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Cover Page Footnote

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INTERACTING ACTION OF ALKALI-SILICA REACTION AND CHLORIDE-INDUCED STEEL CORROSION ON THE REINFORCED CONCRETE STRUCTURES – A CRITICAL REVIEW

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ABSTRACT

The degradation of reinforced concrete (RC) structures amidst the progression of corrosion within alkali-silica reaction (ASR)-affected structures is a complex phenomenon marked by diverse causal factors and repercussions. While the initiation phase of chloride-induced steel corrosion and ASR in RC structures has received extensive scrutiny, insufficient attention has been dedicated to comprehending the propagation phase (tp). Therefore, this study addresses this gap by centering its focus on the propagation phase, driven by the imperative need to formulate efficient and sustainable maintenance, repair, and management strategies for RC structures grappling with the concurrent impacts of degradation mechanisms such as ASR and corrosion. The use of corrosion initiation for predicting the operational lifespan of RC structures has been subject to rigorous examination by researchers and engineers, especially in light of recent breakthroughs in the concrete construction industry. In this context, the present investigation presents early findings, employing durability index tests to analyze the durability attributes of concrete incorporating both reactive and non-reactive materials (aggregates). Furthermore, the study proposes enhancements to prior research endeavors in this domain. While additional data is requisite to ascertain the cumulative influence of ASR and corrosion, conducting a comparative analysis of fluid transport rates through ASR-susceptible and ASR-non-susceptible concretes offers valuable insights into the maintenance and restoration of RC structures afflicted by both corrosion and ASR.

Keywords: Alkali-silica reaction; Chloride-induced steel corrosion; Durability performance; Reinforced concrete structures; Transport properties

1. INTRODUCTION

Chloride-induced corrosion, an electrochemical process at the steel-concrete interface, significantly accelerates the deterioration of reinforced concrete (RC). Driven by the ingress of hazardous species into concrete, it expands hygroscopic corrosion products and consequently causes concrete cover cracking structures (Angst et al., 2011). In varius studies (Enevoldsen et al., 1994; Gouda, 1970; Otieno & Alexander, 2010; Tuutti, 1982; Mehta, 2008), the degradation process is commonly divided into two phases: initiation and propagation (see Figure 1).

Before corrosion initiation, the initial stage exhibits minimal to negligible detrimental effects. However, the ingress of hazardous substances such as chlorides can penetrate the concrete to the steel reinforcement surface, resulting in the degradation of its protective coating and subsequent corrosion.

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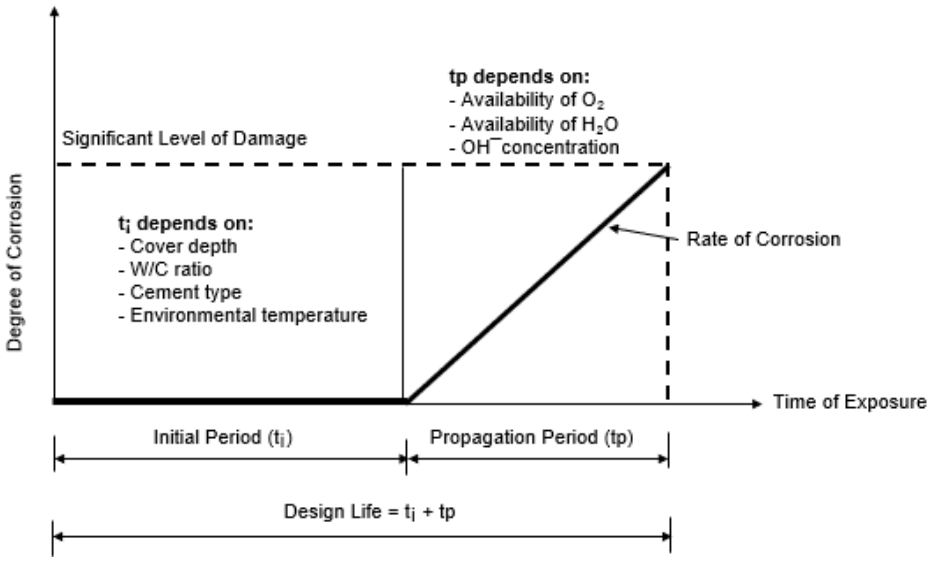


Figure 1: Corrosion initiation and propagation phases (Otieno & Alexander, 2010).

