

# A Review: Durability of Fired Clay Brick Masonry Wall due to Salt Attack

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## Abstract

This paper offers a review on durability of fired clay brick masonry wall due to salt attack. Durability of brick normally affected when an external masonry walls are exposed to aggressive environment. Masonry structures, when subjected to salt attack or exposed to aggressive environment during their service life may suffer degradation due to the formation of crystallization pressure as a result of the evaporation of soluble salt in clay masonry structures. The crystallization pressures produce normally higher than tensile stress of clay brick and sufficient to damage the masonry structures. The mechanism of salt attack must be prevented and addressed thoroughly in order to maintain the integrity and service life of masonry wall. Therefore, the summary of durability, factors, mechanism and main sources of salt attack on fired clay brick masonry walls are discussed.

**Keywords:** Durability, Salt attack, Fired clay brick, Salt crystallization

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## 1. INTRODUCTION

Masonry structures, when subjected to an aggressive environment during their service life may suffer degradation derived from the type of their component materials and the technique of construction (Gravaglia et al, 2000). In order to ensure the strength and performance of fired clay brick masonry wall is maintained, the problems of durability must be considered. As the factors affecting the durability, the physical characteristics of fired clay brick or masonry mortars display a dense, homogenous and impermeable characteristic (Larbi, 2004). In fact, on a micro-level, they contain several voids and inhomogeneities that can adversely affect their durability. In addition, DeVekey (2008) found that mortar is generally a less durable material than fired clay or dense concrete. This because it contains reactive and finely divided binders such as ordinary Portland cement and it usually has a relatively high porosity and comparatively, a lower hardness and abrasion resistance. Philips and Zsembery (1982) indicated that, durability of fired clay brick normally affected when fired clay bodies are exposed to aggressive environment. However in practical purpose, Hendry and Khalaf (2001) explained the durability is regarded as the ability of the material to remain serviceable for an acceptable period without excessive or unexpected maintenance. Jordan (2001) suggested that the durability of masonry is affected by its ability to resist the cycles of heat and cold, wetting and drying and the absorption of various contaminants from its environment. Contaminants, particularly salts, can attack the masonry both physically and chemically. In contrast, Elert et al (2003) also explained the brick durability is considered to be closely related

to the vitrification degree. However, Elert et al in addition, the vitrification degree alone has been shown to be insufficient to predict weathering behaviour. Therefore in order to estimate brick durability, porosity and particularly pore size distribution must be considered as well.

One of the criteria in selecting fired clay bricks is the ability of the materials to withstand the damaging affects of the exposure conditions to which they are likely to be subjected during the life expectancy of the structure in which they are to be used (Philips and Zsembery, 1982). This in line with the suggestion made by Maurenbrecher et al (2001) which indicated that a building and its component should be durable enough to perform the required function in its service environment over the design life usually 50 to 100 years without unforeseen cost for maintenance and repair.

The quality and durability of fired clay bricks are varies depending on the types of raw material, the forming process and firing condition used in manufacturing. Currently with advance materials or extrusion, more sophisticated kiln firing techniques, more rigid mortars, less robust construction and the almost casual introduction of chemical additives, durability problems can be more complex (Parkinson et al, 1996). Khalaf and DeVenny (2002) found that the main factor influencing the durability of masonry is the degree of saturation. Saturation could occur in three ways which either directly through rainfall, indirectly by water moving upward, by capillary action, from foundation or laterally from retained material. Therefore, due to water penetration are the main element that leads to the degradation of masonry, an accurate value for water absorption and the saturation coefficient is required. However,

Zsembery (2001) suggested that, the most important factors are the severity of the environmental conditions the units are exposed to, which is, moisture and the availability of soluble salts, and the amount of glass formed in the masonry unit body during firing. Furthermore, Binda and Molina (1990) explained that the factors such as structural behavior like porosity, mechanical strength and deformability, types of salt and the frequency as well as duration of wetting drying cycles could influenced the durability of material to salt decay. Yet, the wetting and drying phase of material by salt solution could give the disruptive effect which cause alternative dissolution and crystallization of soluble salts (Fassina et al, 2002).

