardening plasticity behaviour of sand-lime mortar joints to predict joint rotation and shortening and to construct moment/thrust yield envelopes.
Notes: Out of purpose - mostly relevant for building engineers

103: Functionality: Shrinkage cracking
Applications: Self-compacting concrete
Scientific notion (1-3):
Summary:
Notes: Out of purpose

105: Functionality: Carbonation
Applications: Cement mortars
Scientific notion (1-3): 3
Summary: Carbonation is going on if both CO_2 and H_2O are present at the same time
Notes: Out of purpose

110: Functionality: Miscellaneous
Applications: Self-consolidating concrete
Scientific notion (1-3): 3
Summary:
Notes: Out of purpose

113: Functionality: Bond strength
Applications: Masonry in general, cement and cement-lime mortars
Scientific notion (1-3): 1
Notes: Out of purpose

115: Functionality: Miscellaneous

Applications: Lime and lime pozzolan mortars
Scientific notion (1-3): 3
Summary:
Notes: Out of purpose

116: Functionality: Miscellaneous
Applications: Lime mortars
Scientific notion (1-3): 3
Summary:
Notes: Out of purpose

125: Functionality: Material properties
Applications:
Scientific notion (1-3):
Summary: Investigation of material properties of ancient bricks and lime mortars with ceramic fill and the earthquake resistant construction techniques and materials.
Notes: Out of purpose. No clear characterization of the mortar.

126: Functionality: Structural renovation
Applications: Masonry structures
Scientific notion (1-3): 1
Summary:
Notes: Out of purpose

133: Functionality: Porosity, vapour permeability
Applications: Masonry in general, cement and lime mortar
Scientific notion (1-3): 1-2
Notes: Out of purpose

141: Functionality: Pozzolanicity
Applications:
Scientific notion (1-3):
Summary: Investigation of the pozzolanicity of different bricks and clays to give guidelines for the production and use of pozzolanic bricks and clays for the preparation of hydraulic mortars and grout.
Notes: Out of purpose

164: Functionality: Carbonation, vapour permeability
Applications: Ancient masonry walls
Scientific notion (1-3): 1
Summary: Finite element analysis of moisture diffusion and carbonation based on data from others' work.
Notes: Out of purpose

176: Functionality: Carbonation
Applications: masonry in general, cement mortars
Scientific notion (1-3): 2
Summary: Comparison of solvent exchange and vacuum drying techniques to remove free water from early age cement-based materials. The solvent exchange technique is not preferable as the calcium hydroxide content is underestimated by thermal analysis. The main conclusion is that in absence of solvent, the vacuum drying technique is an easy and fast preparation method prior to thermal analysis and XRD.
Notes: Out of purpose

181: Functionality:
Applications: Repair of historic buildings and monuments, type S hydrates dolomitic lime
Scientific notion (1-3): 1 (proceedings)
Summary: Review article on hydrated lime as restoration material.
Notes: Out of purpose.

182: Functionality:
Applications: Repair and maintenance, lime putty
Scientific notion (1-3): 1 (proceedings)
Summary: Two case studies.
Notes: Out of purpose. Not reviewed.

193: Functionality:
Applications: Lime type S
Scientific notion (1-3): 1 (not reviewed)
Summary: Description of the characteristics of S type cement-lime mortar.
Notes: Out of purpose

196: Functionality: Salt crystallization
Applications: Restoration of historic buildings, bricks
Scientific notion (1-3):
Summary: Investigation of physic-mechanical characteristics and durability of bricks from monuments in Milan.
Notes: Out of purpose

198 + 199 + 200 + 201 + 205 + 206 + 207: Functionality: Mechanical properties
Applications: Ancient masonry, hydraulic lime and pozzolanic materials
Scientific notion (1-3):
Summary: Investigation of mechanical behaviour of masonry prisms with thick mortar joints reproducing a byzantine masonry.
Notes: Out of purpose

202: Functionality:
Applications: Historic buildings
Scientific notion (1-3): 1 (proceedings)
Summary: Investigation of masonry samples from civic tower of Pavia.
Notes: Too specific on conservation. Out of purpose.

