Arriscraft.NOTE Series

Volume 3

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Introduction
This ARRISCRAFT•NOTE discusses the basic principles of symptom identification and fault diagnosis of masonry-related building envelope problems.

Distinctions between building maintenance and building envelope repair are examined. By developing an understanding of the relationships between symptoms and faults, the reader should gain a clear understanding of how the long-term performance of the building envelope is affected.

Further, a variety of common symptoms and their underlying causes are discussed relative to possible repair activities.

Is it Maintenance or Repair?
Just as in the world of medicine symptoms are not necessarily the cause for the "illness" – or in the case of building forensics, a building envelope problem. Rather, they are the clues that help the investigator determine what "treatment" may need to be undertaken,

Distinguishing whether a symptom is indicative of a building envelope problem or simply the need for normal building maintenance will not necessarily be clear cut. Typically, symptoms necessitating only routine maintenance are static; whereas, dynamic symptoms are more commonly a sign that repair of a building fault is first required. A sound understanding of building forensics will be required in order to distinguish whether the symptom is either static or dynamic in nature.

Maintenance of Masonry Veneer
Just as with all other types of building cladding systems, masonry veneer will experience predictable levels of deterioration over time due to its continuous exposure to its local environment (*ref. Drysdale, R.G. and Sutter, G.T., <u>Exterior Wall Construction in High-Rise Buildings</u>, Canada Mortgage and Housing Corporation, pg. 17-1*). Such deterioration is considered acceptable and unavoidable; thereby necessitating that building owners undertake scheduled maintenance of their building's cladding system. This maintenance may be either proactive, reactive or some combination of both.

Symptoms indicative of deterioration that necessitate maintenance should not be attributed to a fault or defect in the veneer wall system. Rather, they are symptoms that may be expected to occur during the service life of the building (*ref. Cody, Gina P., <u>Deterioration of Masonry, Causes and Prevention</u>, Seventh Canadian Masonry Symposium, June 4-7; pg. 833*).

Symptoms requiring maintenance of the masonry veneer may include mortar crack repair, general removal of pollutant build up and initial efflorescence, joint sealant repair, and the removal of graffiti.

Mortar joint cracks that require re-pointing as a part of a maintenance program typically could result from:

- singular occurrences of deflection and/or settlement;
- curling of a structural concrete slab; or
- hairline shrinkage cracks.

Cracks resulting from singular occurrences of settlement or deflection tend to appear within the first annual cycle and do not increase in size or thickness thereafter, provided they are not left exposed to the effects of mortar erosion and freeze-thaw cycling indefinitely. They will typically have a tapered profile with the joint appearing widest at its lowest point.

As a concrete slab cures, it may curl upwards at its ends. When masonry is attached to or supported by such a slab, a horizontal crack may occur.

These types of cracks rarely re-occur once repaired.

Hairline shrinkage cracks are generally only surface cracks that do not penetrate the entire bed of the joint. They result from the shrinkage of the mortar as it dries and are more likely to occur when mortars of high cement content are used, when the mortar joints are installed too wide, when large masonry units with clean cut arris are used, or when tooling of the joints is inconsistent or improperly preformed.

Hairline shrinkage cracks are generally considered to be an aesthetic issue rather than a wall performance issue. Progressive deterioration of these cracks is not expected. Their repair is usually undertaken at the discretion of the building owner for aesthetic purposes.

Discolouration of the masonry may result gradually from the building's exposure to pollutants within the surrounding environment or from initial efflorescence forming on the wall's surface. Over time the deposit of pollutants on the building's façade may be deemed unsightly and should be removed from the masonry surface using recommended cleaning methods. Initial efflorescence, sometimes referred to as building bloom, is expected to occur during a building's first annual cycle. Typically, such deposits will disappear after one or two rainfalls and should not reoccur.

Joint sealants used in conjunction with masonry veneer have a service life and will most likely need to be replaced a number of times during a building's life cycle. The frequency of this replacement is largely dependant on the quality and composition of the sealant. If not maintained on a regular basis, deteriorated sealant may result in water penetration and joint failure, leading to larger building envelope problems.

Graffiti and other such instances of vandalism may also need to be addressed. Reputable masonry manufacturers, in consultation with cleaning product manufacturers, can assist building owners on a case-by-case basis to solve aesthetic maintenance issues.

Symptoms Necessitating Fault Repair

Too commonly our building industry perceives wall cracks, water leaks, efflorescence, unit spalling, and unit displacement as building or product faults rather than what they really are - symptoms of a fault (*ref. Genge, Gerald R., Repair of Faults in Masonry Building Envelopes, Seventh Canadian Masonry Symposium, June 4-7, 1995; pg 840*). Considerable effort is sometimes spent examining, categorizing and documenting symptoms rather than the actual root causes of the noted distress or deterioration. Basing repair decisions solely on these symptoms without determining their underlying causes, however, will not result in acceptable results.

Symptoms that can be indicative of a building envelope problem include:

- cracked mortar joints and masonry units;
- displaced masonry units;
- unit spalling and scaling;
- unit staining; and
- recurring instances of efflorescence.

Prior to any restoration work being undertaken, the nature of the problem should first be accurately identified.

Fault Diagnosis and Determining Treatment

Cracked mortar joints and masonry units can be a symptom of uncontrolled differential movement. The cracks may take a variety of different shapes and patterns, and these differences will help with diagnosing the nature of the underlying cause of the cracking.

Vertical Step Cracks indicate inadequate accommodation for movement from volumetric change. These types of cracks are most prevalent at building corners and along parapet walls where the sum of the forces acting on the walls is typically the greatest. Without adequate accommodation for movement a masonry wall will create its own movement joint by cracking along the weakest plane, generally in a stepped fashion along the mortar-unit interface. Repairing such a crack without providing additional movement capability within the wall assembly will only result in further cracking.