Normally, when the materials exposed to the surrounding environment for certain period, this situation will cause the damage or deterioration of building material. Hendry and Khalaf (2001), Surej et al (1998) and Curtin et al (1997), agreed that the main factors which can cause problems with bricks and brickwork are sulfate attack, frost attack and crystallization of soluble salts. In contrast, Binda and Molina (1990) considering the salt crystallization as one of the most important factor causing decay to brick and stone masonry particularly in marine or industrial environment. These problems could be reduced and directly can enhance the durability by stopping the moisture or water penetration into the masonry because all of these problems involve the presence of water. DeVekey (2008) categorized the mechanism of attack which lead to deterioration of fired clay masonry structure into:

- i. chemical biological attack on either the mortar or the unit or both, due to

water and waterborne acids, sulfates, pollution and chemical released by growing plants;

- ii. corrosion of embedded metal (usually steel) components, particularly ties, straps, reinforcing rods etc., which is a special case of chemical attack;
- iii. erosion of unit or mortar by particles in flowing water and wind, by frost attack and by salt crystallization;
- iv. stress-related effects due to movement of foundation, movement/consolidation/washout of in-fill, vibration, overloading, moisture movement of bricks and blocks, thermal movement, growth of plants;
- v. staining due to efflorescence, lime, iron, vanadium and biological growth.

## 2. SALT ATTACK

Salts in masonry wall are either present in the masonry at the time of building or are absorbed from atmosphere or groundwater during the life of the building (Jordan, 2001). Sulfate normally are present in many bricks and stone, in Portland cement and in some groundwater and are formed in masonry from sulfur dioxide and sulfurous acid in the atmosphere. However, chloride comes chiefly from salt-laden air near the sea, mixing water and groundwater. In fact, the source of salt may be one or a combination of the following (Young, 1995):

- i. Saline soils and groundwater
- ii. Sea spray
- iii. Air-borne salt
- iv. Air pollutants

- v. Biological – pigeon poop, microorganism, leaking sewers
- vi. Salt naturally occurring in the stone, brick clay or mortar sand
- vii. Salt water used for puddling brick clay or mixing mortar
- viii. Salts used for de-icing roads in cold climates
- ix. Inappropriate cleaning compounds

Espinosa et al (2008b), Rijniers et al (2005) and Buchwald and Kaps (2000) agreed that the cause of decay and deterioration are due to the influenced of the existence and movement of water and damaging salt. In Australia, the salt attack has been the primary mechanism of masonry decay and more severe (Young, 1995). Espinosa et al (2008b) noted that a significant part of the damage of the building material is due to the salts contained in the pores of the material due to the hygroscopic properties of salts and solutions.

Zsembery (2001) revealed that not all salt that exist in moisture will cause damage, even liable to attack. The most problematic salts are sodium sulfate ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ) and magnesium chloride ( $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ) which actually attract and absorb water. Nevertheless, the types of salt commonly found in masonry walls are sodium chloride and calcium sulfate (Young, 1995). Yet, Zsembery (2001) reported that, in practice, sodium sulfate or sodium chloride are the most cases of salt attack. However Binda and Molina (1990) revealed that, sulfate attack is one of the salt types that most frequent and destructive for masonry materials. The amount of salt required to cause damage will depend on the nature of the

masonry but more than 0.5% by weight is considered cause for concern.

Bucea et al, (2005) studied on the effect of sodium sulfate and sodium chloride in the brick-mortar stack. The sulfate solution used was 6.2% by weight volume and chloride 14% by weight volume as recommended by AS4456.10. They exposed to seven cycles which seven days wet and seven days dry for each cycles. After one cycle the salt appeared at the surface of the brick and the mortars deteriorated which there were losses the binder and cohesion. However, after seven cycles the mortars become soft especially in sodium sulfate solution. This situation is due mainly to the crystallization of sodium sulfate and sodium chloride.