According to Beushausen et al. (2012), the infiltration of hazardous substances, as well as the advancement of chloride ingress, is primarily influenced by the concrete's quality in terms of its penetrability, the chemical composition of the pore solution, the prevailing environmental conditions, the thickness of the concrete cover, and the probability of concrete cracking.

During the subsequent phase, known as corrosion propagation, the process of corrosion activation leads to the formation of corrosion products. These products subsequently undergo expansion, resulting in cracks within the cover concrete. The primary factors contributing to this phenomenon are the interplay between oxygen and chloride transport, the chemical composition of the pore solution, and the prevailing temperature conditions. In the context of reinforced concrete exposed to externally aggressive ions, the effectiveness of the cover in preventing the ingress of hazardous compounds assumes significant importance.

The phenomenon of alkali-aggregate reaction (AAR) can be categorized into two distinct mechanisms, namely alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). The formation of ASR, as detailed in studies by Attar et al., (2020) and Gorga et al., (2022), results from a chemical reaction between alkali in the concrete pore solution and reactive minerals in the aggregate (Fournier & Bérubé, 2000). Concurrently, ASR poses another threat to the structural integrity of RC structures. Furthermore, ASR is the prevailing mechanism observed in concrete structures. The development of ASR necessitates the presence of three key components: an aggregate comprising reactive mineral phases, a high moisture level typically exceeding 85%, and a high alkali concentration. This reaction produces an expansive gel, leading to structural damage.

According to Gautam and Panesar (2017), enhancing durability necessitates the capacity to quantify the fundamental determinants of durability with utmost clarity and precision. This study aims to bridge the gap in understanding the interplay between chloride-induced corrosion and ASR in RC structures. While traditional quality control tests have focused on concrete strength, they must address durability concerns. Our research critically examines the durability index test, which assesses material resistance to degradation agents (Cl^-, H_2O, and O_2), which is fundamental in steel corrosion and ASR. By analyzing existing literature and conducting an ongoing investigation, we seek to understand the combined effects of these two degradation processes on RC structures. Our goal is to offer insights for developing more effective maintenance and repair strategies, enhancing the durability and longevity of RC infrastructures.

2. LITERATURE ON THE CHLORIDE-INDUCED STEEL CORROSION AND ALKALI-SILICA REACTION IN REINFORCED CONCRETE STRUCTURES

Research on RC structures traditionally focuses on damage caused by ASR or chloride-induced corrosion (Michel et al., 2016; Otieno et al., 2016; Karthik et al., 2018; Giaccio et al., 2019), but Trejo et al. (2017) highlight, the combined effects of these two degradation mechanisms still need to be fully understood, particularly in environments like marine settings where both are prevalent. In a marine environment, RC structures can have alkali-silica reactions and be subject to corrosive conditions (chloride-induced corrosion). So, it is important to know how the activities of the degradation processes work together to affect the durability of RC structures.

Studies (Yu et al., 2015; Otieno et al., 2010; Francois and Arliguie, 1998) have demonstrated that aggressive agents can reach steel reinforcement through cracks in RC, which ASR often exacerbates. This suggests a synergistic effect where ASR can accelerate chloride transport, potentially hastening the onset of active corrosion. The challenge remains to quantify how these combined effects influence the longevity of RC structures, a crucial aspect for those working with concrete in developing durable infrastructures.

There are three existing research on the combined effect of chloride-induced steel corrosion and ASR reviewed in thi study, including study by Mitsunori et al. (1989), Trejo et al. (2017), and Wang & Sugiyama (2022).