Diagonal Step Tapered Cracks are indicative of differential settlement or deflection, where one portion of a structure has settled more than its adjacent parts. Prior to repairing such cracks as a maintenance item, it should first be determined if the crack is static or dynamic. If static, then re-pointing the cracked joint will resolve this condition. If the crack is determined to be dynamic, however, the solution may not be quite so simple. An investigation of concealed conditions might be necessary to determine the scope and nature of the settlement or deflection with remedial action first being undertaken to resolve the source of movement before the crack repair can commence.

Inadequate diagonal wind bracing of the structural back-up walls, particularly relevant when more flexible steel stud is used, has also been known to result in cracking of masonry veneer. Such conditions must be rectified prior to repairing the cracked masonry wall. This is generally not a simple or cheap exercise as it requires the dismantling of either the veneer wall or the finished interior to gain access to the structural wall components. Alternatively, breaking the wall surface into smaller panels by incorporating additional movement joints might better accommodate the movement of the veneer materials without resulting in uncontrolled cracking.

Horizontal Cracks may result along masonry bed joints from shortening of the structural frame or deflection of shelf angle supports if adequate accommodation for this vertical movement is not incorporated in the veneer by means of horizontal movement joints. Such cracking is usually accompanied by unit displacement.

Refer to ARRISCRAFT•NOTE Vol. I, No. 1, titled Building Movement Joints for further information pertaining to the control of differential movement.

Equally, inadequate lateral restraint of the veneer due to an insufficient quantity or quality wall ties could result in applied loads that will crack the mortar. Such cracks are generally accompanied by portions of the masonry "bowing" out from the plane of the wall. Prior to crack repairs being undertaken, the masonry veneer would need to be laterally secured to the structural back-up using purpose-made repair connectors.

Unit Displacement is normally a symptom of uncontrolled differential movement. Units become displaced when sufficient stress has been allowed to act upon the unit such that the combination of the gravity load, shear resistance and lateral restraint normally holding the unit in place have all been exceeded. Such stresses could result from inadequate lateral load transfer or uncontrolled cyclic volumetric change resulting from inadequate accommodation for movement or moisture infiltration.

As noted above inadequate accommodation for movement resulting from volumetric change will crack the veneer, and masonry units in this vicinity will be most susceptible to displacement. Typically, the larger the unit is, the more likely it will become displaced after cracking has occurred. By their very nature larger masonry units will have a lower ratio of mortar-to-unit area compared with smaller units. As such, the mortar holding these units in place is more susceptible to further deterioration after initial cracking has occurred, and this will eventually lead units that are free to be moved by the stresses being imposed on them. Units that have a means of providing a mortar key may exhibit less significant displacement deepening on the applied stresses.

As with vertical step cracks, this displacement is most prevalent at building corners and along parapet walls where the sum of the forces acting on the wall is greatest. Prior to resetting displaced units within the wall, it is essential that additional accommodation be made for differential movement, normally accomplished by incorporating additional movement joints within the general location of the displacement.

Uncontrolled moisture penetration could result in the progressive erosion of the mortar joints until there is no longer a sufficient quantity of mortar to secure the wall tie system to the veneer. Under this condition wind or seismic loads could result in unit displacement. In colder climates water resting within the wall will also be subjected to freezing, causing its volume to expand and potentially imparting a force large enough on the masonry to also cause it to move.

Displacement may also occur due to shortening of the structural frame or deflection of shelf angle supports if there is inadequate accommodation for vertical movement.

Equally, inadequate lateral restraint of the veneer due to an insufficient quantity or quality of wall ties could result in applied loads gradually displacing the masonry. Refer to ARRISCRAFT•NOTE Vol. I, No. 3, titled Connectors Part I – Masonry Ties for further information regarding wall ties and lateral restraint requirements for masonry veneer walls.

Spalled and Scaled Units can be indicative of poor moisture management or uncontrolled differential movement. Masonry units will spall or scale once they become saturated by a continuous source of moisture and are then subjected to freeze-thaw cycling. The application of water repellent sealers to some masonry units may also contribute to spalling or scaling as they tend to inhibit the masonry's ability to breathe and trap moisture just behind the unit's surface. Sealed units will remain wetter longer and could be damaged by moisture freezing within the unit's pore structure and subsequently damaging the unit's face.

Some typical sources of moisture leading to unit saturation include roof leaks, improperly constructed flashing membranes, non-functioning air/vapour barrier membranes that allow condensation to occur, poorly detailed sills, caps and copings, and clogged or non-existent weep hole vents. Wind-driven rain is unlikely to cause a continuous state of masonry saturation unless drainage detailing is deficient.

Spalling may also occur when shortening of the structural frame or deflection of shelf angle supports impart stress into the masonry units below. This could occur if inadequate accommodation for vertical movement is included in the form of horizontal movement joints below shelf angles.

In colder climates extended exposure to de-icing compounds has also been known to contribute to spalling and scaling.

Prior to replacing or repairing spalled and scaled units, the source of moisture must be identified and repaired; otherwise, the problems will persist.

Stained Units may be a symptom of poor moisture management or continuous exposure to sources of moisture. Saturated masonry units, particularly lighter coloured units, will appear darker wherever the moisture has been wicked into the material. The moisture may include particles of dirt and pollution that will be deposited within the pore structure of the masonry. For example, masonry units that are installed in direct contact with topsoil will draw a quantity of dirt-laden moisture from the topsoil into its pore structure. Similar conditions will occur from water run-off, where the moisture contains pollutants, such as from the tops of wall caps, sills, copings, etc. After lengthy exposure to these conditions, the resulting stain may prove difficult to remove.

