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Research article

PREDICTIVE MODEL TO DETERMINE THE RATE OF SULPHATE EFFECT ON PORTLAND CEMENT BASE MATERIAL

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Abstract

The prediction of sulfate attack on cement base material has been of serious concern to experts in construction industries; the rate of sulfate attack on cement base material has been observed from experts in different dimensions, sulfate attack depends on the type of construction application and environmental conditions, this reduce the compressive strength and the life span of structures. The established models were developed on the influential parameters that are found to cause sulfate attack on cement base materials in the system. More so it has been found in another development that Concrete sewer lines are found to be susceptible to acid attack, sewage itself is usually neutral and with slightly acidic. The declines of concrete in sewer lines were observed above through water line, rather than below where the sewage is in direct contact with the concrete. Problems of acid attack above the water level in sewers arise indirectly from the bacterial decomposition of sewage, which produces hydrogen sulfide gas. Engineers are often faced with questions concerning whether concrete will be resistant to acidic solutions of varying concentrations. As acid solutions are commonly described in terms of pH, most engineers are interested in rules of thumb regarding the resistance of concrete to acids at various pH levels The fact that plain concrete (nonreinforced) of good quality can have good resistance to seawater is amply demonstrated by the many examples of structures showing good service life after many years exposure to seawater, the conceptualize development of this model are based on the these establish variables to ensure that model developed will monitor the rate of sulfate attack on cement base materials.

Keywords: predictive model, sulphate effect, Portland and cement base material

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1. Introduction

Deterioration due to sulfate attack is generally attributed to chemical decomposition of certain portland-cement hydration products after hardening, and formation through solution and precipitation of less soluble reaction product [Tuthill,1936, McMillan et al 1949, Bogue,, 1955, Hanson, 1966, Hanson 1968,lea 1971, Kalousek 1976]. This may produce expansive forces and a subsequent physical disruption of the concrete. Sulfate solutions may also react with the cement paste to form products that have little cementing value, and thereby turn the concrete into mush with little apparent change in volume [Tuthill, 1936, Mehta, 1983]. The main reaction products involved in sulfate attack are calcium sulfoaluminates. Calcium sulfoaluminates form during the normal hydration of Portland cement, and also form as reaction products of sulfate ion with calcium hydroxide and calcium aluminate hydrate. Calcium sulfoaluminates hydrate occurs in two forms, depending largely upon the supply of sulfate and alumina: a low sulfate form called calcium monosulfoaluminate or monosulfate (3CaOAl, 03Ca504 12H20), and a high sulfate form called calcium trisulfoaluminate or ettringite (3CaOAl2O33CaSO432H2O). The monosulfate form may be converted to ettringite when exposed to sulfate solutions, and the associated volume increase is potentially destructive. Formation of ettringite, often from monosulfate, is the reaction that is considered the main destructive force in sulfate attack. However, there is some controversy over the formation of ettringite and the deterioration of the concrete [Skalny, 2002, Hanson, 1966, Chatterji, 1989, and Cabrera, 1988]. The presence of ettringite alone is insufficient evidence of a destructive sulfate attack, as ettringite is also a secondary reaction product from the hydration of Portland cement. Magnesium compounds are potentially more destructive to concrete as the magnesium ion is capable of completely replacing the calcium in hydrated Portland cement. Magnesium sulfate is highly soluble (70 000 ppm) and can form more highly concentrated sulfate solutions than sodium sulfate. Strong solutions of magnesium sulfate are capable of reacting with the calcium silicate hydrate phases as well as calcium hydroxide and calcium aluminate hydrate phases. The concentration of magnesium sulfate may affect the course of the reaction [Biczok, 1967]: • At low concentrations (less than 3200 mg S04/L—or less than 4000 mg MgSO4/L), the attack is characterized by ettringite formation. However, in the continued presence of MgSO4, ettringite is eventually decomposed to gypsum, magnesium hydroxide, and hydrated alumina [Lea, 1971].