3.1 Mitsunori et al. (1989)

Mitsunori et al. (1989) focused on how ASR affects steel corrosion in chloride-contaminated mortar. The experiment was conducted with 40 × 40 × 160 milimeters (mm) mortar specimens made from regular Portland cement containing 0.93% Na_2O equivalent. Beltane opal aggregate with sizes ranging from 1.2 mm to 0.6 mm was employed as a reactive aggregate. A non-reactive aggregate of Toyoura siliceous sand was also employed. Mortars were produced using a water-to-cement ratio of 0.5. Reactive aggregate was used to replace 3% of the overall aggregate. Sodium chloride was pre-dissolved in the combined water of mortar specimens in amounts equal to chloride ion addition levels of 0.25, 0.5, 1.0, and 2.0% by weight of cement. Mortar cylinders 5.6 cm × 10 cm for pore solution expression were kept at 38°C in sealed vinyl bags within a fog box. After a predetermined curing time, the high-pressure equipment extracted pore solutions from mortar samples. Chloride ion concentrations were determined using coulometric titration. In addition, the hydroxyl ion concentration of the extracted solutions was measured using a phenolphthalein endpoint titration with hydrochloric acid. Mortar sample length differences were measured. The mortar samples were fitted with a mild steel electrode and a stainless-steel counter electrode, and the corrosion intensities of the steel electrodes were measured using polarization resistance. The electrochemical test was carried out on specimens kept at 38°C in a fog box. For over a month, duplicate specimens were measured every day, then every two days. The following conclusions were drawn from the study:

- Mortar specimens containing reactive aggregate experience more expansion than reactive aggregate-free mortar specimens.
- The addition of the reactive aggregate accelerated the corrosion of steel embedded in reactive aggregate mortars due to some changes in the microstructure of the mortar phase brought on by the alkali-silica reactions (i.e., cracks).
- The measured Cl^-/OH^- ratios in pore solutions extracted from mortars containing the reactive aggregate are greater than those without the reactive aggregate at a given chloride ion addition amount.

3.2 Trejo et al. (2017)

Furthermore, Trejo et al. (2017) explored the impact of ASR on chloride transport and corrosion initiation. They used reactive and non-reactive aggregates in their specimens and observed expansion and cracking in those containing reactive aggregates. The specimens were designed following the general specifications (ASTM C1293, 2008). As anticipated, certain specifications and criteria have been adjusted to satisfy the aims of this study. Ten 285 x 152 x 114 mm specimens were manufactured and evaluated. Utilized were a non-reactive limestone coarse aggregate, a non-reactive limestone fine aggregate, and a highly reactive natural siliceous river sand. Prior to this work, the reactivity of these aggregates was validated using (ASTM C1260, 2010). Five samples included fine aggregate that was reactive, while five contained fine aggregate that was non-reactive. All samples had coarse aggregate that was non-reactive. The specimens were strengthened with 285 mm-long pieces of reinforcing bars. Each end of the steel reinforcement was covered with electroplating tape, revealing the 200 mm test section. In order to determine the length change of the specimens, two-gauge studs were inserted in the concrete at each end of the specimens. As required by ASTM C1293, sodium hydroxide was added to the concrete mixing water to enhance the alkali content to 1.25% Na_2O_{eq} by cement mass.

A water-cement ratio (w/c) of 0.45 was utilized for all specimens. After curing, the specimens were exposed to 100°F (38°C) and 95% RH. Specimens were exposed for two weeks to a 3% sodium chloride (NaCl) solution ponded on the specimen's surface. In addition to being ponded, specimens were housed in plastic containers with airtight lids. This was done to maintain a high RH and encourage ASR. The bottoms of the containers were filled with water. As specified by ASTM C1293, a plastic rack was inserted in the bottom of the containers to elevate the specimens above the water. After demolding, the first expansion of the specimens was measured (24 hours after casting). Comparator readings were taken one and four weeks following the original reading and, after that, monthly until the initiation of corrosion. The subsequent findings were reached:

- The formation of ASR gel in specimens containing a reactive fine aggregate resulted in expansion and cracking of the specimens containing reactive aggregate, but this was not observed in the specimens containing non-reactive aggregate.
- The specimens containing reactive and non-reactive aggregate showed similar times to corrosion initiation.
- Specimens containing non-reactive aggregate exhibited a higher corrosion rate than those containing reactive aggregate. This indicates that ASR resists the transport of chlorides, and the presence of ASR gel can act as a barrier against chloride transport in concrete, resulting in a lower overall penetration rate of the chlorides.