The continual presence of moisture could also lead to the formation of biological stains such as mould and mildew within the pore structure of the masonry units. Such stains may prove difficult to remove due to their organic nature. The growth must be stopped and then the stain removed. There are propriety agents that can be used, but their effect on the masonry's appearance must be tested.

Cleaning stained masonry without first determining the cause of the staining will most likely not result in a satisfactory solution. The source of the moisture must first be identified and rectified if subsequent staining is to be avoided.

Recurring Efflorescence is normally indicative of poor moisture management. Efflorescence is a crystalline deposit of water-soluble compounds on the surface of unit masonry. In order for efflorescence to occur soluble salts must be present within the wall construction; a source of water must be present and in contact with the soluble salts for a sufficient period of time to permit then to dissolve; and the migration of these salts in solution to the masonry surface where the moisture is allowed to evaporate.

The most realistic means for preventing recurring efflorescence is to limit the extended presence of moisture within the wall assembly. Two considerations which must be addressed to successfully reduce efflorescence–causing moisture within the wall are to:

- prevent sufficiently large quantities of water from penetrating the wall; and
- ensure that any water penetrating the wall is allowed to quickly leave the wall assembly, thus minimizing absorption by the masonry units and the mortar.

Refer to ARRISCRAFT•NOTE Vol. II, No. 1, titled Efflorescence for further information pertaining to the prevention of efflorescence in masonry walls.

When recurring efflorescence is noted as a symptom of a building fault, the source of the moisture penetration and the cause of its retention should both be identified and rectified prior to removing the efflorescence.

Summary

This ARRISCRAFT•NOTE discusses the basic principles of symptom identification and fault-diagnosis of masonry-related building envelope failures. Distinctions between maintenance and repair, and symptoms and faults are described, while a variety of common symptoms and building faults are discussed relative to their repair.

The information and suggestions contained herein are based upon the available data and information published by the listed references and the experience of Arriscraft International architectural and engineering staff. More detailed information may be found by referring to any of the related references listed below.

The information contained herein must be used in conjunction with good technical judgment and a competent understanding of masonry construction. Final decisions on the use of the information contained in this ARRISCRAFT•NOTE are not within the purview of Arriscraft International and must rest with the project designer or owner, or both. It remains the sole responsibility of the designer to properly design the project, ensure all architectural and engineering principles are properly applied throughout, and ensure that any suggestions made by Arriscraft International are appropriate in the instance and are properly incorporated through the project.

Related References

1. Aberdeen Group, Masonry Inspection and Maintenance, Aberdeen's Magazine of Masonry Construction, 1994.
2. Brick Industry Association, Technical Notes on Brick Construction.
3. Canada Mortgage and Housing Corporation, Best Practice Guides – Building Technology.
4. Drysdale, R.G. and Sutter, G.T., Exterior Wall Construction in High Rise Buildings, Canada Mortgage and Housing Corporation.
5. Cody, Gina P., Deterioration of Masonry, Causes and Prevention, Seventh Canadian Masonry Symposium, June 4-7, 1995; pp. 833-839
6. Genge, Gerald R., Repair of Faults in Masonry Building Envelopes, Seventh Canadian Masonry Symposium, June 4-7, 1995; pp. 840-849

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Introduction

This ARRISCRAFT•NOTE discusses the properties of the calcium silicate masonry units (CSMU), including the applicable reference standards, physical characteristics, freeze-thaw durability and cyclic volumetric changes. CSMU are distinct from both clay bricks and concrete masonry products. Thus it is important that designers develop an understanding of these aspects as they relate to the design of a building.

Basic Description

Calcium silicate masonry units are a manufactured masonry product. Lime and silica-based sand are mixed and then pressed into modular-sized units under high pressure. The "green" units are then subjected to high-pressure steam in an autoclave to produce a masonry unit with uniformly fine-grained texture. A calcium silicate hydrate binder is formed when the elements in the raw materials chemically react in the autoclave. This results in a durable, strong and integrally bonded unit. This process distinguishes calcium silicate units from cement-based masonry units.

Production techniques utilizing high pressure and stringent quality control mean that no significant change in the shape or size of the units occurs when the units are cured. Thus, both the strength and the critical dimensions of the calcium silicate masonry units are extremely uniform.

A wide variety of distinctive colours can be produced, many of which cannot be matched by other types of masonry units. These range from natural white to pastel shades to earthen tones. Proprietary colour blending techniques make it possible to produce striations and ranges similar to those in natural stone.

Calcium silicate masonry units can be cut, shaped, hand-chiseled or dressed while maintaining a fine-grained texture and through-body colour. Calcium silicate masonry units mature in appearance under exposure to normal atmospheric conditions in a manner similar to many natural stones, such as limestone.

Calcium silicate masonry units provide building designers with the opportunity to use a material of controlled high strength with natural appearance and well-established durability at an economical cost.

Applicable Standards

In North America calcium silicate products are described by ASTM C73-99a, *Standard Specification for Calcium Silicate Face Brick*. This standard specifies the requirements for compressive strength and absorption in order for the material to be classified as either moderate- or severe-weathering.

It is important to realize that calcium silicate masonry units are distinct from cement-based products and, therefore, product standards specific to cement-based materials do not apply.

Within the calcium silicate standards there are no performance requirements with respect to freeze-thaw durability. It is generally accepted that the durability of calcium silicate masonry is closely related to its strength properties. Freeze-thaw performance is thus controlled by the strength requirements in the standard. Further discussion on performance testing for freeze-thaw durability follows.

Arriscraft calcium silicate products meet the "severe-weathering" requirements of the C73 standard.