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2	Durability of lime-based mortars in a severe climate. Results from field and artificial ageing tests.	Waldum, A., Anda	01-01-1999	12 th International RILEM Workshop on Historic Mortars: Characteristics and Tests	No 1999	297-309
3	A new generation of cement-based renderings: An alternative to traditional lime based mortars?	Marie-Victoire, E., Bromblet, P.	01-01-2000	12 th International RILEM Workshop on Historic Mortars: Characteristics and Tests Proceedings	No 2000	371-393
4	Comparison of the properties of lime mortars in dependence of the used binder and aggregate / Vergleich der Eigenschaften von Kalkmörteln in Abhängigkeit vom verwendeten Bindemittel und Zuschlag	Böttger, K., Knöfel, D.	17-12-1996	4th Internationales Kolloquium Werkstoffwissenschaften und Bauinstandsetzen	No 1996	779-799
5	Testing the mechanical behaviour of lime-mortar masonry on model specimen / Untersuchung der mechanisher Eigenschaften von Kalkmörtelmauerwerk an Prüfkörpern im Modellmaßstab	Neuland-Burg, Sand, J.	19-12-1996	4th Internationales Kolloquium Werkstoffwissenschaften und Bauinstandsetzen	No 1996	861-875
6	Effect of high lime fly ash content on water demand, time of set, and compressive strength of concrete	Naik, T., Ramme, B.	01-01-1990	ACI Mater J	87 (6) 1990	619-626
7	Effect of deliquescent salt additives on the reaction of SO2 with Ca(OH)2	Ruiz-Alsop, R., Rochelle, G.	01-01-1986	ACS Symposium Series	1986 (319)	208-222
8	Measurement of the water retentivity of cement mortars	Carter, M., Green, M., Wilson, M.A., University of Manchester, Hoff, W.D.	26-06-2003	Advances in Cement Research	15 (2003)	155-159
9	Investigation of shale brick interface with cement-lime and polymer-modified mortars	Marusin, S.	08-08-1990	American Ceramic Society	73 (8) 1990	2301-2308
10	Comparative investigation of plastic properties and water permeance of cement-lime mortars and cement-lime replacement mortars	Schuller, M., Van der Hoeven, R., Thomson, M., Chemical Lime Company	01-01-1999	American Society for testing and Materials	1999 (1352)	145-158
11	Interaction between clay and lime in "cocciopesto" mortars: a study by 29Si MAS spectroscopy	Zendri, E., Lucchini, V., Biscontin, G., University of Venice, Morabito, Z.M.	04-06-2003	Applied Clay Science	25 (2004)	1-7
12	A rheological fuzzy model for, lime plasticity and mortar consistency	Atzeni, C., Sanna, U., Spanu, N., University of Cagliari	22-12-2005	Applied Rheology	16 (2) 2006	80-89
13	Blended pastes of cement and lime: Pore structure and capillary porosity	Arandigoyen, M., Alvarez, J.	11-11-2005	Applied Surface Science	252 (2006)	8077-8085
14	Variation of microstructure with carbonation in lime and blended pastes	Arandigoyen, M., Bicer-Simsir, B., Alvarez, J., University of Navarra, Lange, D.A.	17-10-2005	Applied Surface Science	252 (2006)	7562-7571
15	Lime-pastes with different kneading water: Pore structure and capillary porosity	Arandigoyen, M., Bernal, J., Bello, M., University of Sevilla, Alvarez, J.	23-05-2005	Applied Surface Science	252 (2005)	1449-1459
16	Sand-lime mortar joint hardening behaviour	Rosson, B.	01-09-2001	ARCH'01 :	2001	573-578
17	Lime mortars: Some considerations on testing standardization	Charola, A., Henriques, F.	01-01-1999	ASTM Special Technical Publication	1355 (1999)	142-151