3.3 Wang & Sugiyama (2022)

Study by Wang and Sugiyama (2022) investigated steel corrosion in steam-cured concrete under simultaneous chloride attack and ASR. They employed various concrete mixes, aggregates, and testing methods to evaluate expansion rates, corrosion risks, and chloride diffusion coefficients. Figure 2 shows prismatic concrete examples of 100 mm in width, 300 mm in length, and 128 mm in height constructed in this work. Two deformed steel bars with a 19 mm diameter were placed in parallel on each specimen at 30 mm concrete thickness intervals along the height direction. The following concrete mix proportions are marked: H (100% PC) with no reactive aggregate, HA (100% PC) with reactive aggregate, FB (80/20 PC/FA) without reactive aggregate, FBA (80/20 PC/FA) with reactive aggregate, and BB (50/50 PC/SL) without reactive aggregate. The water-to-binder ratio in SCM-containing concrete (FA and SL) was 0.35, compared to 0.40 in 100% PC examples (H and HA). The HA and FBA coarse aggregate comprised 30% active alkali

andesite and 70% limestone. The most reactive andesite comprises tridymite, cristobalite, volcanic glass, and micro secondary quartz.

To accelerate ASR, the total alkali content of HA and FBA concrete was increased to 5.5kg/m3 using a sodium hydroxide reagent. All specimens in this study were subjected to 24 hours of steam curing following casting. The heating rate was kept constant at 15°C per hour during steam curing, and the maximum temperature reached 60°C for four hours. Specimens H, FB, and BB were cured at 20 ±2°C in a temperature-controlled chamber. Water curing of HA and FBA was followed by air curing in a typical setting. The specimens were subjected to length variation testing. In contrast, the half-cell potential approach (using a lead/lead sulfate reference electrode) was utilized to evaluate the electrochemical reaction process at the steel/concrete contact in the chloride penetration test. After the experiment, the following conclusions were drawn from the findings.

- During the first five weeks of the accelerated length change test, the expansion rate of HA concrete with the pessimum proportion of reactive andesite aggregates was 0.133%. Adding fly ash to FBA concrete reduced but did not eliminate the expanding behavior caused by ASR.
- Even when the reference electrode (RE) was positioned on the bottom surface of the concretes, the upper rebar's corrosion was accurately identified using the specimen half-cell potential tests. As a result, the half-cell potential test is appropriate for high-strength, steam-cured concrete with a thick cover, such as a real concrete bridge slab.
- According to the overall trend of the specimens, all specimens with reactive aggregate exhibited a higher risk of embedded reinforcement corrosion than specimens without reactive aggregate. Reactive aggregate specimens have a lower (more negative) half-cell potential than non-reactive aggregate specimens. The HA (100% PC) half-cell potential with reactive aggregate exhibited the highest corrosion chance (greater negative value). This reveals that sodium chloride penetration causes early rebar de-passivation in HA due to the combined effects of ASR and chloride intrusion.
- The chloride diffusion coefficients of H and HA concrete were 47.9×10^{-12} m^2 /s and 63.4×10^{-12} m^2 /s, respectively. On the other hand, the chloride diffusion coefficients of FA and BB concrete were 1.0×10^{-12} and 0.9×10^{-12} m^2 /s, respectively. This demonstrates that using fly ash and blast furnace slag for corrosion prevention of reinforcements in high-strength steam-cured concrete is successful.

