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Simple criteria for evaluating sulphate attack in concrete

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Abstract. This paper attempts to analyse results from the standard test methods employed for sulphate attack and evaluates their correlations, consistency and contrasts, as well as physical observations. Data from expansions and mass change of 25 x25 x 285 mm mortar prisms and 75 x 75 x 285 mm concrete prisms were used. Mortar mixtures consisted of 1: 2.25: 0.5 cement to sand to water while concrete mixtures were of water-cementitious ratio (w/cm) of 0.45, 0.50, 0.65. Mixtures were made using CEM I 42.5N with or without 30, 50, 70% ground granulated blast furnace slag (GGBS) and stored in sodium sulphate solutions of 28 g/L and 50 g/L as SO_4. Results show that ASTM C 1012 mortar expansion criteria of 0.10% corresponds to 1.2% mass gain. Similarly, concrete prism expansion criteria of 0.05% is equivalent to 0.75% mass gain. It is proposed that in the absence of expansion monitoring, the use of mass gain criteria of 1.2% mass in mortar prisms or 0.75% in concrete prisms may be sufficient for evaluating sulphate attack.

Keywords. Sulphate attack, mass gain, expansion, mortar/concrete prisms

Introduction

The existing accumulated wealth of knowledge concerning sulphate attack has led to well-established current understanding of the mechanism of attack. Through this scientific understanding, some standard methods have been developed such as ASTM C1012 currently used in evaluating external sulphate attack. However, there remain major shortfalls concerning current techniques that fuel researchers to continue efforts towards better and improved methods as evident from the wide range of attempts published [1-3]. But it is evident that much attention has been given to simulation of chemical resistance of the cementitious system and using this measure as the overriding criteria for evaluating the sulphate resistance of the system. But there is growing recognition that chemical resistance evaluation may be relevant but not sufficient in certain cases to fully assess the effect of sulphate attack. Magnesium sulphate ions attack process, for example, is characterised by more severe physical deterioration rather than expansion. Therefore techniques for evaluation of cementitious systems for resistance to physical deterioration are of interest.

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In [4], it was reported that permeability of concretes influenced expansion behaviour but the parameter on its own was insufficient to account for full effects. Use of other transport properties in the sulphate attack evaluation, including water absorption and diffusion, have been given consideration by researchers [5].

1. Background

Most developing countries would seek to use reliable but simple techniques, in view of the requirements of monitoring equipment. There are few experiments where sulphate research has been conducted extensively on the basis of properties other than length change [6,7]. The equipment needed to monitor weight or physical examination of the specimens are all but basic and simple, while length change monitoring apparatus are often costly and found mostly in well equipped, specialised cement and concrete laboratories. However, while mass change and physical damage are generally monitored in sulphate attack studies, it is rare to find studies where these properties have been given focussed attention as a criteria in evaluation of sulphate attack. The work presented here was conducted with the intention of primarily examining these simple properties with potential to utilize them as key indicators of potential sulphate attack.

A key consideration of interest in using weight change and physical deterioration characteristics is the potential to evaluate effects of different sulphate salts by using the same methodology. In the present test methods, it is not possible to evaluate both sodium and magnesium sulphate attack using the same standard method. Yet in field situations, mixed salt types are possible as can be found in soils and water, which may result in combined sulphate attack on concrete [8]. A hypothetical but meaningful situation is explained by Neville [8] in which a house or structure can be within the proximity of a garden or farm where fertilizers are used. Fertilizers and greening agents may contain potassium, magnesium and ammonium sulphates that can attack foundations and walls of the structure. Each of these salt types may have different attack mechanisms but the common feature to their manifestation is physical damage, although this may take different forms which some researchers have categorised as acid type, expansive type, and onion peeling type [2]. It has been suggested that where mixed sulphates salt types may exist, the magnesium sulphate attack is the controlling attack mechanism, which primarily results through severe physical softening deterioration as opposed to expansion-induced damage [9].

The research question addressed in this paper is whether standard tests can be based on physical degradation analyses or combined forms of simple physical and chemical indicators of deterioration. In 1969, Neville [8] remarked that his work on sulphate attack consisting of monitoring length change, weight change and resonance frequency led to the conclusion that they do not all reflect the same pattern of behaviour. In the present investigation, this question is highlighted in view of scientific understanding that has come a long way.

2. Experimental

The data used in this paper is based on experimental work presented in separate investigations involving evaluation of sulphate resistance using:- (a) the conventional ASTM C 1012 accelerated mortar expansion test method, (b) Concrete prism expansion test [4]. In the mortar study, expansion and mass change were monitored in the experiment. Similarly in the concrete study, expansion and mass change of prisms were measured. Concrete prisms 75 x 75 x 285 mm were also used to monitor physical damage and related changes in the samples. Further details regarding the mixtures, materials and methods employed in the investigations are found in other papers [10,11].