Quality Assurance Program

The quality assurance program of any masonry product manufacturer must ensure that their products meet the requirements of the standards by means of a proven sampling and testing program. An internal program must ensure that product sampling adequately represents the production and that action limits are set to minimize the chances that any unacceptable product may reach the job site.

Calcium silicate products are typically sampled and tested on a lot-by-lot basis. All sampled products are tested for hardness. This property can be correlated to the compressive strength of the material. Select samples from each production line are then subjected to intensive testing for compressive strength, absorption, density and freeze-thaw durability. Pre-screening of aesthetic properties such as colour and colour distribution are also performed on all sampled material so that production personnel can be alerted to any possible concerns. The production process is configured to allow for 100% inspection of the product for conformance to the aesthetic criteria discussed below.

Physical Properties

Compressive strength is the ultimate crushing load at which a material will commence to fail by fracturing. This property has been used as a measure of quality and as a means of prediction of other properties. Note that tested or apparent compressive strengths will vary with the size and the shape of the specimen tested mainly due to constraint on the contact area between the specimen and the loading platens of the testing machine. Therefore, when comparing compressive strength values, the possible effects of varying specimen size and shape must be considered.

Modulus of rupture is a measure of resistance to bending action or flexural strength, and in the case of calcium silicate masonry units, can also be used as a measure of the resistance to cracking of individual units due to internal bending stresses set up within the wall.

Absorption is the ratio expressed as a percentage of the weight of water absorbed by the specimen when soaked in cold water for 24 hours compared to the original dry weight. Alternatively, the 24-hour absorption can be expressed as a ratio of the weight of water absorbed per unit volume of masonry material. Limits may be established for different types of material to minimize the potential for freeze-thaw damage, excessive volumetric change or excessive permeability to water penetration. For calcium silicate masonry units the absorption typically varies inversely with the compressive strength and maximum levels are assigned for freeze-thaw durability.

Arriscraft calcium silicate masonry units have been independently tested to ensure that they meet and exceed the severe-weathering requirements for ASTM C73.

Freeze-Thaw Durability

The best indicator of satisfactory durability of any masonry unit is its proven performance under similar conditions of use. Arriscraft calcium silicate masonry products have over a 50-year history of achieving excellent durability in a variety of climatic conditions and installations.

Laboratory tests can also be performed to give a reasonable confidence in the CSMU's performance. Proper design, detailing and construction of the wall assembly are critical to long-term masonry performance. (*ref. Drysdale, Hamid, Baker; Masonry Structures – Behavior and Design - Second Edition, 1999; pg. 117*). It must be acknowledged that under extreme service conditions, even product with an excellent history of durability might fail.

Given that a freeze-thaw test is a performance-based test, the freeze-thaw performance of calcium silicate products should be compared to other materials that would be used in the same unit masonry applications. The U.S. industry standard test method for freeze-thaw performance is ASTM C67-03a, *Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile*, a freezing and thawing test method for clay brick masonry. In Canada calcium silicate masonry units would most appropriately be tested in accordance with the Test for Freezing and Thawing as described in CAN3-A82.2-M78 (Reaffirmed 2003), *Methods of Sampling and Testing Brick*.

The same performance criteria as those used for evaluating clay facing brick (defined in either ASTM C216-04, *Standard Specification for Facing Brick (Solid Masonry Units Made From Clay or Shale*) or CAN/CSA-A82.1-M87 (Reaffirmed 2003) *Burned Clay Brick Solid Masonry Units Made From Clay or Shale*, are also a fair measure of performance for calcium silicate products. Both clay brick standards stipulate a maximum allowable loss in weight of 0.5% with no breakage when tested in accordance with their respective methods.

It has been suggested that freeze-thaw tests utilizing saline solutions are necessary for evaluating freeze-thaw durability of masonry veneer products. Masonry veneer products, however, are intended to be used above grade and should not be directly exposed to a de-icing salt environment. Using a saline-based freeze-thaw test, therefore, would not be relevant.

A good quality calcium silicate masonry unit will exhibit exceptional durability when subjected to the above-referenced standard freeze-thaw tests. For instance, when Arriscraft CSMU are tested, they yielded no net loss in weight and they were in excellent condition with no observable signs of distress.

Aesthetic Considerations

At the very least manufacturers must meet the criteria for acceptance pertaining to aesthetic acceptability that are outlined in the applicable standard. ASTM C73 stipulates chips or cracks shall not be visible from a distance of 20 feet. It further states that 5% of a shipment containing chips no larger than ½" or cracks no wider than 0.02 inches and not longer than 25% of the nominal height of the unit is permitted.

Where the nature of the finish necessitates a restriction on chippage, better quality calcium silicate masonry units exceed these criteria. For example, smooth finished Renaissance® Masonry units are inspected to be free of chips, cracks or other blemishes on the finished face or front edges of the material exceeding 10 mm (3/8") or that are objectionable from a distance of 3 m (10'-0"). Units provided with rusticated faces are inspected for cracks and blemishes only as chippage considerations do not apply when the desired surface texture and unit shape is intended to be uneven.

Good quality calcium silicate masonry units must also be packaged to maintain this level of good quality during shipment. The masonry contractor is expected to take the proper precautions during storage and handling. Recommendations are contained within the ARRISCRAFT•CARE sheet. Any damaged, chipped or broken product that arrives on site should be brought to the attention of the manufacturer prior to the installation as installation constitutes acceptance of the product.

Movement Characteristics

Dimensional change of a material resulting from changes in temperature is expressed by its coefficient of thermal expansion. Similarly, changes in moisture content over the service life of a building will result in dimensional changes. This property is often expressed as a strain or a percentage based on the material's initial length at ambient conditions. The movements caused by thermal and moisture changes are generally not additive. Actual movement in a masonry wall will be affected by both the unit age and degree of unit saturation at the time of construction and the temperature and humidity conditions to which the wall is exposed. These types of movements are cyclical in nature (e.g. reversible).