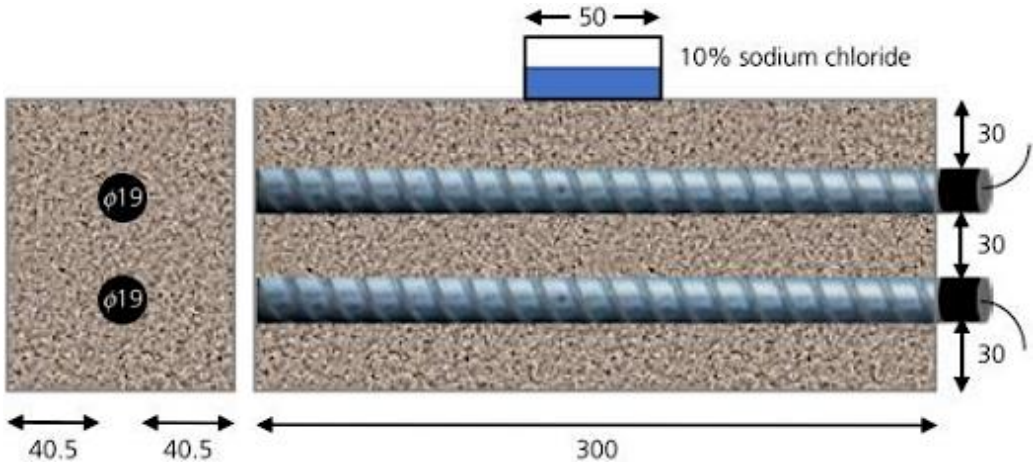


Figure 2. Schematic representation of the specimen set-up (Wang & Sugiyama, 2022)

3. DISCUSSION AND CRITIQUE OF THE EXIXTING STUDIES

3.1 Discussion of the Existing Study's Findings

The intricate interplay between ASR and chloride-induced corrosion within RC structures has garnered considerable individual attention in previous research. However, the amalgamation of these two degradation mechanisms poses a multifaceted challenge, necessitating further investigation to comprehensively understand their combined effects on steel corrosion in RC structures. Previous studies have predominantly focused on corrosion initiation, employing various assessment procedures and methodologies to explore the intricate interaction between ASR and chloride-induced corrosion. Notably, the research by Mitsunori et al. (1989) and Wang & Sugiyama (2022) revealed a consistent trend, indicating that concrete specimens containing reactive aggregate (ASR-susceptible) exhibited a higher susceptibility to steel corrosion when exposed to chloride solutions compared to specimens with non-reactive aggregate (not susceptible to ASR). This susceptibility was attributed to alterations in the concrete microstructure induced by ASR, including the formation of cracks and detachment of aggregate from the cement paste matrix, which facilitated the ingress of chloride ions to the steel surface. Furthermore, the alkali-silica reaction in concrete led to a lower hydroxyl (OH-) to chloride ions (Cl-) ratio in the pore solution, promoting corrosion due to an elevated concentration of Cl- ions.

The findings of Trejo et al. (2017) contradicted those of Mitsunori et al. and Wang & Sugiyama. Trejo's study suggested that the initiation of corrosion occurred concurrently in specimens containing reactive aggregate and those without reactive aggregate. During the monitoring period, the corrosion status of specimens with reactive aggregate improved relative to those without reactive aggregate. This divergence in results may be attributed to the disparate methodologies employed by each research group. Trejo's experiment involved maintaining specimens at high humidity and elevated temperature without a drying cycle, which may have saturated the specimens and limited the availability of oxygen at the steel surface, hindering the cathodic reaction essential for corrosion. In contrast, other researchers introduced wetting (Polder & Peelen, 2002; Wu et al., 2016; Ye et al., 2016) as well as drying cycles (Otieno et al., 2016; Malumbela, 2010; Otieno et al., 2010; Scott & Alexander, 2007), which facilitate chloride penetration through capillary suction during wetting and replenishing dissolved oxygen at the steel surface during drying, thereby promoting the corrosion process. Moreover, air-drying or drying at elevated temperatures can be achieved through the concrete specimens' drying phase (Yuan et al., 2008; Scott & Alexander, 2007). These variations in experimental conditions underscore the need for a comprehensive examination of ASR and chloride-induced corrosion interactions in RC structures, considering diverse environmental factors and methodologies.

3.2. Critique to Existing Combined Action of the Deterioration Mechanisms

Studies focusing on the initiation phase of corrosion, such as those by (Mazarei et al., 2017; Mitsunori et al., 1989; Trejo et al., 2017; Wang & Sugiyama, 2022), and others, have been instrumental in understanding the early stages of RC degradation. However, as Jung et al. (2003) and Otieno & Alexander (2010) assert, this focus might underestimate the actual service life of structures. As a result, it has become critical to measure corrosion propagation and structure performance carefully during this time. However, according to a recent assessment of the relevant research (El Maaddawy & Soudki, 2007; Zhang et al., 2009; Otieno & Alexander, 2010), the emphasis is on propagation duration. The following factors could have contributed to this shift in perspective:

- Making a structure last longer than its original service life is usually described as the end of the initiation phase.