The assessment of the salt resistance on fired clay brick was studied by Phillips and Zsembery (1982) using a cycling test method. The period of exposure was 2 hours exposed to sodium chloride and sodium sulfate with the concentration of 14% by weight volume (w/v) and then dried 22 hours at 110°C. The number of cycles was in ranging of 1 to up to 80 cycles and depends on types and quality of brick such as firing temperature. They reported that less sodium chloride cycles in average between 4 to 13 cycles approximately were needed to cause failure in specimens fired at lower temperatures in ranging 900 to 1000°C than was the case with sodium sulfate in average between 8 to 15 cycles approximately. On the other hand, in specimens fired at 1050°C, sodium sulphate caused failure in a limited number of cycles while many of the specimens survived a large number of sodium chloride cycles. It is parallel with van Hees and Brocken (2004) reported the same finding which sodium sulfate provide more severe condition than sodium chloride where in sodium sulfate a brick masonry

showed quite intensive spalling and scaling of bricks and push out of mortar joints. However when the masonry was treated with siloxane after contamination with salt, the damage of masonry exposed to sodium chloride is more serious than that exposed to sodium sulfate.

The effect of sodium and magnesium sulfate on the masonry mortar were explored by Lee et al (2008) and Santhanam et. al (2002). Lee et al (2008) cured the specimens into the solutions until up to 15 month. After 15 months the mortar specimens deteriorated due to sulfate attack and as a result surface damage and reduction in compressive strength occurs. Beside that, the expansion of mortar specimens that exposed to magnesium sulfate solution was lower than the mortar specimens exposed to sodium sulfate solution. This situation occurs because in different pH environment, the sulfate expansion properties are significantly related with the stability of products formed by sulfate attack (Al Amoudi et al, 1995).

Brickwork is a composite material with combination of mortars and bricks. When the expansion occurs in mortar, the effect is normally to the overall expansion of the brickwork. DeVekey (2008) explained that sometimes small horizontal cracks are visible in the centre of the wall because typically the mortar is affected more within the body of the wall than on the surface. Due to the greater expansion in the centre of the wall which remains wetter for long period than the outside, vertical crack may appear on the external elevation in thick masonry. Yet, the horizontal cracking may occur as well, but it is likely to be less obvious where there is a high vertical dead load stress.

## 2.1 Influence of Clay Unit

Clay is one of the most abundant natural mineral materials on earth. Clay brick is made from selected clay and produce by shaping it to the standard or suitable shape and size. The type of clay used is an important factor because it is among the raw material that the majority of the soluble salts originate which the special attention must be given to calcium carbonate and sulphates.

During firing, important irreversible chemical and physical transformations take place within the material (Binda and Baronio, 2006). The firing temperature below than 600°C, loss of the chemically bonded water takes place, with consequent demolition of the crystal lattice. Meanwhile for the firing temperature between 600°C and 900°C, an amorphous silica and alumina are formed. The calcium carbonate dissociation also occurs with the removal of CO<sub>2</sub> and the formation of CaO. This then reacts with the amorphous material producing calcium silicate and aluminates. Futhermore, when the firing temperature beyond 900°C the formation of mullite (3Al<sub>2</sub>O<sub>3</sub> 2SiO<sub>3</sub>) take place

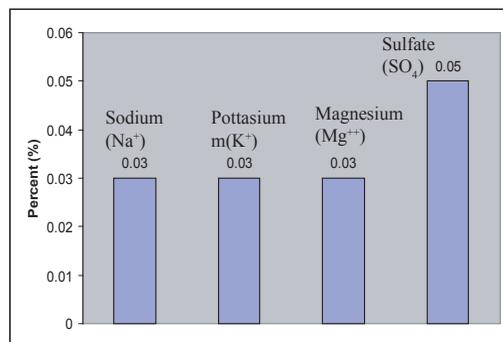


Fig. 1 Low class (L)

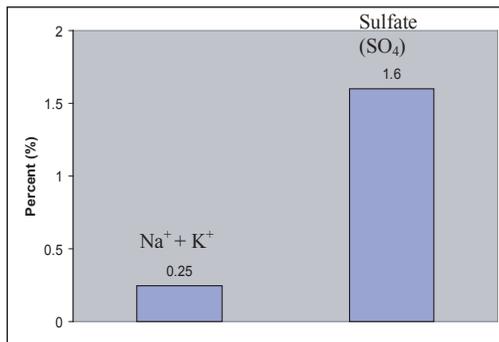


Fig. 2 Normal class (N)