Typically, clay bricks undergo a permanent moisture expansion over the life of the brick; whereas, cement-based units undergo a degree of permanent shrinkage. While some sources site a permanent shrinkage of calcium silicate units, with better quality CSMU any shrinkage would only occur very early in the life of the unit, during the production process. It is imperative, therefore, that the building movement joints in a CSMU veneer be designed and constructed as *elastic* joints so that they can accommodate the associated cyclical expansion and contraction of the masonry veneer due to temperature and moisture conditions.

When determining the placement of the building movement joints, the building designer must consider the cyclical movement characteristics of the masonry unit. Values for thermal movement and reversible moisture movement of CSMU are within the same range as those for clay units. Thus, required placement and spacing considerations for movement joints would be similar. For further information on the proper design and detailing of movement joints, refer to ARRISCRAFT•NOTE, Vol. I, No. 1, titled Building Movement Joints.

Summary

This ARRISCRAFT•NOTE discusses the properties of calcium silicate masonry units (CSMU), including the applicable reference standards, physical characteristics, freeze-thaw durability and cyclic volumetric changes. CSMU are not the same as clay brick or concrete-masonry products, and their properties are sufficiently distinct to warrant some consideration during the design of a building.

Calcium silicate masonry units are a manufactured masonry product offering a wide variety of distinctive colours and textures, closely simulating the appearance of many natural stones. They provide building designers with the opportunity to use a material of controlled high strength, with a natural appearance and a well-established durability at an economical cost.

The information and suggestions contained herein are based upon the available data and information published by the listed references and the experience of Arriscraft International architectural and engineering staff. More detailed information may be found by referring to any of the related references listed below.

The information contained herein must be used in conjunction with good technical judgement and a competent understanding of masonry construction. Final decisions on the use of the information contained in this ARRISCRAFT•NOTE are not within the purview of Arriscraft International and must rest with the project designer or owner, or both. It remains the sole responsibility of the designer to properly design the project, ensure all architectural and engineering principles are properly applied throughout, and ensure that any suggestions made by Arriscraft International are appropriate in the instance and are properly incorporated through the project.

Related References

1. American Society for Testing and Materials, ASTM C67-97, Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile.
2. American Society for Testing and Materials, ASTM C73-97a, Standard Specifications for Calcium Silicate Face Brick.
3. American Society for Testing and Materials, ASTM C216-97, Standard Specification for Facing Brick.
4. Canada Standards Association, CAN/CSA A82.1-M87 (Reaffirmed 2003), Burned Clay Solid Masonry Unit Made From Clay or Shale.
5. Canada Standards Association, CAN3-A82.2-M78 (Reaffirmed 2003), Methods of Sampling and Testing Brick.
6. Drysdale, Hamid, Baker; Masonry Structures - Behavior and Design - Second Edition, The Masonry Society, 1999.

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Introduction

This ARRISCRAFT•NOTE discusses the basic principles pertaining to the selection and use of mortar in masonry veneer construction. This paper does not address issues relevant to engineered structural masonry mortars, restoration or other specialty mortars.

The integrity of a masonry veneer assembly relies upon many factors including the proper selection of complementary materials and products, proper configuration of various elements designed to accommodate the different forces acting on the wall, proper workmanship, and suitable environmental conditions during construction.

The mortar is only one component of an entire masonry veneer assembly and must be selected with respect to complementing the other components, such that the entire assembly will provide a long-lasting, aesthetically pleasing building façade over the life of the building.

The earliest mortars were primarily lime-based, utilizing calcium-based materials indigenous to the geographic area of use. At the beginning of the 20th Century the introduction of Portland cement to the mix enabled faster initial set and thus faster construction. Today, combinations of Portland cement, lime, sand and water are mixed to specific proportions to achieve the desired properties. The cement adds strength, the lime contributes to the workability and durability and the sand is inexpensive filler. (*Ref. Drysdale, Hamid, Baker; Masonry Structures - Behavior and Design - Second Edition, 1999; pg. 147*)

The Function of Mortar

The mortar's primary function within a wall veneer is to accommodate minor variations in tolerance in unit dimensions, thus helping to resist moisture infiltration. Other functions of mortar are to secure joint reinforcement and metal ties so that they can act integrally with masonry and to facilitate ease of construction.

The weather resistance of a wall is a function of properly tooled mortar joints combined with the incorporation of suitably designed drainage or barrier wall elements. It is not the function of the mortar however to act as a "*glue*" that permanently holds the units in place nor to ensure the monolithic nature of the wall veneer. Other wall elements are relied upon to minimize wall cracking.

For instance mortar cannot be relied upon to accommodate the significant stresses imposed on masonry veneers as the result of differential movements. That is the function of properly located and constructed movement joints. In fact it is generally accepted that mortar should be designed as the weaker, sacrificial element in the wall. Thus, any cracking that may result from inadequately accommodated movement will occur along the mortar joints and not through the masonry units themselves. Whereas a cracked mortar joint can easily be re-pointed, replacing masonry units is relatively more difficult and costly.

Mortar Types

Mortar, its production and use are generally specified by reference to specific standards published by either the Canadian Standards Association (CSA A179) or the American Society for Testing and Materials (ASTM C270). There are five basic types of mortar described, although two types in particular are the most commonly used in masonry construction: Type N and Type S.

Type N mortars exhibit good workability in their plastic state and greater flexibility in their hardened state. The increased flexibility better accommodates minor load variations, thus resulting in better joint durability. As such, Type N mortars are ideal for use in non-load bearing veneer applications.