- There are already a lot of RC structures in the propagation stage that need to be fixed. You must know much about corrosion processes to make correct predictions and diagnoses.
- The need to forecast the performance of new structures in conditions prone to alkali-silica reactions in corrosive environments (marine environment). If this is achieved, effective repair and maintenance management strategies can be developed to ensure timely and optimal intervention.

Moreover, the existing studies on the combined action of the deterioration mechanisms (corrosion and ASR) had not distinguished between concrete specimens containing reactive aggregate and those containing non-reactive aggregate. In the context of this paper, the prospective durability of concrete is defined as the cover concrete's resistance to chloride conduction, oxygen permeation, and water absorption. This paper will thus present preliminary results from durability index tests, contributing to the broader discourse on RC structure longevity in corrosive and ASR-prone environments, and characterize the concrete matrix of the specimens as a basis for comparison using durability parameters (Cl-, H_2O, and O_2).

4. FUTURE OUTLOOK: AN ONGOING STUDY

The current investigation of the deterioration of RC structures due to alkali-silica interactions and chloride-induced steel corrosion inspired the review presented in this paper. This ongoing study aims to understand the corrosion propagation phase of structures that display alkali-silica interaction and are exposed to corrosive circumstances (chloride-induced steel corrosion); this will aid in developing proactive maintenance and repair techniques. Moreover, it is necessary to highlight the necessity to address some of the inadequacies of the existing studies described in this work. In the next part, a synopsis of the preliminary results of the durability index test of the research is offered.

4.1. Objectives and Expected Outcomes of the Ongoing Study

The primary goal is to assess the impact of both ASR and chloride-induced corrosion on the durability of RC structures. This involves conducting corrosion assessment experiments on specimens with and without reactive aggregate, encompassing corrosion initiation and propagation phases. Key aspects of this study include analyzing the influence of different aggregate types (reactive and non-reactive) on concrete structures, with durability performance evaluated through chloride conductivity, oxygen permeability, and water sorptivity tests. Furthermore, to account for the inherent variability of corrosion rate, an analysis will be performed on the corrosion-influencing parameters of aggregate types (reactive aggregate and non-reactive aggregate) and concrete quality of binder types (OPC, slag, and fly ash).

It is anticipated that, upon completion of the study and achievement of the objectives above, the following outcomes will be realized:

- Recommendations for proactive conservation (maintenance and repair) strategies to enhance or extend the initial design service life, focusing particularly on the corrosion propagation phase.
- The durability performance of concrete structures under the combined action of the degradation mechanisms (corrosion and ASR) will be measured using measurable metrics such as durability index tests (oxygen permeability index, water sorptivity index, and chloride conductivity index). In addition, corrosion and ASR assessment tests (corrosion rate, concrete resistivity, and corrosion potential, while longitudinal and transverse expansion of concrete specimens due to ASR will be utilized to determine the performance of the structures.

Figure 3 outlines the experimental work plan detailing the methodology used for assessing the deterioration of RC structures under the combined effects of chloride-induced steel corrosion and ASR. The experiments are divided into two parts: one focuses on corrosion assessment and monitoring, and the other employs tests like ASTM C 1260, ASTM 1293, compressive strength, and durability index tests for ASR measurement.