Brick are also classified to their resistance to soluble salt content and frost. However due to climates which are humid and warm, resistance to frost attack was neglected in Malaysia condition. BS 3921:1985 limits soluble salts content of fired clay brick unit for two categories which are Low (L) class as shown in Figure 1 with restrictions on the ions of magnesium, potassium and sodium as well as total amount of sulfate and Normal (N) class as shown in Figure 2 with limits on the amount of specific soluble salts in combination of sodium, magnesium and potassium as well as total amount of sulfate. In contrast, BS EN 771-1 classified into three categories of soluble salt contents which are category S0, S1 and S2. Category S0 is a bricks that are not subject to any limit on specified soluble salt and are intended for use in situations where the total protection against water penetration is provided. However, category S1 gives a limit for brick on soluble salt which are sodium, potassium and magnesium contents. Then for category S2 the bricks have a lower limit than S1. This classification is very important for the durability of masonry wall because soluble salt can damage cement mortar if it is exposed into wet condition continuously.

## 2.2 Influence of Mortar

The purpose of the mortar mix is to distribute the pressure throughout the brickwork, to bind the bricks together and to prevent the transmission of heat, sound and moisture from one side of the wall to the other. Incomplete bond could permit water to penetrate while complete bond makes the structure watertight and able to withstand lateral stresses. The bond strength depends on the mortar, the masonry unit, its moisture content and the workmanship (Surej et al 1998).

BS 6100: Section 5.1: 1985 defined mortar as a mixture of fine aggregate with water and hydraulic cement or lime or a combination of both, that hardens after application and used for jointing. BS 5628-3:2001 described the mortar for the building, made by one part of binder which is cement or lime or both and three part of sand to give a workable mix and has been used for a very long time. Improved workability of mortars containing less cement can be achieved by incorporation of lime, plasticizers or entrained air or any combination of these.

The durability of mortar could be enhancing if the lime content is increased. It is confirmed by Ibrahim et al (2006) which found that increasing the porosity by increasing the lime portion could increase the resistance to deterioration due to salt attack. Their result shows that, the strength of mortar increase when the percentage of lime content increase from 50% to 75% as the higher porosity reduced the crystallization pressures and salt crystal filled the pores. The weight loss in the salt destruction test is affected not only by the intensity of crystallization and hydration pressure taking place inside the pores

but also by the strength of the mortar. Good grading of the sand used also could influence the engineering properties of the mortar. The type of sand used has an influence on the ease with which water can be transported through the mortar due to the difference in particles size characteristic of sands (Bruemner, 2002).

Increasing the proportion of Portland cement generally has been shown to increase the intensity of efflorescence due to the additional alkaline content of the mortar. The use of high alkali cement or clayey mortars is a possible source of soluble potassium and sodium nitrate and sulphates which are the most dangerous soluble with the highest destruction potential (Ibrahim et al, 2006). As discussed by many researchers, the deteriorations caused by soluble salts are mainly due to salt crystallization. The use of impermeable mortars will cause crystallization to take place between mortar joints and bricks causing complete disrupting of the bond between them. The resistance of mortar to salt crystallization pressure could be observed after exposure to high concentration of salt solutions based on two criteria which are expected decreases in compressive strength and expected loss in weight.

### **2.3 Influence of Microstructure**

Most masonry building materials such as clay bricks are permeable or to some extent porous that is they contain voids or pores. Such permeable structures allow water vapor to be transmitted, but also allow liquid water to penetrate. Liquid water or moisture can penetrate permeable masonry building materials due to natural capillary absorption such as for the masonry which

contact with the soil which ground water drawn into pores by capillary suction. According to BS 3921:1985, the total porosity of the fired clay brick can be measured by water absorption test which are using the 24 hours cold water or 5 hours boiling water test. BS3921 classified the water absorption for Engineering Class A ( $\leq 4.5\%$ ) and Engineering Class B ( $\leq 7.0\%$ ). However for design purpose, BS5628: Part 1 has relates three categories of water absorption to characteristic flexural strength which are less than 7%, between 7% and 12% and more than 12%. The water or moisture also, generally will carry the soluble salt together into the masonry material.