There are some other unconfirmed theories: a) that there is more than one type of ettringite, and not all types are expansive [Mehta, 1983 Kalousek, and Benton, 1970, Cohen, M. D. and Mather 1991]; b) that the mode of formation may also have an effect, that is, ettringite formed by solid-state reactions is more expansive than that formed by through-solution reactions [Hanson,1968, Mathe,1966]. However, according to Brown and Taylor, ettringite forms typically by through-solution rather than by top chemical mechanism [Brown, 1999]. Mechanisms for the expansion of ettringite have been reviewed by Cohen [Cohen, 1983], Ping and Beaudoin [Ping, 1992], and others [Skalny, 2002]. Thaumasite (CaCO3 CaSO4 CaSiO3l 5H20) is structurally similar to ettringite and was observed by numerous authors in concrete attacked by sulfate solutions [Erlin, and Stark,1965, Lukas 1975, van Aardt, and Visser 1975, Gouda et al 1975, Regourd 1980, Crammond 1985, Berra, and Baronio, 1987 Collepard, 1990, Bensted, 1999, Crammond, 1999, Building Research Establishment,2002]. Thaumasite may form as a conversion product from ettringite by carbonate and silicon substitutions, or may form directly under favorable conditions when there is a supply of alumina, calcium silicates or free silica gel, sulfate, and carbonate [van Aardt, 1975, Crammond, 1985]. It would appear that the presence of C3A is not necessarily a prerequisite for thaumasite formation, and therefore such precautions as Type V cement would not necessarily provide protection against the formation of thaumasite. Thaumasite forms preferentially at low temperatures due to the higher solubility of calcium salts at low temperatures, and appears to form rather quickly at temperatures around 5 C [van Aardt,1975 Crammond,1985]. The carbonate ions can be derived from sources within the concrete such as limestone used as an aggregate or a cement addition or can be supplied as carbonate or bicarbonate ions dissolved in the soil or groundwater.

The American Concrete Institute (ACI) divides sulfate attack into two general categories: (1) a sulfate reaction with calcium hydroxide to form gypsum (sometimes called gypsum attack, gypsum corrosion, and acid type of sulfate attack), and (2) a sulfate reaction with calcium aluminate hydrate to form ettringite (sometimes called sulfoaluminates attack or corrosion) [American Concrete Institute, 2001]. In more severe forms of the reaction, other constituents of concrete are susceptible to sulfate attack, such as calcium silicate hydrate, and even some types of aggregate particles such weathered feldspars. The reactions are more complex, however, as both anions and cations are involved. The type of chemical reaction that will be prevalent is related, among other effects, to the cations associated with the sulfates in solution, which most commonly are Ca^{++}, Na, and Mg^{++}. The cations affect the solubility of sulfate minerals ad the concentration of the sulfates in solution, and also the course of the reaction. With extremely high concentrations of sulfate, the reaction may intensify into acid attack that forms a different reaction product [Biczok, 1967, Cohen.1991]. These reactions will be discussed in the following paragraphs. The course of the reaction.

2. Theoretical back ground

Surface attack is on the major deformations of cement base material; these are observed in constructions of several types of infrastructures for environmental development of human. Sulfate attack, sometimes are also called "sulfate corrosion," is a precisely severe type of worsening resulting from chemical reactions occurring when concrete mechanism react with sulfate ions (5Q42) currently in solutions get in touch with concrete or, under convinced situation, within the concrete mixture itself. Sulfate reported attack has been in Nigeria and many parts of the world, for example western United States, the northern Great Plains area of the United States and Canada, Spain, Great Britain, the Middle East, and in industrial situations where concrete has been exposed to solutions containing sulfates. The attack is predominantly common in arid regions where obviously occurring through natural sulfate minerals that are present in the water and ground in contact with the structures. The necessary conditions for sulfate attack are known and preventive measures can be taken to eliminate or minimize the risk of sulfate attack. A comprehensive description of the different forms of sulfate attack and methods of prevention was recently published by Skalny et al.2002. without taking sufficient safety measures, concrete structures such as floors, foundations, drainage pipe, and lower parts of canal structures may completely break up in only a very few years when exposed to water containing dissolved sulfates. The harshness of the attack can be pretentious by the presence of other dissolved substances in the water, but generally increases as the attentiveness of sulfates in the water increases, and becomes even more severe if the concrete is subjected to frequently alternating periods of wetting and drying. On the other hand, concrete exposed to dry sulfate-bearing soils will not be attacked. The source for the sulfates involved in the chemical reaction may be either external or internal to the concrete [Skalny et al, 2002 Al-Rawi, 1985, Ouyang,et al 1988, Grabowski,et al 1992, Sulfate Attack Mechanisms ,1999, American Concrete Institute, Detroit 1998, Thomas,2002, Scrivener,2004]. In the case of external attack, the sulfates may originate from groundwater or from sulfates leached from adjacent soil as the reaction progresses from the surface into the interior of the concrete. In the case of internal attack, the sulfates may come from minerals in the aggregates, sulfates dissolved in the mix water, admixtures and additives, and possibly from sulfates in the portland cement, It is therefore necessary to have a chemical analysis of the ingredients of the concrete and of the groundwater and soil surrounding the structure in order to assess the probability of sulfate attack.