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18	Atmospheric deterioration of ancient and modern hydraulic mortars	Sabbioni, C., Zappia, G., Riontino, C., Institute ISAO, Bologna, Aguilera, J., Puertas, F., Van Balen, K., Toumbakari, E., Blanco-Varela, M.	08-06-2000	Atmospheric environment	35 (2001)	539-548
19	Vorsicht bei viel Feuchte / Watch for too much humidity. Lime plasters in monument preservation - "relevant advice"	Gaenssmantel, J.	01-01-2000	B+B-Bautenschutz Bausanierung	2000 - 23(6)	32-37
20	Untersuchungen zur Rissefreiheit bei stumpfgestoßenem Mischmauerwerk mit Kalksandsteinen / Investigation on the Risk of cracking in Butt-Jointed Mix-Masonry with lime-sand Bricks	Schneider, K., Wiegand, E.	01-01-1986	Bauingenieur	61 (1) 1986	35-41
21	Untersuchugen zum Phänomen der Kalkausblühungen auf Beton und Asbestzement / Studies of the phenomenon of efflorescence on concrete and asbestos cement	Kresse, P.	01-01-1986	Bauingenieur	1986-61 (1)	35-41
22	Influence de la suction des supports poreux sur la prise et la résistance au cisaillement des morties moulés à leur contact	Détriché, Grandet, J.	01-01-1981	BORDAS-DUNOD		91-102
23	Building masonry with lime-based bedding mortars	De Vekey, B.	01-01-2005	BRE Good building guide	66 (2005)	1-8
24	Study of the laboratory Vane test on mortars	Bauer, E., De Sousa, J., Guimarães, E., University of Fetra de Santana, Silva, F.G.S.	01-01-2006	Building and Environment	42 (1) 2007	86-92
25	Equilibrium moisture content of clay bricks: The influence of porous structure	Raimondo, M., Dondi, M., Mazzanti, F., CNR-Instituto di Scienza e Tecnologica dei Materiali Ceramici, Stefanizzi, P., Bondi, P.	20-10-2005	Building and Environment	42 (2007)	926-932
26	A research about a method for restoration of traditional lime mortars and plaster: A staging system approach	Arioglu, N., Acun, S.	10-05-2005	Building and Environment	41 (2006)	1223-1230
27	Studies on termite hill and lime as partial replacement for cement in plastering	Olusola, K., Olanipekun, E., Ata, O., Obafemi Awolowo University	25-01-2005	Building and Environment	41 (2006)	302-306
28	Plasticity and water retentivity of Hydrated Limes for structural purposes.	Levin, Clarke, A.N., Wells, S.	20-02-1956	Building Materials and Structures	146	
29	Modern limes	Thomas	02-11-1989	BUILDING TODAY	02-nov-89	28-29
30	Optimisation of properties of lime mortars based on pure lime hydrate	Böttger, K.	01-01-2004	CDCh-Monographie	31 (2004)	177-182
31	Thaumasite formation due to atmospheric SO2-hydraulic mortar interaction	Blanco-Varela, M., Aguilera, J., Martinez-Ramirez, S., Instituto de Ciencias de la Construccion Eduardo Torroja, Madrid, Palomo, A., Sabbioni, C., Zappia, G., Riontino, C., Van Balen, K., Toumbakari, E.	01-01-2003	Cement and Concrete Composites	25 (2003)	983-990

