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An Experimental Investigation Of A Micromechanical Method To Simulate The Degrading Effects Of The Alkali-Silica Reaction On Concrete

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ABSTRACT

The multiscale nature of this long-term phenomenon makes the assessment of concrete structures impacted by alkali-silica reaction (ASR) a challenging problem. The formation of an expansive alkali-silica gel at reaction product level signals the beginning of the reaction within the components of the concrete. Given that the expansive gel is constrained within the concrete micro-structure, an internal pressure builds up and causes damage to the aggregate.The experimental analysis, which combines laboratory testing with literature data, reveals a statistically significant correlation between concrete expansion and the deterioration of the mechanical properties of concrete specimens damaged by ASR maintained under free-expansion circumstances. The strongest indicator of ASR signals in concrete, as opposed to compressive strength, is the elastic modulus, which exhibits the quickest rate of degradation and lowest residual value.A significant difference is seen when comparing the behaviour of unaffected and damaged concretes in terms of strength-stiffness correlations. The suggested multiscale material modelling technique yields a method for material characterization that can be expanded to the structural level as well as the reaction products.

Keywords: Alkali-Silica Reaction, Mechanical Properties, Concrete, Deteriorating,Characterization

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1. INTRODUCTION

A hazardous long-term degrading process that occurs at various scales is the alkali-silica reaction (ASR), which belongs to the category of alkali-aggregate reactions. Alkali ions, which are typically found in pores mixed with water, and silica ions, which are present in the aggregates, are both used in the chemical reaction [1].In general, the alkali-silica reaction in concrete is seen as a combination of two distinct stages: in the first stage, the chemical reaction creates the reaction products inside the boundaries of the aggregates, and in the second stage, the physical water absorption by the reaction products causes local swelling [2].The quantity of expansion developed is highly related to the concrete mix design. A minimum amount of water, alkali, and silica ions to be present to start the reaction, but there is a maximum proportion that causes the greatest expansion, which is determined by the characteristics of the reactive aggregates and the mobility of the pore fluids in the concrete [3]. The latter is controlled by the material's porosity and, consequently, by the water to cement ratio (W/C).The maximum value and rate of concrete expansion are influenced by aggregate size. The results of experimental studies on quartz-containing aggregates [4] show that for grains with sizes between 0.15 and 10 mm, the smaller the aggregate size, the more concrete will expand. Similar findings were made by [5], who reported that adding fine reactive aggregate to concrete microbar mixtures caused expansion to increase.The variance in concrete's tensile strength has a greater impact on the shear capacity of reinforced beams. [6] Examined the behaviour of bridge beams made from flat slabs without shear reinforcement. Only 75% of the predicted capacity for the undamaged concrete was present in the beams. The beams didn't fail in flexural shear as expected, but they did in diagonal shear. They propose measuring the shear resistance of affected beams based on the tensile strength along the casting direction in order to take these modifications into account.ASR-affected concrete specimens held under circumstances of free expansion were the subject of limited analyses of the development of engineering properties. The most sensitive parameter is found to be the elastic modulus, followed by the tensile strength. On the other hand, conflicting data regarding compressive strength are reported.

This study's objective is to investigate the relationship between concrete's mechanical deterioration and the alkali-silica reaction's detrimental effects.

2. Materials and Test Methods

The ASR's degrading effects on concrete and concrete structures were discussed in light of the key experimental findings. The development of engineering characteristics, such as elastic modulus and compressive and tensile strengths, in concrete specimens damaged by ASR that were held under free-expansion conditions is the main emphasis of this study. There is a

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connection between concrete expansion and material deterioration. Because mechanical property evolution is typically stated as a function of time, inconsistent findings are seen [7].

In the beginning, fresh experimental findings on two comparable concrete compositions with Norwegian and Dutch aggregates are given. The latter is the reference material that was retrieved from the severely damaged Nautesundbridge in Oslo, Norway, and used as part of a larger experimental programme to investigate the effects of ASR at the aggregate and concrete levels [8].While the compressive strength is less affected by the process, the elastic modulus and splitting tensile strength are two of the most negatively affected properties. For unaffected concrete subjected to mechanical loading, the established engineering strength-stiffness relations are inapplicable.

Table 1: Mixture proportions

Material	**Amount kg/m^3**	**Density kg/m^3**	**ASG m^2/kg**	**Absorption %**	**Moisture w.%**
RR1 mix design (natural Dutch aggregates)					
Cement	370	3050			
Water	170				
Aggregate 0-2 mm	555	2430	4.87	0.68	0.23
Aggregate 2-4 mm	345	2420	2.03	0.65	0.22
Aggregate 4-8 mm	290	2215	1.84	0.42	0.07
Aggregate 8-16 mm	210	2170	0.67	0.30	0.02
RR2 mix design (crushed Norwegian aggregates)					
Cement	370	3050			
Water	170				
Aggregate 0-2 mm	570	2540	4.87	0.27	0.04
Aggregate 2-4 mm	324	2425	2.03	0.27	0.04
Aggregate 4-8 mm	276	2240	1.84	0.27	0.07
Aggregate 8-16 mm	450	2870	0.67	0.13	0.05