Table 1. Chemical compositions of the cementitious materials [10]

	CEM1 42.5N	GGBS	50/50 CEM/GGBS
SiO_2	21.7	38.3	30.1
Al_2O_3	5.3	13.4	9.4
Fe_2O_3	2.0	0.8	1.4
CaO	62.5	35.3	48.4
MgO	4.6	7.5	6.1
K_2O	0.6	1.0	0.8
TiO3	0.3	0.9	0.6
Mn2O3	0.9	1.1	1.0
Na_2O	0.1	0.3	0.2
SO_3	2.0	12.4	2.3
Cl-	0.02	0.02	0.02
LOI	2.9	0.7	1.1
C_3A	10.7		
C_3S	45.3		
C_2S	28.3		
C_4AF	6.1		
Blaine fineness (m^2/kg)	337.5	384.1	364.1
45 μm sieve residue (%)	14.9	14.8	14.7

3. Results

3.1. Assessment of chemical resistance

3.1.1. Monitoring expansion

Tests for length change using prisms are generally regarded to be evaluation of the chemical resistance of the cementitious system. In the data presented, expansion was determined using both mortars and concretes.

The durations and trends in development of expansion monitored by the standard mortar prism method and by the concrete prisms are given Figure 1. In the legend of the graph, 'M' stands for mortars of 0.5 w/cm made in accordance with ASTM C 1012, while 'C' represents concrete. Hence M-CEM I are mortars made using plain CEM I Portland cement and C-0.5w/c-CEM I are 0.5 w/c concretes made using CEM I only.

It is seen in Figure 1 that both the mortars and the prisms took several weeks to develop significant expansion. The typical sulphate resistance criteria for 0.5 w/c mortar expansion is 0.10% after one year of storage in 0.5% sodium sulphate. According to the results presented, it can be seen that CEM I would be such cement that could be regarded susceptible to sulphate attack. However, based on 0.5 w/c concretes, the development of expansion is expectedly far more subdued in the concrete prisms than mortar prisms of 0.5 w/c. Once expansion initiates, it progresses more rapidly in the small mortar prisms than in the concretes. At 69 weeks, the 0.50 w/c concrete prisms gave 0.05% expansion compared to 0.65% for the corresponding mortar prisms. However, by increasing the w/cm ratio of the mix to 0.65, expansion of about 0.10% was attained in four to six months, potentially reducing the duration to failure significantly. Other conditions that have the potential to accelerate the attack are elevated temperature, maintaining constant pH of the sulphate solution, wet-drying cycles, although it ought to be recognized that some of these factors my alter the nature of the attack [12,13]. Nonetheless, incorporation of these factors into the test methods could result in significantly improved rapid evaluations.

3.2. Mass change

While expansion in sulphate attack is primarily attributed to volume increase from the ettringite product formation within the pore structure of the cementitious system, the product also leads to increase in mass, although the initial weight gain within the first week would be attributed to water uptake by the unsaturated concrete. Thereafter, the increase in weight would mainly be expected from the reaction products, consisting of ettringite and gypsum in the case of sodium sulphate attack. The monitoring of mass change is usually done or recommended as part and parcel of the test requirement during expansion monitoring using prisms. However, lesser importance is generally attached to weight change relative to length change parameters. Basically, the standard methods of this category including ASTM C 452, C 1038, C 1012, use length change as the failure criteria and typically give no similar or parallel failure criteria on the basis of weight change. Few standards such as the Chinese standards GB 2420, GB 749 specify flexural strength criteria. Perhaps one of the reasons for attachment of comparatively less value to weight change may be related to its distant association with physical deterioration. Typically, it is the expansion-induced stresses that lead to cracking and ultimately, cause structural disintegration of concrete.

Weight change on the other is only indicative of the internal expansive reactions and in addition, it may be difficult to account for initial weight change from initial water uptake by the samples. Despite the relatively lower place usually assigned to weight change, it is evident that this parameter is consistent and could as well be a fairly reliable indicator of expansive cementitious systems. In situations, such as found in most developing countries, where laboratory facilities are limited or lacking, the simplicity of using weight change as an evaluation parameter can be an attractive option.