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33	The role of aggregates on the structure and properties of lime mortars	Stefanidou, M., Papayianni, I.	15-07-2005	Cement and Concrete Composites	27 (2005)	914-919
34	Carbonate binders: Reaction kinetics, strength and microstructure	De Silva, P., Bucea, L., Moorehead, D., Arup, Sirivivatnanon, V.	09-06-2006	Cement and Concrete Composites	28 (2006)	613-620
35	Strength development and lime reaction in mortars for repairing historic masonries	Moropoulou, A., Bakolas, A., Moundoulas, University of Athens, Anagnostopoulou, S.	01-01-2004	Cement and Concrete Composites	27 (2005)	289-294
36	The formation of thaumasite in a cement:lime:sand mortar exposed to cold magnesium and potassium sulphate solutions	Gaze, M., Crammond, N.	20-12-1999	Cement and Concrete Composites	22 (2000)	209-222
37	Pore structure and mechanical properties of cement-lime mortars	Arandigoyen, M., Alvarez, J.	22-02-2007	Cement and Concrete Research	37 (2007)	767-775
38	Addition of cement to lime-based mortars: Effect on pore structure and vapour transport	Mosquera, M., Silva, B., Prieto, B., University of Santiago de Compostela, Ruiz-Herrera, E.	13-10-2004	Cement and Concrete Research	36 (2006)	1635-1642
39	Forced and natural carbonation of lime-based mortars with and without additives: Mineralogical and textural changes	Cultrone, G., Sebastian, E., Ortega-Huertas, T., University of Granada	11-12-2004	Cement and Concrete Research	35 (2005)	2278-2289
40	Irreversible dilation of NaCl contaminated lime-cement mortar due to crystallization cycles	Lubelli, B., Van Hees, R., Huinink, H., University of Eindhoven, Groot, C.J.W.P.	09-10-2005	Cement and Concrete Research	36 (2006)	678-687
41	Crystallisation of calcium hydroxide in early age model and ordinary cementious systems	Gallucci, E., Scrivener, K.	10-01-2007	Cement and Concrete Research	37 (2007)	492-501
42	Mineral admixtures in mortars effect of type, amount and fineness of fine constituents on compressive strength	Lawrence, R., Cyr, J., Ringot, Laboratoire Matériaux et Durabilité des Constructions INSA-UPS, Toulouse	06-07-2004	Cement and Concrete Research	35 (2005)	1092-1105
43	Estimating transport properties of mortars using image analysis on backscattered electron image	Wong, H., Buenfeld, N., Head, M., Imperial College, London	09-05-2006	Cement and Concrete Research	36 (2006)	1556-1566
44	Carbonation reaction of lime, kinetics at ambient temperature	Van Balen, K.	09-06-2004	Cement and Concrete Research	2004	647-657
45	Effect of carbonation on the pore structure of non-hydraulic lime mortars	Lawrence, R., Mays, T., Rigby, S., University of Bath, Ayala, R.E., Walker, P.	20-07-2007	Cement and Concrete Research	37 (7) 2007	1059-1069
46	The effect of temperature on the hydration rate and stability of the hydration phases of metakaolin-lime-water systems	Rojas, Cabrera, J.	30-07-2001	Cement and Concrete Research	32 (11) 2002	133-138
47	Study of rehabilitation mortars: Construction of a knowledge correlation matrix	Marques, S.F., Ribeiro, R., Silva, L., University of Aveiro, Labrincha, J., Ferreira, V.M.	20-07-2006	Cement and Concrete Research	36 (10) 2006	1894-1902