3. A Model for Micro-Poro-Fracture

The micro-poro-mechanics theory, which combines the ideas of poro-mechanics and micro-mechanics techniques, is used to examine the behaviour of concrete as a porous media. The poro-mechanics theory examines how fluid and solid phases interact in porous media under external loading (figure 1). Its significance was initially realised during the soil consolidation phase, where the pressure from the trapped water may be significant. Utilizing events occurring

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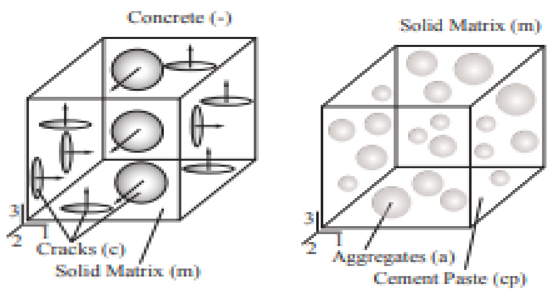
at the component level of a heterogeneous material, the micro-mechanics theory is used to predict the macroscopic behaviour of the material (micro scale). It makes use of homogenization procedures, which establish a composite material's macroscopic mechanical characteristics based on its constituent components [9].



(a) (b)

Figure 1: Micro-mechanical model: (a) Concrete; (b) Solid matrix.

Table 2: Concrete properties for each cast.

Property	Unit	Value			
Mix design		RR1	RR1	RR2	RR2
Air content	%	5.1	3.2	4.3	4.2
28-dcompressivestrength	MPa	70.24	65.63	68.46	65.12
Specific weight	Kg/m^3	2463	2357	2476	2671
Slump H	mm	99	-	157	125

4. Results and Discussion

The material deteriorates as a result of swelling, aggregate and concrete level cracking, and other factors. The expansion development has been the main focus of research so far on the impacts of ASR on concrete. There is disagreement over the results of the limited research that was done to estimate the degradation of engineering properties.

The attribute that is most affected is the elastic modulus, followed by the tensile strength, and the compressive strength has a varied trend. For laboratory specimens held under free-expansion conditions, Figure 2 illustrates the evolution of the expansion and mechanical

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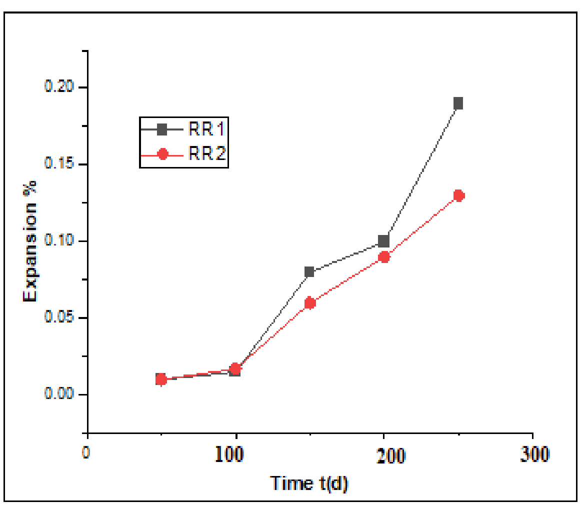
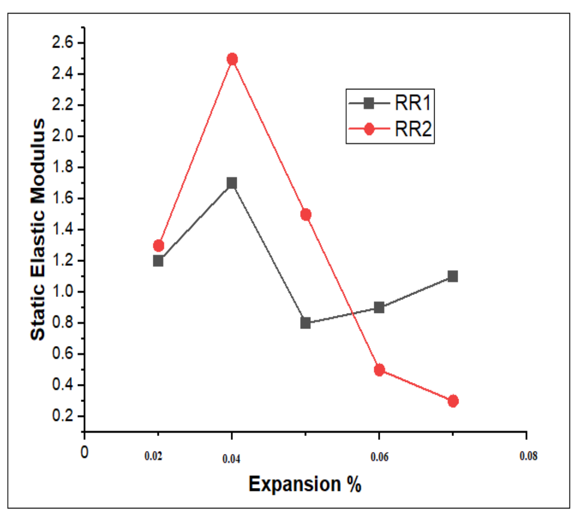
properties as a function of time. All of the authors exposed the samples to a high humidity level.With the exception of [10], who used room temperature (T = 15oC), the storing temperature was roughly T = 35 to 45 oC. With the exception of the extreme case of the mix B tested by [11], which reached = 2.55%, the specimens reach an asymptotic expansion value between 0.24 and 0.68%. The elastic modulus Y (Figure 2b) exhibits an asymptotic residual value, which indicates a significant degradation of up to 85% of its initial value [11]. According to findings from earlier studies by [12], the compressive strength fc (Figure 2c) does not function as a good indicator for the detection of ASR signs.Other mix designs show an increase or no fluctuations, while in certain cases it drops down to an asymptotic residual value, much like the elastic modulus does. Similar to the elastic modulus, the splitting tensile strength (Figure 2d) deteriorates. It reaches greater residual levels in comparison. Concrete mixtures made with Norwegian and Dutch aggregates are categorised as RR1 and RR2, respectively. In the RR2 mix design, coarse-grained quartz, quartzite, gneiss, and other minor rock types made up the majority of the Norwegian aggregates. The point count method was used to determine the potential alkali reactivity of 33% of aggregates with a size of 0–9 mm and 40% of coarse gravel.The majority of the Dutch aggregates used in the RR1 mix design were quartz, quartzite, volcanic rock pieces, and other minor rock types. These aggregates have not yet been associated with any alkali reactivity. The two concrete mixtures were intended to have comparable aggregate gradations and compressive strengths after 28 days [13].