Type S mortars are reasonably workable in their plastic state and exhibit high strength and adequate flexibility in their hardened state. The higher cement content, however, tends to make them slightly less flexible than Type N mortars and more susceptible to the formation of shrinkage cracks. They are commonly used for engineered masonry and below grade applications, although their use in some veneer construction has proven appropriate.

Specification Conventions

The mortar type should conform to one of two specification conventions: either the Property or the Proportion specification method. Mortars prepared to the Proportion specification method are described as a relative volume of ingredients; whereas, mortar prepared to the Property specification method are described in terms of their expected hardened properties.

Acceptance criteria relative to the specification method used do differ between the CSA and the ASTM reference standards. Design consultants doing cross-border work should be cognizant of these differences and not simply replace one standard reference with the other, while still expecting compliance with the standard with which they are more familiar.

Types of Mortar Mixes

There are a variety of commonly recognized means for the production of masonry mortars. Basically, however, the combination of various cementitious materials with aggregate and water produces a mortar exhibiting distinct properties in the plastic and hardened states.

Today there are generally three basic "recipes" for mortar considered acceptable for use in building construction:

- Portland cement – Lime (PLC);
- masonry cement (MC); and
- mortar cement (MortarC)

Portland cement **-** lime mortars are mixed using the basic original ingredients. The quality and quantity of both the cement and lime in the mix are known and are under the mason's control. Most specifically the use of a good quality lime within the mortar mixture will assure consistent plasticity and workability; higher water retentivity; high sand-carrying capacity; more flexibility under stress; ease of re-tempering; and will impart autogenous healing qualities to the hardened mortar. (*Ref. Boynton, R.S.; Chemistry and Technology of Lime and Limestone, 1966; pg 396.*)

Empirical observations tend to suggest that PCL mortars exhibit reasonably consistent strength properties in the hardened state and will provide superior durability and flexibility.

Where hairline cracking occurs within the mortar joints due to mortar shrinkage or cyclical movements, the use of a lime-based mortar tends to re-seal the hairline cracks or minute voids in the mortar. This tendency is called autogenous healing and occurs as the lime recarbonates in the mortar mix following cycles of wetting and drying.

Portland cement-lime mortars are particularly well suited for use in masonry veneers where the flexibility and autogenous healing properties of the mortar are used to their best advantage.

Masonry cement **-** is a mixture of Portland or hydraulic cement and plasticizing materials (such as crushed limestone, hydraulic and/or hydrated lime) together with other materials introduced to enhance properties such as setting time, workability, water retention and durability. Manufacturers of masonry cement blend and process the various ingredients in proprietary mixes designed to meet specific requirements for particular properties. Masonry cements tend to optimize the plastic mortar properties, as such; their use is preferred by many masons. Variations in quality and quantity of the basic materials, however, may contribute to a wider variation of the hardened properties between masonry cements produced by different manufacturers.

Mortar **-** cement is similar in concept to masonry cement in that the constituent materials are plant batched and processed. The standards governing their production include additional requirements to those governing masonry cement. Mortar cement was primarily developed to address issues of acceptability under the building code within areas of higher-seismic risk. As such, in the simplest of terms it is considered to be an enhanced masonry cement.

Selecting the Appropriate Mortar Mix

In the case of exterior masonry veneers it is recommended that the mortar and masonry unit should be selected such that their respective properties complement one another. They should work together to ensure a durable, weather-resistant joint.

Mortar for unit masonry veneer should exhibit good workability and board life in its plastic state and good durability and flexibility in its hardened state. Empirical observations and data suggest that type N PCL mortar provides the best combination of these key properties.

Portland cement should conform to a recognized standard (either ASTM C150 or CAN/CSA-A5) and would be typically graded as "Normal".

Hydrated lime used in the production of masonry veneer mortars should conform to ASTM C207, Type S. Type N lime should only be used when it is proven not to be detrimental to the performance of the mortar. Air entrained lime may be beneficial where freeze-thaw resistance is important but may also result in a reduction of bond and compressive strength. As such, the use of air-entrained lime may be limited by some building codes.

Masonry aggregate, typically well graded sand, should conform to the appropriate governing standard (either ASTM C144 or CSA A179) and should be clean and free of salts and organic contaminants.

In-the-Wall Performance

Quality of Work: Just as with any other type of building construction, good workmanship is critical to the subsequent performance of the masonry veneer. If improperly applied or applied under adverse environmental conditions, the mortar will most likely not perform as intended. The following checklist outlines some basic guidelines for the proper storage, blending and application of mortar and its constituent materials:

- protect the mortar and masonry materials from freezing;
- accurately site measure ingredients by volume using a suitably sized gauge box or hopper;
- use mortar immediately after mixing, retempering as necessary and as allowed by local codes or standards. Discard mortar older than 2-1/2 hours;
- place mortar on the units for full bed coverage. Do not slush-fill joints;
- do not break the mortar-unit contact once the masonry units have been set in place. If subsequent adjustment of the units is deemed necessary, remove the masonry units from the wall, clean any old mortar from the surfaces, and reinstall using new mortar; and
- tool mortar joints when thumbprint hard to a tightly compressed, weather-resistant surface.

Mortar-Unit Bond: The mortar-unit bond is just one aspect of a wall's integrity. As stated, the mortar's principle functions in a masonry veneer are to accommodate minor construction tolerances and provide long-term protection against the elements. The mortar is not intended to serve as a type of glue that will hold the wall together irrespective of the forces being imposed upon it.

In fact, the mortar joint is designed as the sacrificial element within the masonry veneer. It is expected that some degree of cracking will occur during the service life of the building, and the desired place for such cracks to occur is within the mortar joint rather than within the masonry units themselves.

Essentially mortar bond can be described by the bond strength, extent of bond and bond durability.

Bond Strength is defined as the force required to separate the mortar-unit assembly.