The movement of soluble salt within the bricks unit is one of the most important factors in the development of crystallization pressure. Salt crystallization depends greatly on pore structure parameter. Benavente et al (2006) classified the main pore structure parameters into three which are porosity, pore size distribution and pore shape. Porosity is defined as the ratio of the volume of voids to total volume of bricks and expressed as a percentage. More specifically, connected porosity is related to the flow of weathering agents and the remaining moisture in such way that it produces a negative influence on brick durability. Additionally, porous bricks with a high porosity and a large percentage of pores measuring less than 1-2.5  $\mu\text{m}$  in radius are having a tendency to decay.

The rate of crystallization pressure depending on pore size whereby if the pore size is large will generate a low pressure (Scherer, 1999). Ordenez et al (1997) cited by Benavente et al (2006) have recognized stone durability based on the fact that crystallization pressure is inversely related

to pore size, extrapolating salt stress in one pore to the whole porous stone. This fact was established by defining the durability dimensional estimator (DDE) as follows:

$$DDE(\mu\text{m}^{-1}) = \sum [D_v(r_i)/r_i]P_{\text{conc}} \quad [1]$$

Where;

- $D_v$  = pore size distribution
- $r_i$  = pore size
- $P_{\text{conc}}$  = connected porosity

Porosity is directly related to the mineralogical composition of the raw material, since ceramic manufactured with a high sand fraction tend to be extremely porous and permable (Benavente et al, 2006). Products fired at a high temperature are generally more vitreous, have a higher degree of durability and undergo the greatest changes in pore size and porosity (Cultrone et al, 2004).

**Table 1:** Weight loss and porosity of limestone after crystallization text (Navarro and Doehne, 1999)

Salt	RH conditions (%)	Weight loss (%)	Porosity (%) with salt	Porosity without (%) salt
NaCl	60	0.68	8.8	19.3
	35	2.67	10.3	21.9
Na <sub>2</sub> SO <sub>4</sub>	60	7.06	20.2	20.5
	35	21.43	21.4	20.8

## 2.4 Influence of Moisture

Moisture is the main sources of deterioration of masonry building materials and if refer to the most previous research the all salt problems in masonry is influenced by the presence of moisture. The source of moisture must be in contact with the salts for sufficient time to allow them to

dissolve and then form a solution. Espinosa et al (2008) indicated that moisture plays an important role as transport medium introducing salts into the material and moving them inside the material. Problems such as rising damp, moisture penetration, efflorescence on external walls, stains, fungi or algae growth, concrete corrosion, and loss of thermal insulation are all due to water penetration. Damp or moisture occurs as result of capillary action or suction of water through of small pores in a permeable masonry material (Young, 1995).

Beside as the agent for the salt attack in fired clay brick, Gurevich (2005) explained that this factor will cause the deformation of brick and depend on the types of brick uses. Therefore, when the dimension of brick change, the structural performance of masonry wall will be affected. Furthermore, Selvarajah and Jonhston (1995) also expressed, the presence of water in masonry wall also will lead to:

- i. a decrease in its strength
- ii. the growth of fungus and degradation of aesthetic value
- iii. an increase in the operating cost associated with either air-conditioning or heating the building

## 2.5 Influence of Temperature and Relative Humidity

In practice, Young (1995) indicated that the evaporation rate of water from the wall surface would determine the height of water will rise in a wall. The rate for external surface is related to the nature of the wall surface, climate, season and sitting and for internal walls to ventilation and air-conditioning. In masonry structures, the rate of evaporation is higher than the rate

of migration of water from the internal part of the masonry (Binda and Baronio, 2006). The salts dissolve into water and then crystallize at the surface of the masonry into anhydrous or a hydrated state. However the salt crystallization is depending on the temperature and relative humidity.