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49	Study of the water-retention capacity of a lime-sand mortar: Influence of the physicochemical characteristics of the lime	Sebaibi, Y., Dheilly, R.M., Queneudec, M., University of Picardie	22-10-2002	Cement and Concrete Research	33 (2003)	689-696
50	Micro-Raman spectroscopy applied to depth profiles of carbonates formed in lime mortar	Martinez-Ramirez, S., Sanchez-Cortes, S., Garcia-Ramos, Instituto de Estructura de la Materia, Madrid, Fortes, C., Blanco-Varela, M., Domingo, C.	08-08-2003	Cement and Concrete Research	33 (2003)	2063-2068
51	Cement-lime mortars joining porous stones of masonries able to stop the capillary rise of water	Calantuono, Vecchio, Marino, University of Napoli, Vitale, Mascolo, G.	09-04-1996	Cement and Concrete Research	26 (6) 1996	861-868
52	Frost resistance of cement mortars with different lime contents	Müller, A., Fuhr, Knöfel, D., University of Siegen	10-03-1995	Cement and Concrete Research	25 (4) 1995	809-818
53	Opal-A rich additives used in ancient lime mortars	Tunçoku, S., Caner-Saltik, E.	23-06-2006	Cement and Concrete Research	36 (2006)	1886-1893
54	Stability of ancient masonry towers: Stress redistribution due to drying, carbonation, and creep	Ferretti, D., Bazant, Z.	16-03-2006	Cement and Concrete Research	36 (2006)	1389-1398
55	The effects of lime and admixtures on the water-retaining properties of cement mortars	Green, M., Carter, M., Hoff, W., UMIST, Manchester, Wilson, M.A.	06-07-1999	Cement and Concrete Research	29 (1999)	1743-1747
56	Composite materials in ancient structures	Moropoulou, A., Bakolas, A., Anagnostopoulou, S., University of Athens	01-01-2005	Cement and Concrete Research	2005 (27)	295-300
57	Behaviour of repair lime mortars by wet deposition process	Martinez-Ramirez, S., Puertas, F., Blanco-Varela, M., Instituto de Ciencias de la Construccion Eduardo Torroja, Madrid, Almendros, P., Thompson, G.E.	05-12-1997	Cement and Concrete Research	28 (2) 1998	221-229
58	Accelerated microstructural evolution of a calcium-silicate-hydrate (C-S-H) phase in pozzolanic pastes using fine siliceous sources: Comparison with historic pozzolanic mortars	Moropoulou, A., Cakmak, A., Labropoulos, University of Athens, Torfs	12-05-2003	Cement and Concrete Research	34 (2004)	1-8
59	Study of the mechanical behaviour of masonry repair lime-based mortars cured and exposed under different conditions	Lanas, J., Sirera, R., Alvarez, J., University of Navarra	07-12-2005	Cement and Concrete Research	36 (2006)	961-970
60	Studies on degradation of lime mortars in atmospheric simulation chambers	Martinez-Ramirez, S., Blanco-Varela, M., Thompson, G.E., UMIST, Manchester	01-04-1997	Cement and Concrete Research	27 (5) 1997	777-784
61	Mechanical properties of natural hydraulic lime-based mortars	Lanas, J., Bernal, J., Bello, M., University of Sevilla, Alvarez Galindo, J.I.	05-02-2004	Cement and Concrete Research	34 (2004)	2191-2201

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63	Effect of dry Deposition of pollutants on the degradation of lime mortars with sepiolite	Martinez-Ramirez, S., Puertas, F., Blanco-Varela, M., Instituto de Ciencias de la Construccion Eduardo Torroja, Madrid, Thompson, G.E.	06-11-1997	Cement and Concrete Research	28 (1) 1998	125-133
64	Correlation of physicochemical and mechanical properties of historical mortars and classification by multivariate statistics	Moropoulou, A., Polikreti, K., Bakolas, A., University of Athens, Michailidis, P.	10-12-2002	Cement and Concrete Research	33 (2003)	891-898
65	Hydraulic lime mortars with siloxane for waterproofing historic masonry	Maravela-Kalaitzaki, P.	01-02-2007	Cement and Concrete Research	37 (2007)	283-290
66	Characteristics of brick used as aggregate in historic brick-lime mortars and plasters	Boke, H., Akkurt, S., Ipekoglu, B., Institute of Technology, Izmir, Ugurlu, E.	16-03-2006	Cement and Concrete Research	36 (2006)	1115-1122
67	Lime pozzolana mortars in Roman catacombs: composition, structures and restoration	Sánchez-Moral, Luque, L., Cañaveras, University of Alicante, Garcia-Guinea, J., Aparicio, A., Soler, V.	19-08-2004	Cement and Concrete Research	35 (2005)	1555-1556
68	Study of ancient mortars from Sagalassos (Turkey) in view of their conservation	Degryse, P., Elsen, J., Waelkens, M., Katholieke Universeit Leuven	03-04-2002	Cement and Concrete Research	32 (2002)	1457-1463
69	Fungicidal effect of organic tin in cements, limes and plasters	Bartl, M., Velecky, R.	02-03-1971	Cement Technology	2 (2) 1971	54-57
70	Effect of warm and dry curing on the pore structure of cement-lime mortar	Cebeci, O., Al-Noury, S., Mirza, W., King Abdulaziz University	01-01-1988	Characterization of Porous solids	39 (1987)	611-617
71	Future is green, Lime green	Pritchet, I.	01-01-2003	Concrete Engineering International	7 (4) 2003	49-50
72	Durability of masonry systems: A laboratory study	Cultrone, G., Sebastian, E., Ortega-Huertas, T., University of Granada	23-09-2005	Construction and Building Materials	21	40-51
73	Effect of pozzolanic admixtures on mechanical, thermal and hygric properties of lime plasters	Cerny, R., Kunca, A., Tydlitat, V., Czech Technical University, Drchalova, J., Rovnanikova, P.	24-08-2005	Construction and Building Materials	20 (2006)	849-857
74	Mapping defect sensitivity in external mortar renders	Gaspar, J., De Brito, T.	08-03-2005	Construction and Building Materials	19 (2005)	571-578
75	Optimisation of calculation method for determination of composition of hardened mortars of Portland cement and hydrated lime made in laboratory	Quarcioni, V., Cincotto, M.	27-09-2005	Construction and Building Materials	20 (2006)	1069-1078
76	Gypsum coatings in ancient buildings	Silveira, Rosário-Veiga, De Brito, T., Technical University of Lisbon	19-08-2005	Construction and Building Materials	21 (2007)	126-131