Extent of Bond is defined as the degree of complete and intimate contact between the mortar and the unit.

Bond Durability is defined as the mortar's ability to maintain the integrity of the extent of bond and the bond strength over the service life of the building.

These three characteristics are all affected by the type of mortar used, the type of masonry unit used and the quality of work exercised by the installer.

Mechanical Keying: A common myth within the construction industry is that to achieve adequate bond cores or frogs in the masonry must be filled with mortar. Mortar bond, however, occurs at a microscopic level within the pore structure of the masonry units. As moisture from the mortar is absorbed by the masonry unit, cement particles are drawn into the unit, resulting in a bond between the two materials.

This differs from keying that results from mortar being allowed to harden within a core or frog. When properly detailed and constructed, a mechanical key is unnecessary. However, when detailing is insufficient, mechanical keying may help minimize the displacement of individual units within the wall.

Summary

This ARRISCRAFT•NOTE discusses masonry mortar for use in veneer construction. It discusses the mortar's function in a veneer wall, characteristics affecting mortar bond, mechanical keying, mortar mix criteria and issues of workmanship.

The information and suggestions contained herein are based upon the available data and information published by the listed references and the experience of Arriscraft International architectural and engineering staff. More detailed information may be found by referring to any of the related references listed below.

Related references

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Introduction
This ARRISCRAFT•NOTE addresses some common sources of moisture infiltration relative to masonry veneer wall systems and highlights the negative effects moisture may have on a wall assembly. Strategies for the proper management of moisture are outlined and specific recommendations are reviewed relative to properly managing moisture in conjunction with the various wall components and elements.

Moisture may be considered the cancer of any masonry wall, particularly when the moisture penetrates the wall assembly in sufficient quantities over extended periods of time. It is critical to the long-term performance of a wall assembly that moisture infiltration be controlled and moisture drainage is effective. Otherwise, the potential for wall deterioration will greatly increase.

Common Sources or Moisture Infiltration
Moisture can occur within a wall assembly due to a variety of different causes. Some common defects in the design and construction of masonry veneer walls that allow moisture into the wall system include:

- uncontrolled passage of water vapour through the wall assembly, resulting in condensation;
- poorly detailed, constructed or maintained roof parapets;
- water from non-absorbent surfaces, such as sloping roof surfaces or sloping glass assemblies, allowed to flow down onto the vertical wall surfaces;
- poorly detailed or constructed mortar joints where the joint is not completely filled with mortar or poorly compacted and finished, thus allowing moisture to enter at openings in the mortar joints;
- lack of proper flashing and drainage elements at wall openings, shelf angles and at foundation level;
- masonry in direct contact with the ground and exposed to splash water;
- cracks in masonry induced by excessive foundation settlements, lack of movement joints or structural deflection of the supporting structure; and
- horizontal masonry surfaces with inadequate drainage. (*Ref. CMHC Best Practice Guide – Brick Veneer Concrete Masonry Unit Backing, 1997; pg. 3-12.*)

Effects of Moisture Penetration
Moisture, when present in sufficient quantities over extended periods of time, can contribute to the deterioration of the wall assembly by means of the following processes:

- uncontrolled dimensional change resulting from moisture saturation of materials;
- metal corrosion leading to weakened or ineffective connectors and deterioration of mortar joints due to the expansion of the corroded metal;
- freeze-thaw cycling of saturated materials, resulting in spalling or scaling of the masonry units, or displacement of materials; and
- efflorescence. (*Ref. CMHC Best Practice Guide – Brick Veneer Concrete Masonry Unit Backing, 1997; pg. 3-12.*)

Moisture Management Strategies
There are a variety of strategies that can be implemented during the design and construction of a masonry veneer that will help ensure that the wall will perform better over the long term. Some of these include:

- control the passage of water vapour through the wall assembly;
- minimize the quantity of water that comes into contact with the exterior wall;
- ensure integrity of joints and junctions in the exterior wall;
- neutralize all the forces that can move water through openings in the wall; and
- drain moisture that does enter the wall.

Controlling the passage of water vapour through the wall will help prevent moisture form condensing within the wall assembly. Moisture will typically travel through a wall due to the mechanisms of vapour diffusion and/or air movement. Installing a vapour retarder membrane will help minimize the effects of vapour diffusion from areas of high humidity to areas of low humidity. Moisture travelling across a wall due to air movement can be controlled by designing and constructing an air barrier system as a part of the wall assembly. Typically, it is best to locate the air barrier within the assembly such that it is structurally ridged and protected from subsequent damage. Placement and location of the vapour retarder and air barrier will depend on the geographic location of the building and the anticipated set of design conditions.

Minimizing the quantity of water that contacts the exterior wall is particularly challenging near the top of buildings. Parapets, the junction of the parapet with the roof, and the junction of the other vertical wall elements and the roof are the most vulnerable to moisture penetration, although any horizontal projections from the main vertical wall surface (including the grade-to-wall junction) are also vulnerable. To minimize these effects the following guidelines should be implemented:

- use cap flashings at window sills, roof parapets and other horizontal masonry surfaces and ensure that overhangs and drips are provided to drain the water away from the wall;
- ensure that metal cap flashings are properly lapped and sealed against water leakage and always provide an under-cap flexible flashing membrane between the metal and the sub-assembly;
- keep the exterior wythe of masonry at least 150 mm (6") above finished grade or provide some other design element that will segregate the masonry from moisture laden soil;
- do not drain water from a sloping roof or skylight directly onto the wall's surface. Use architectural elements such as gutters, overhangs, downspouts, etc., to properly drain water away from the wall;
- consider providing roof overhangs to reduce the quantity of water coming into direct contact with the wall; and
- eliminate water spray from ground sprinkler systems.