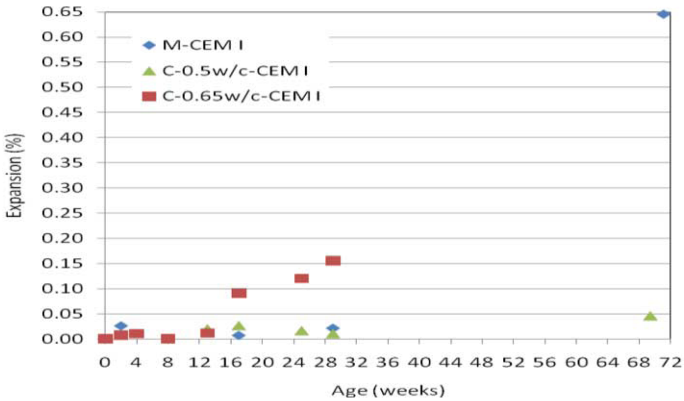

Figure 1. Expansion development in mortar and concrete prisms stored in Na_2SO_4 solution

Figure 2 is a plot of results relating the length change and weight gain for mortar prisms that expanded as well those that did not show expansion. It can be seen that those specimens that showed expansion, had greater weight gain such that 0.10% mortar expansion corresponds to about 1.2% of their mass gain. Hence all specimens that exceeded 1.2% weight gain showed expansion but there was one exception 50%-28g/L-i that exhibited up to 3% mass gain but showed no expansion. Figure 3 gives similar results for concrete prisms. Here all the concrete prisms that did not expand, never exhibited more than 1.0% mass gain. It can be seen that 0.10% concrete expansion corresponds to 1.0% of their mass gain and 0.05% expansion relates directly to 0.75% mass gain. These criteria were satisfied by all the concrete specimens without exceptions.

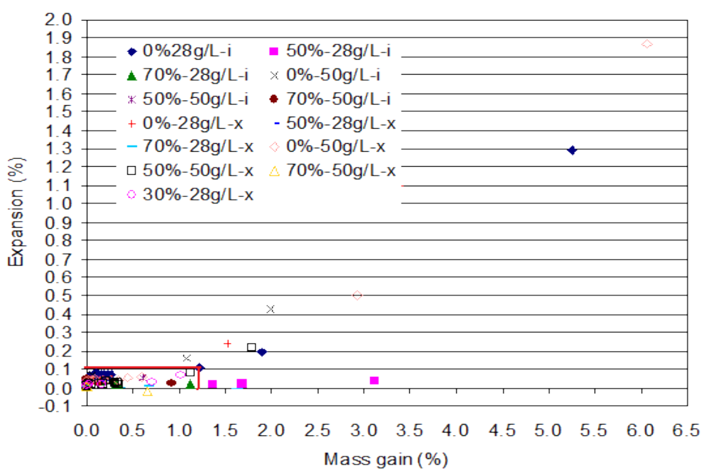

Figure 2. Relationship between expansion and mass gain of 25x25x285mm mortar prisms stored in Na_2SO_4 solution for up to 69 weeks

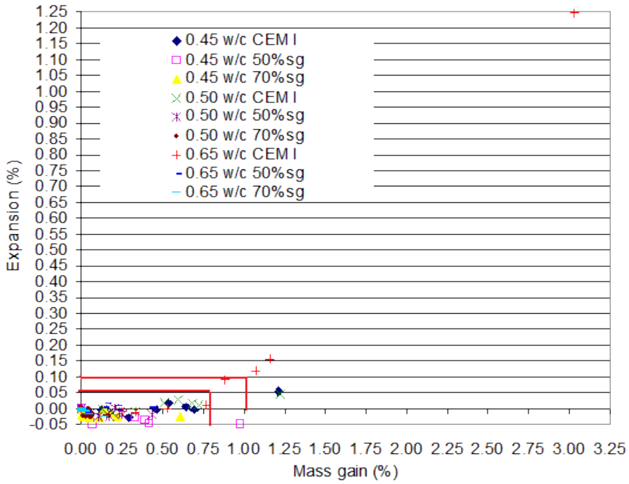

Figure 3. Relationship between expansion and mass gain of 75x75x285 mm concrete prisms stored in Na_2SO_4 solution for up to 69 weeks

4. Conclusions

The results generated through standard test methods for sulphate resistance have been compared in the foregone analyses. The following findings have been reached, keeping consideration of the limitations of this study which was conducted with only one type of slag and one type of cement. The results are, however, generated based on wide ranging parameters of varied w/c ratios, curing periods, sulphate types and concentrations.

Both the standard mortar ASTM C 1012 test method and concrete prisms required extended durations of at least 6 months to develop significant expansion adequately notable for use as criteria. However, use of increased water-cement ratio such as 0.65w/c has the potential to give accelerated results within 3 months. Further research is needed to consider other test conditions such as pH, temperature, wet-dry cycles, that may lead to greater acceleration of results.

When using mortar and concrete prisms stored in Na_2SO_4 solution, it was found that 0.10% mortar prism expansion corresponds to 1.2% mass gain and 0.05% concrete prism expansion relates directly to 0.75% mass gain. In the absence of expansion monitoring, the use of this mass gain criteria appears to be an adequate evaluation parameter. Further work in this regard is being undertaken by the authors.

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