The crystallization of sodium sulphate from water solution in different shape and volumes is influence by the cycles of temperature and humidity conditions (Binda and Baronio, 2006). For the temperature between  $-1.42^{\circ}\text{C}$  and  $32.4^{\circ}\text{C}$  it crystallizes decahydrate as monoclinic prisms. However if temperature more than  $32.4^{\circ}\text{C}$  it crystallizes in an anhydrous phase (stable phase). Furthermore, the anhydrous sulphate also could crystallizes into unstable phase ( $\text{Na}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$ ) if temperature below  $24.4^{\circ}\text{C}$  and then could be transformed into  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$  in humid environment.  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$  does not dehydrate (reverse process) when the relative humidity is near 100%. This compound could be dehydrate if the vapour pressure of the hydrated salt is higher than atmosphere vapour pressure whereby sodium sulphate could again absorb moisture in liquid or gaseous state and become  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ . Therefore due to the changes of crystalline phase as well as temperature and humidity conditions variations may cause fatigue phenomena in the brick or mortar which then bring it to failure.

Navarro and Doehne (1999) reported about the effect of sodium sulphate and sodium chloride on the oolitic limestone due to different relative humidity which is less than 50% and more than 50% at constant temperature  $20^{\circ}\text{C}$ . They concluded that under constant capillary rise, the highest supersaturation ratio should be occurring at low relative humidity. Beside that, sodium

chloride and sodium sulphate evaporated faster at low relative humidity than at high relative humidity. However, under similar temperature and relative humidity condition, the evaporation rate of sodium chloride faster than sodium sulphate, but steadily reduced after some days cause by the pores were filled with precipitated halite crystal. Navarro and Doehne also reported the average weight loss and porosity values for macro scale experiments at age 30 days as shows in Table 1. The result highlighted that, just a little damage took place from crystallization of sodium chloride either at low and high relative humidity. Instead, impressive damage occurs due to crystallization of sodium sulphate.

### 3. MECHANISM OF SALT ATTACK IN MASONRY WALL

#### 3.1 Salt Crystallization

Crystallization of salts in porous bodies has been investigated by many researchers. Bruemner (2002) indicated that the early test on salt crystallization has been investigated by Bonnell and Nottage in 1939. According to Bruemner, their finding showing that anhydrous salt or lower hydrate may be hydrated producing relatively high stresses. The expansions generated showed that hydration within the brick unit pores may exert enough pressure to bring about disintegration of the microstructure.

The salt crystallization pressure is the main cause for the damage or deterioration of building materials under normal climatic conditions. Microscopically, deterioration due to salt crystallization is characterized by local scaling of the surface, micro cracking in the mortar, loss of binder-

aggregate bond and cohesion of binder and in severe cases spalling (Larbi, 2004). However, macroscopic stress by means of the modulus of elasticity could determine the time dependent course of the material strain due to the crystallization pressure (Espinosa et al, 2008). In fact, the reduction in modulus of elasticity may occur because of micro cracking induced by the crystallization pressure.

Generally, in most cases the salt may be carried into masonry pores structures by moisture. According to Larbi (2004), when salt either soluble or insoluble crystallize within the pores of fired clay bricks and mortars, particularly at underneath their surface, stresses or pressure may develop that may sufficiently cause deterioration of the materials. Thaulow and Sahu (2004) postulated that crystallization is impossible in an under saturated condition and would not grow from just saturated condition. Nevertheless, crystal growing from a supersaturated condition can exert high crystallization stress. These mechanisms have been approved by Scherer (2004) which indicated a salt crystal can exert a pressure on the pore wall due to

- i. the hydration pressure caused by the increase of the salt volume induced by hydration
- ii. the linear crystal growth from supersaturated solution
- iii. the hydrostatic pressure owing to the increase of the total volume consisting of solution and salt crystals compared to the volume of the supersaturated solution before crystallization occurs.

Thaulow and Sahu (2004) suggested the pressure generated may be calculated by using a Correns's method as given in

equation [2]:

$$P_c = (RT/v_c) \ln(C/C_s) \quad [2]$$

where;

$P_c$  = pressure generated by a growing crystal in atmosphere (Pa)

$C$  = the saturation concentration in the pore

$C_s$  = the saturation concentration in bulk solution

$v_c$  = the molar volume of solid salt ( $m^3 \cdot mol^{-1}$ )

$R$  = the molar gas constant ( $8.3 J \cdot K^{-1} \cdot mol^{-1}$ )

$T$  = absolute temperature ( $^{\circ}K$ )

The term in equation [2] is clearly showing that the crystallization pressure depends on the supersaturation ratio ( $C/C_s$ ) whereby according to Espinosa et al (2008b), the crystallization could begin when the starting supersaturation ratio is larger than one. The supersaturation ratio is dependent on both salt and pores system. It is also proportional to crystallization rate where by the celerity rate of crystallization is high when the supersaturation ratio is larger.