3. Governing Equation

$$\frac{\partial C_m}{\partial T} = D\frac{\partial^2 C_m}{\partial x^2} - KVC_A \qquad \text{………………………………..} \qquad (1)$$

The governing equation to monitor the rate of surface attack on cement through concrete are expressed bellow, the expressed governing equation are formulated through the influential parameters in the system, the condition of structural components are base on the binding agent called cement paste, the expressed mathematical equation are thoroughly developed base on the characteristic formations of the sulfate attack commonly found under environmental influence known to be one of the factor in the system. The gypsum normally added to Portland cement to control setting characteristics is not sufficient to cause sulfate attack. Portland cement normally contains gypsum, which is added in amounts of about 2.5—4 0 as SO3 to control setting characteristics. This gypsum is consumed during the normal course of the cement hydration process. The main constituents of hardened portland-cement paste susceptible to sulfate attack are the hydration products of the tricalcium aluminate (3CaO-A1203 or C3A) phase. Other cement hydration products can also be attacked in more severe sulfate environments [Joseph and James, 2006].

Let $(x,t) = X_{(x)}\,T_{(t)}$ be the solution

$$XT^1 = DX^{11}T - KVC_A \qquad \text{………………………………..} \qquad (2)$$

Dividing (1) by XT

$$\frac{T^1}{T} = D\frac{X^{11}}{X}T - KVC_A \qquad \text{………………………………..} \qquad (3)$$

$$\frac{T^{1}}{T} \quad - D\frac{X^{11}}{X} \; - \; KVC_{A} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

From (4) we have

$$\frac{T^{1}}{T} \quad = \lambda^{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (5)$$

$$T \; + \; \lambda^{2}\, T \; = \; 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

Also from (2)

$$D\frac{X^{11}}{X} \; - \; KVC_{A} \; = -\lambda^{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (7)$$

$$D\frac{X^{11}}{X} \; - \; KVC_{A} \; = -\lambda^{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (8)$$

$$X^{11} \; - \; \frac{1}{KVC_{A}} X \; = \; 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (9)$$

$$X^{11} \; - \; X^{11} \; - \beta X \; = \; 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (10)$$

Where $\beta \; = \; \frac{1}{KVC_{A}} + \lambda^{2}$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (11)

The expression from [2-11] show the derived solutions on the parameters that are applied to formulate the system, the foundation were the state derived solution are to streamline the relationship that simultaneously practice the react of attack on the cement base materials through the binding agent known as cement paste. For example Sodium sulfate are found prominently to be more destructive than gypsum as it is more soluble (40 000 mg/L water) compared to that of calcium sulfate, and because it penetrates into two types of reactions with the hydrated cement phases in the hardened cement paste. Moreso it is noticeable that Sodium sulfate reacts with calcium hydroxide as well as the calcium aluminate hydrate phases. At lesser concentrations as confirmed experimental by experts, (SO4 content less than 1000 mg/L), sulfate reacts with the hydrated calcium aluminate phases to produce ettringite and subsequent deterioration; at higher concentrations, sodium sulfate reacts with calcium hydroxide to produce gypsum [Biczok,1967,]. Gypsum formation results in a volume increase, but there is some controversy as to whether the formation of gypsum produces a harmful expansion in concrete. The evidence for gypsum producing expansion and deterioration of the concrete does not appear as straightforward as does the case for ettringite formation [Cohen, 1991, Joseph and James 2006].