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78	Study of the lime-cement paste: Influence of the physico-chemical characteristics of lime	Sebaibi, Y., Dheilly, R.M., Queneudec, M., University of Picardie	01-01-2004	Construction and Building Materials	18 (9) 2004	653-660
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80	Strength-porosity relationships in lime-pozzolan mortars	Papayianni, I., Stefanidou, M.	14-04-2005	Construction and Building Materials	20 (2006)	700-705
81	Experimental study of the mechanical anisotropy of aerated concretes and the adjustment parameters of the introduced porosity	Cabrillac, R., Fiorio, B., Beaucour, A., University of Paris 6, Dumontet, H., Ortola, S.	10-05-2005	Construction and Building Materials	20 (2006)	286-295
82	Evolution of structural consolidation and strengthening of masonry in Belgium: historical overview and case studies	Van Gemert, D., Ignoul, S., Van Rickstal, F., Katholieke Universeit Leuven, Toumbakari, E.	01-01-2005	Department of civil Eng. Of KU Leuven		
83	Microscope and Lime	Walker, D.		Duncanville : Proceedings of the International Conference on Cement Microscopy 4th		21-48
84	Effect of air content on durability of cement-lime mortars	Davison, J.	01-01-1982	Durability of building materials	1 (1982)	23-34
85	Inelastic behaviour of sand-lime mortar joint masonry arches	Rosson, B., Soyland, K., Boothby, T., The Pennsylvania State University	01-02-1997	Engineering Structures	20 (1998)	14-24
86	Lime versus cement: traditional methods for today's buildings	Pritchet, I.	01-06-2003	ICE Proceedings: Engineering sustainability	156 (2003)	83-85
87	Modelling moisture distribution and isothermal transfer in a heterogeneous porous material	Philippi, P., Souza, H.A.	14-11-1994	Int. J. Multiphase Flow	21 (4) 1995	667-691
88	The development of a method to evaluate bioreceptivity of indoor mortar plastering to fungal growth	Shirakawa, M., Beech, I., Tapper, R., University of Portsmouth, Cincotto, M., Gambale, D.	01-03-2003	International Biodeteration & Biodegradation	51 (2003)	83-92
89	Weaker can be better : learning from the past contributes to sustainable construction technology with lime	Van Balen, K., Hayen, R., Van Gemert, D., Katholieke Universeit Leuven	09-03-2005	International Building Lime Symposium	2005	
90	Lime-based plasters and renders for architectural heritage: WTA-Recommandation 2-7-01/D	Auras, M.	01-01-2004	International Journal for Restoration	10 (6)	663-666
91	Effects of ageing on lime putty	Hansen, E., Tagle, A., Erder, E., Katholieke Universeit Leuven, Connell, S., Rodriguez-Navarro, C., Van Balen, K.	01-01-2000	International workshop Historic Mortars characteristics and test	2000	197-206

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93	Succeeding with hydraulic lime mortars	Livesey, P.	01-01-2002	Architectural Conservation	8 (2) 2002	23-37
94	Field and Laboratory assessment of lime-based mortars	Stewart, J., Glover, R, Houston, J., Proudfoot, I.	01-03-2001	Architectural Conservation	7 (1) 2007	15158
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