In study of crystallization in pores, Scherer (1999) concluded that the upper bound on the crystallization stress is set by the supersaturation and normally it is lower in the larger pores size. Besides the crystals form, Scherer (2004) also agreed the salt supersaturation is a factor that influences the extent of damage besides the other factors such as the pores size and the magnitude of the repulsive force between the salt and the confining pore surface. It is not feasible to prevent the ingress of crystallization solution, so it is essential to prevent the nucleation and growth of

crystal or to provide protection that allows the porous material to accommodate crystallization without harm (Scherer, 1999). The supersaturation of salt can result from capillary rise and evaporation or from cycles of wetting and drying as well as influenced by the nature of the salt and the rates of the supply of the solution and evaporation of water (Scherer, 2004). Elert et al (2003) confirmed that brick with high compression strength, modulus of elasticity or ultrasonic wave propagation velocities tend to have a longer durability. It is clearly to show that the resistance of the brick to the salt attack or crystallization pressure strictly related to strength.

Winkler and Singer (1972) cited by Jordan (2001) explained that the crystallization pressures in salts common in masonry can be extremely high with some example as shown in Table 2. From the table, it has been shown that halite that present from crystallization of sodium chloride has an extreme crystallization pressure compared to other salt solutions.

**Table 2:** Crystallization Pressure (Winkler and Singer, 1972)

No	Salt	Crystallization Pressure (MPa) at $C/C_s = 2$ at $0^\circ\text{C}$	Crystallization Pressure (MPa) at $C/C_s = 2$ at $50^\circ\text{C}$	Crystallization Pressure (MPa) at $C/C_s = 10$ at $0^\circ\text{C}$
1.	Anhydrite ( $\text{CaSO}_4$ )	33.5	39.8	112.0
2.	Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )	28.2	33.4	93.8
3.	Halite ( $\text{NaCl}$ )-common salt	55.4	65.4	184.5
4.	Hexahydrate ( $\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$ )	11.8	14.1	39.5
5.	Thernardite – $\text{Na}_2\text{SO}_4$	29.2	34.5	97.0

The crystallization pattern of sodium sulphate was strongly affected by relative humidity. It is confirmed by Navarro and Doehne (1999) which studied the crystallization pattern on oolitic limestone. They indicated that the formation of mirabilite will occur when the solutions crystallize at relative humidity more than 50% and thenardite at relative humidity lower than 50%. Beside that, thenardite may generate greater crystallization pressure and damage than mirabilite.

### 3.2 Sulphate Attack

Larbi (2004) highlighted the sulfate attack to brick and hardened mortar joints occur when sulfates in solution react with the tricalcium aluminate in Portland cement to form an ettringite or tricalcium sulfoaluminate hydrate. Veniele et al (2003) also considered the sulphate attack on cement based construction material is one of the most frequent and damaging phenomena that can be observed through expansion, cracking, decomposition etc. of the resulting product of cement. Normally the resulting expansion causes both local disruption of mortar beds and stresses in the brickwork. However this damaging only occurs in wet or saturated condition and where there is a source of water soluble sulphate content usually sodium and potassium sulphate which present in adjoining bricks.

The sulphate ions are transport to the mortar joints from the bricks by percolating water. The mechanism of sodium sulphate attack in mortar has proposed by Santhanam et al (2003) as shown in schematic diagram in Figure 3. The proposed mechanism suggests the formation of distinct zones



However, mostly the main source is related to the sea spray.