The mechanical and expansion tests for both mixtures. Each result was calculated as the mean of three measurements taken on samples from the same cast. The cast number from which each set of three specimens was created is listed, allowing for the distinction between specimens used for the mechanical and expansion tests. Table 2 displays the mix design, fresh concrete properties, and 28-day cubic compressive strength of each cast. [14]





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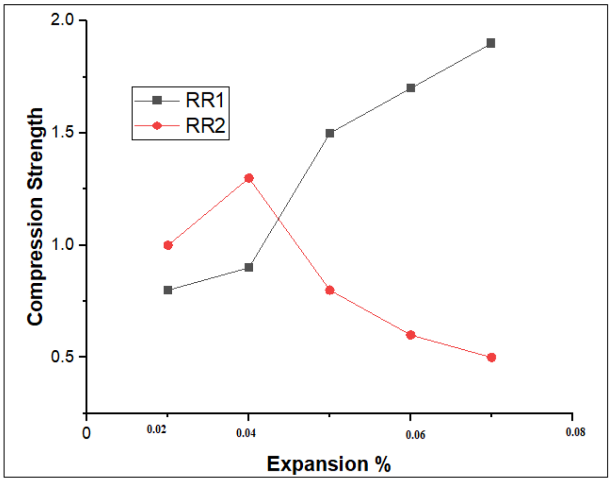
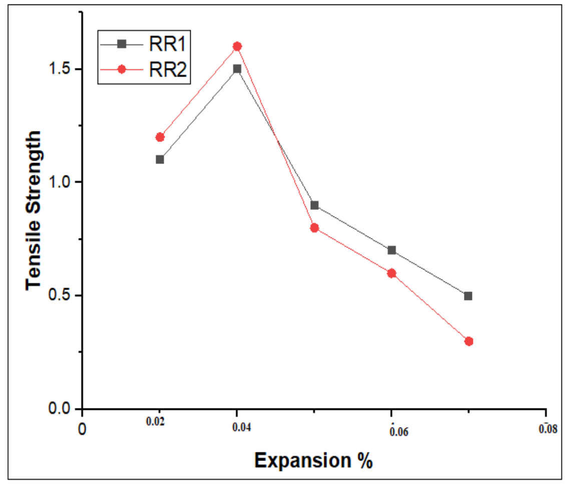
(a) (b)





(c) (d)

Figure 2: Experimental results for RR1 and RR2 concretes: (a) Concrete expansion; (b) Static elastic modulus; (c) Compressive strength; (d) Splitting tensile strength

The degradation of the mechanical characteristics is presented as a function of expansion versus normalised values in Figures 2b–d. Each normalised value was calculated as the difference between the reference value and the current value of the property. The latter was calculated to have a reference expansion of 0.04%, which is the threshold used to distinguish between concrete that is not reactive and concrete that may be reactive. The following sections, which compare and analyse data from the literature to describe the deterioration behaviour, also use this normalisation approach. During the first 90 days, the mechanical properties showed a minor gain, followed by a deteriorating trend.

The concrete mixture RR1's static elastic modulus (Figure 2b) showed only slight fluctuations and varied between 100 and 110% of its reference value. The greatest deterioration of the concrete mixture RR2, in contrast, was 40%. For RR1 concrete and RR2 concrete, the normalised compressive strength (Figure 2c) showed a sharp initial increase from 0.76 to 0.90 and 0.88 to 0.97, respectively. Following a tendency toward the asymptotic value of 1, both concrete combinations similar trends are shown for both mixes by the splitting tensile strength. This got a maximum value of 25% for concrete combination RR1 and 28% for concrete mixture RR2 after relatively minor initial increment degradation was seen.

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CONCLUSION

The results of the model, which describe the uniaxial behaviour of unaffected concrete, are in good agreement with empirical formulations put forth by the Model Codes, which are based on a statistically significant number of experimental results. Peak stresses, hardening/softening shapes, and ultimate strains are used to approximate the well-known stress-strain relationships for both tension and compression.The model can calculate the macroscopic fracture energy in tension by taking into account that the fracture zone serves as the representative elementary volume and that its size can be expected to be three times the largest aggregate diameter. When modelling the material strength for biaxial stress states, the post-peak behaviour of concrete under uniaxial loading is taken into consideration. The model's evaluation of the mechanical properties (stiffness, uniaxial tensile and compressive strengths) of the entire material yielded excellent results, and it is further validated.

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Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analysed in this research work

Conflict of Interest

The authors certify that there is no conflict of interest.

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