Suppose $X \; = \; \ell^{mx}$ in (9)

$X^{11} = M\ell^{mx},\ X^{11} = M^{2}\ell^{mx}$ .... (12)

$M^{2}\ell^{mx} - M\ell^{mx} - \beta\ell^{mx} = 0$ .... (13)

$\left(M^{2} + M - \beta\right)\ell^{mx} = 0$ .... (14)

But $\ell^{mx} \neq 0$

Hence

$M^{2} - M - \beta = 0$ .... (15)

$M_{1,2} = \dfrac{-1 \pm \sqrt{1 + 4\beta X}}{2X}$ .... (16)

$M_{1} = \dfrac{-1 + \sqrt{1 + 4\beta X}}{2X}$ .... (17)

$M_{2} = \dfrac{-1 - \sqrt{1 + 4\beta X}}{2X}$ .... (18)

Therefore,

$X_{(x)} = C_{1}\,\ell^{M_{1}x} + C_{2}\,\ell^{M_{2}x}$ .... (19)

$= C_{1}\,Cos\,M_{1}x + C_{2}\,Sin\,M_{2}x$ .... (20)

Solving equation (6) gives

$\boxed{T_{(t)} = T_{o}\,\ell^{\frac{-\lambda^{2}}{T}}}$ .... (21)

The developed model in [20] shows the predominant rate of setting time on cement base material at different temperature in the system, since the paste is the binding agent to all the characteristics of concrete material and mortal in constructions of structure either reinforced or not, the rate setting time at different temperature in cement base material can be monitored in the derived solution model at twenty. It is of interest to understand that gypsum usually additional to Portland cement to control setting characteristics is not sufficient to cause sulfate attack. Portland cement normally contains gypsum, which is added in amounts of about 2.5—4 0 as SO3 to control setting characteristics. This gypsum is consumed during the normal course of the cement hydration process. The main constituents of hardened portland-cement paste susceptible to sulfate attack are the hydration products of the tricalcium aluminate (3CaO-A1203 or C3A) phase. Other cement hydration products can also be attacked in more severe sulfate environments, the expressions in gypsum if added to cement to increase the setting are involved then the developed derived model conditions will be useful to the system in this direction.

Hence the solution of (20) yield

$$\boxed{C(x,t) = \left(C_1 \, Cos \, M_1 x + C_2 \, Sin \, M_2 x\right) \ell^{\frac{-\lambda^2}{T}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

The final developed model from the derived expressions in [22] will applied to monitor the rate of sulfate attack on cement base materials, the derived solution were expressed through the application of variable separation denoted with mathematical symbols, the parameters were expressed base on the rate of influences in the system through the derived expressions, the rate sulfate attack on cement base material are attributed to several conditions, The major factors governing the sulfate reactions are (1) the level of permeability on concrete to water, which is a control on the rate at which the reactants are brought together; (2) the composition of the hydrated phases of the cement paste, as not all cement hydration products are equally susceptible to reaction with sulfates; (3) the chemical composition and concentration of the sulfate-laden water, which affects the course and the severity of the reaction; and (4) the exposure conditions (i.e., concrete exposed to cyclic wetting and drying, or concrete exposed to moisture gradient will be more vulnerable than concrete continually immersed in sulfate-contaminated groundwater; temperature is also important). There are several different sulfate reaction mechanisms depending on the composition of the sulfate water and the environmental condition The course of the reaction and the mechanism for deterioration may vary according to the situation. As the reaction proceeds inward into the concrete, the composition of the pore water may change and influence the course of the reaction.

4. Conclusion

Predictive model to determine the rate of sulphate effect on Portland cement base material has been thoroughly expressed the model were develop to monitor the rate sulfate attack on cement base material, several attack has been n observed by expert in the several experiment in the aspect of sulfate attack deteriorating cement base material. Although sulfate attack has been extensively investigated and mechanistic aspects of the problem are known, it is still not completely understood. The situation is not as straightforward as might be expected since several different chemical reactions rather than a single reaction may be involved simultaneously. Some controversy still remains over the mechanism responsible for producing expansion and deterioration of the concrete. Most of the knowledge on sulfate attack has been developed from laboratory studies involving relatively simple chemical systems of pure materials, yet in actual practice the situation is more complicated as the exposures may involve varying and changing combinations of impure materials in different proportions. In such cases, the water may contain other aggressive anions and cations that attack hydrated cement constituents by chemical reactions other than those associated strictly with the sulfate anion. At times these reactions may impede the attack, and at other times may aggravate the attack.

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