In Italy, sodium chloride often present on the masonry (Binda and Baronio, 2006). Benavente et. al. (2003) revealed that sodium chloride can lead to durability problems when used as a de-icing salt in cold climates. Lubelli et. al (2004) classified the effect of sodium chloride on masonry damage in two cases which are direct and indirect. Direct case is due to crystallization or hygroscopicity or thermal expansion mechanisms. Mechanism of thermal expansion can be very important in materials contaminated with sodium chloride. The difference between the thermal expansion of pure sodium chloride and brick or rocks can cause internal stress in the material (Benavente et. al. 2004). Larsen and Nielsen (1990) has been test the influence of sodium chloride on thermal expansion and hygroscopic shrinkage of both modern and medieval bricks. They indicated that the thermal expansion in case of sodium chloride contaminated bricks is proportional to the salt content. A 2% by weight of sodium chloride in a brick increase the thermal expansion by 16%. Furthermore, for the hygroscopic shrinkage due to the presence of sodium chloride, Larsen and Nielsen have measured that the shrinkage of the contaminated bricks with sodium chloride is 70 times higher than the non contaminated bricks.

Indirect case related to the catalyst role that halite plays in some chemical reactions (Lubelli et. al, 2004). Halite is a stable phase which presence under room conditions in sodium chloride – water system. It is normally carried by sea spray and penetrates in solution in the masonry which mainly in the most porous bricks. When the masonry dries out, the salt

crystallizes generating pressures that lead to the powdering of the material. The low mechanical strength of the brick contributes to enhance the damage.

The presences of chloride will delay the attack by sulphate ions. Bucea et. al. (2005) indicated that chlorides permeating into the concrete react with tricalcium aluminate (C3A) to form chloroaluminate hydrates and the quantity of C3A available to form expansive ettringite is reduced. As a result shown in Table 3, Al Amoudi et al (1995) in their study about role of chloride ions on expansion and strength reduction of concrete confirmed that the presence of chloride ions in sulphate environment reduced the sulphate attack in both plain and blended cements. However Al Amoudi (2002) in addition, the advantageous of chloride ions is not effective if magnesium attack presence in the process as well. The possible reason for this case is due to the similarity of solubility for both solutions for example the solubility of sodium chloride and magnesium sulphate about 36 g/100ml (Jordan, 2001).

**Table 3:** Summary of strength and reduction and expansion test results (Al –Amoudi et. al. 1995)

Mix	Strength reduction (%)		Expansion (%)	
	Sulphate solution	Combination of Sulphate Chloride solution	Sulphate solution	Combination of Sulphate Chloride solution
1	42	16	0.106	0.045
2	48	17	0.093	0.046
3	47	9	0.099	0.039
4	53	41	0.094	0.036
5	48	14	0.114	0.040
6	54	26	0.096	0.046
7	55	16	0.088	0.025
8	49	40	0.093	0.033
9	55	45	0.113	0.059

## 4. CONCLUSION

In selection of fired clay brick as a building material, the durability properties are very important and should be evaluated to ensure the integrity and service life of building materials. It is no doubt that soluble salt which is transported by the moisture from natural condition or environment could cause a deterioration or decay on the performance of masonry walls. The common soluble salts found in brickwork are sodium sulphate and sodium chloride which carried from different source by moisture. The decay is caused by the crystallization of salt in the pores structures of brick units which may generate the pressure that sufficient to rupture the material microstructure. These effects are controlled by the chemical nature of the crystallizing salts. The all main factors affecting the salt attack must be present in order the decay to occur and if any one factor is removed or incomplete the decay can be prevented. The awareness and consideration on the existing salts in clay bricks and mortar especially sulphate also should not be neglected because when it reacts with water during brick/mortar laying, it can form the crystallization pressure as well which may be enough to damage the masonry wall. The presence of salt attack will effect the expansion of mortar chemically which latter could result the expansion of masonry wall.

The effect of chloride on masonry damage is directly due to crystallization or hygroscopicity or thermal expansion mechanism and indirectly which related to the role of halite in chemical reaction. The sulphate attack will cause the formation of ettringite on cement based material when react with tricalcium aluminate. This salt is very damaging and provides more extreme

condition than chloride, but it is become ineffective due to the presence of chloride in the same process. Chloride could delay the sulphate attack and strictly reducing any decay or deterioration due to sulphate. However the effectiveness of chloride is insufficient when react with magnesium in the same process due to the similarity of solubility.

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