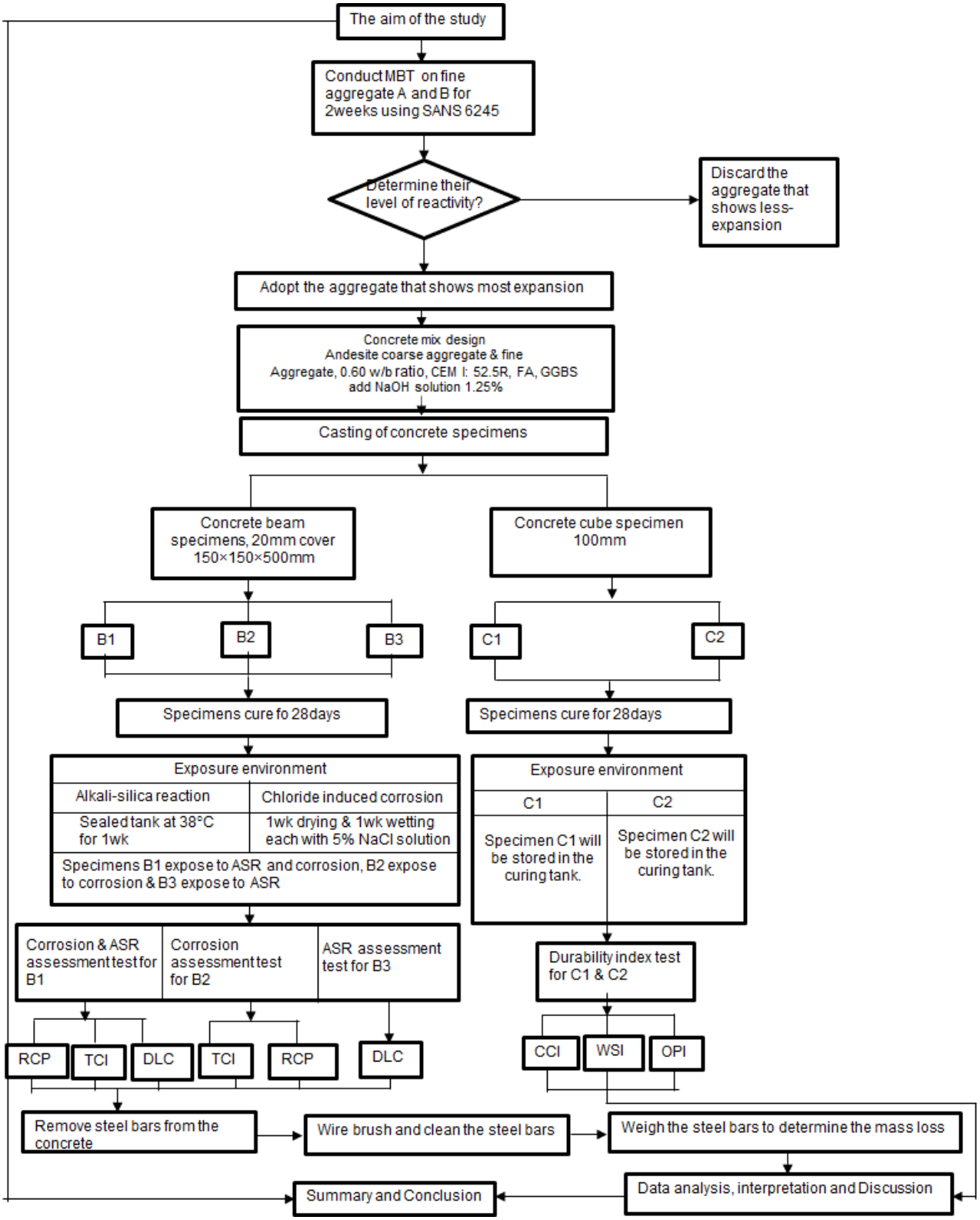


Figure 3. Research methodology flow chart

Legend:
ASR : Alkali-Silica Reaction
B1 : Beam specimen (corrosion scenario)
B2 : Beam specimen (alkali-silica scenario)
B3 : Beam specimen combined (corrosion and ASR) scenario
C1 : Cube specimen containing reactive aggregate
C2 : Cube specimen containing non-reactive aggregate
CCI : Chloride conductivity index
DLC : Dimensional length change
FA : Fly ash
MBT : Mortar bar test
OPI : Oxygen Permeability Index
RCP : Rate of Corrosion Propagation
TCI : Time of Corrosion Initiation
w/b : Water-to-binder ratio
WSI : Water Sorptivity Index

The following sections present the preliminary results of the durability index test conducted in this ongoing study.