Applying a proprietary water repellent coating to the surface of the masonry veneer is an unacceptable substitute for proper design and construction. These coatings, even if described as "breathable", inhibit the natural evaporative properties of the masonry units, causing them to remain wetter longer, particularly if the source of moisture is from within the wall assembly. Such coatings have been known to contribute to wall deterioration and could result in costly repairs.

It is our opinion that better constructed wall systems provide better solutions to moisture management and control. We caution building designers not to rely upon the application of a water repellent sealer to replace good masonry wall design and construction methods.

Ensuring the integrity of the joints and junctions in the exterior wall will also assist with minimizing the potential for moisture infiltration of the wall. Consider and implement the following guidelines;

- ensure head and bed joints are filled solid with mortar and that the mortar joint has been tightly compressed and tooled to a well-weathering profile;
- ensure that movement joints and junctions between dissimilar materials are properly designed, constructed and maintained;
- minimize joints between sills, caps, copings and watertable units by using the maximum lengths possible and ensure joints are properly sealed with a good quality backer rod and joint sealant;
- design walls to avoid cracking of joints by strategically placing properly constructed movement joints in the building veneer. Refer to the ARRISCRAFT•NOTE (Vol. I, No. 1) titled Building Movement Joints for recommendations pertaining to the design and placement of the building movement joints; and
- ensure the proper design, construction and maintenance of metal parapet wall caps and/or flashing membranes

Neutralizing the forces that can move water through openings in walls will assist with preventing moisture and water vapour being "driven" across or through the wall assembly. Wall assemblies should be designed and constructed in accordance with the following:

- reduce the air pressure differential by applying the rain screen principle to the design of the wall assembly. Refer to ARRISCRAFT•NOTE (Vol. I, No. 2) titled The Rain Screen Principle for further information;
- provide overhangs and drips at flashings and sills to direct water away from masonry materials;
- slope surfaces (at least 1:12) that are likely to retain water to make them drain water away from the wall; and
- overlap materials to counter effects of the momentum of water, eg. by lapping the building paper over the vertical leg of the flashing membranes to ensure the continuity of flow of the moisture.

Draining moisture that does enter the wall is critical to maintaining the weather-resistant nature of the wall assembly and to avoid prolonged saturation of the masonry. Implement the following guidelines:

- ensure that a clear draining cavity at least 25 mm (1") in width exists between the masonry veneer and the other wall components;
- provide flashing membranes in the cavity over openings, at shelf angles and at the foundation level to drain any water that does enter the cavity; and
- provide drainage openings, such as weep vents, regularly spaced above flashing membranes to let the water quickly exit the wall assembly.

Additional information may be found by referring to the CMHC Best Practice Guide – Brick Veneer Concrete Masonry Unit Backing, pg.3-15.

Other Construction Issues

Other issues of moisture management include the storage and handling of products on site and the protection of walls during their construction from moisture infiltration.

Delivery Storage and Handling: How materials are handled and stored on site could have some bearing on the amount of moisture that will be present within the wall assembly after initial construction. It is considered prudent to limit the quantity of moisture in the materials to the least amount necessary. Protecting materials from excessive moisture prior to their use will assist in avoiding subsequent moisture being "installed" into the wall. Consider the following guidelines:

- deliver mortar materials in original, unbroken and undamaged packages with the maker's name and brand distinctly marked thereon, and upon delivery store in a shed until used on the work;
- store or pile sand on a plank platform and protect from dirt and rubbish. Store mortar materials and sand in such a manner as to prevent deterioration or contamination by foreign materials;
- deliver masonry units to the site in approved protective film. Prevent damage to units;
- lift skids with proper and sufficiently long slings or forks with protection to prevent damage to units. Protect edges and corners;
- store masonry units in a manner designed to prevent damage and staining of units;
- stack units on timbers or platforms at least 75 mm (3") above grade;
- place polyethylene or other plastic film between wood and other finished surfaces of units when stored over an extended period of time;
- cover stored units with protective enclosure if exposed to weather; and
- do not use de-icing compounds to remove snow and ice from masonry surfaces.

Wall Protection: properly covering the tops or partially completed masonry walls during the construction phase is equally critical to ensuring the wall's performance, at least during the early phases of the building's life cycle. The tops of walls should be covered at the end of every work day and especially in times of inclement weather to protect them from any moisture infiltration due to rain or snow. Often times the tops of walls also need to be protected for an extended period until the permanent wall cap assembly is constructed. Tarpaulins or other weather-resistant material should be securely tied with metal clamps and weighted into position to ensure they do not become displaced. The use of mortar boards, scaffold planks and light plastic sheets weighted with scraps of masonry units is unacceptable as suitable covering. (*Ref. BIA Technical Note 7B revised, Water Resistance of Brick Masonry – Construction and Workmanship, Part III, pp 4-5.*)

Summary

This ARRISCRAFT•NOTE addresses some common sources of moisture penetration of a masonry veneer wall and highlights the negative effects the presence of moisture may have on the wall assembly. Various strategies for proper moisture management are outlined with specific recommendations being made relative to a variety of different wall components.

The information and suggestions contained herein are based upon the available data and information published by the listed references and the experience of Arriscraft International architectural and engineering staff. More detailed information may be found by referring to any of the related references listed below.

The information contained herein must be used in conjunction with good technical judgement and a competent understanding of masonry construction. Final decisions on the use of the information contained in this ARRISCRAFT•NOTE are not within the purview of Arriscraft International and must rest with the project designer or owner, or both. It remains the sole responsibility of the designer to properly design the project, ensure all architectural and engineering principles are properly applied throughout, and ensure that any suggestions made by Arriscraft International are appropriate in the instance and are properly incorporated through the project.

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