4.2. Experimental Set Up

This ongoing study involves a comprehensive experimental set-up to evaluate the durability of concrete structures subjected to the combined effects of ASR and chloride-induced steel corrosion. Utilizing both reactive and non-reactive aggregates, the concrete specimens were subjected to three critical durability index tests: the OPI, WSI, and CCI. Concrete quality was assessed in two categories based on aggregate reactivity. 'Reactive aggregate' specimens, susceptible to ASR, used Sub-Nigel crushed aggregate, while 'non-reactive aggregate' specimens employed Andesite crushed aggregate. The study encompassed various concrete mixes using slag (SL), fly ash (FA), and Portland cement (PC), each with reactive (R) and non-reactive (NR) variants. The sample notations employed in the presentation of the experimental data in this paper are as follows:

a. PC-NR; for 100% Portland cement beam specimen containing non-reactive fine and coarse aggregate.
b. PC-R; for 100% Portland cement beam specimen containing fine reactive aggregate and non-reactive coarse aggregate.
c. 50/50 PC/SL blend-NR for Portland cement/slag beam specimen containing non-reactive fine and coarse aggregate.
d. 50/50 PC/SL blend-R for Portland cement/slag beam specimen containing fine reactive aggregate and non-reactive coarse aggregate
e. 70/30 PC/FA blend-NR; for Portland cement/fly ash beam specimen containing non-reactive fine and coarse aggregate.
f. 70/30 PC/FA blend-R for Portland cement/fly ash specimen containing fine reactive aggregate and non-reactive coarse aggregate. The R and NR, respectively, represent reactive and non-reactive.

After allowing the concrete cubes to cure for a specific time of 28 ± 3 days, in accordance with the instructions provided in the durability manual (SANS 300-CO3-1, 2015; SANS 300-CO3-2, 2015; SANS 3001-CO3-3, 2015; Alexander, 2018), tests to determine the concrete's durability index were performed to evaluate the initial quality of the concrete and determine its prospective durability by examining how fluids, such as gasses, ions, and water, can move through the concrete cover. More precisely, the tests were conducted to quantify the extent to which

corrosion-related substances, including oxygen (O2), chloride ions (Cl-), and water (H2O), can infiltrate the concrete.

As illustrated in Figure 4, discs with a diameter of 70 ± 2 mm and a thickness of 30 ±2 mm were removed from 100 mm concrete cube specimens and subjected to durability index testing. One set of specimens was made with fine reactive and non-reactive coarse aggregates; another set of specimens was produced with non-reactive fine and coarse aggregates were used to investigate the effect of ASR on the durability properties of concrete structures.

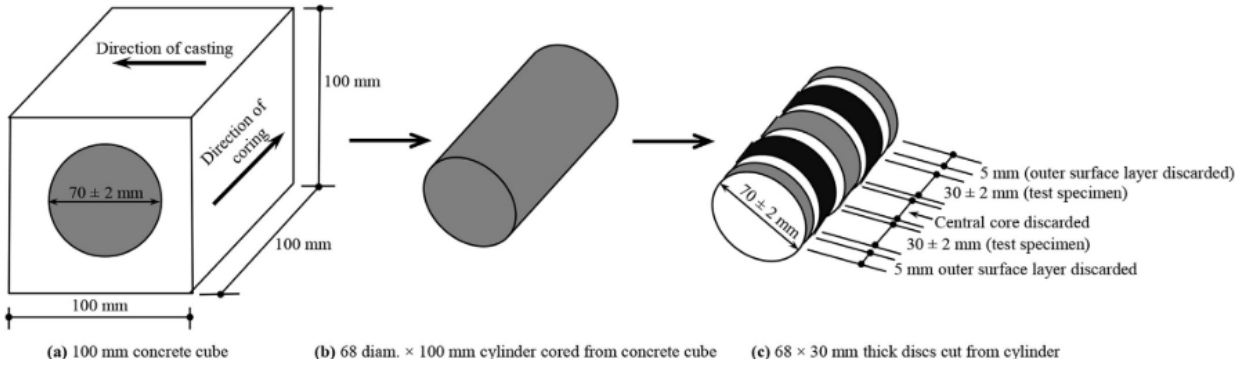


Figure 4. Durability index test disc extraction from 100 mm concrete cube (extracted discs shown in the photo were sourced from SANS 3001-CO3-1:2015; Otieno, 2018)

Evaluating the ability of the concrete cover to withstand the penetration of corrosive substances such as chlorides, oxygen, and moisture is essential in determining its effectiveness as a protective barrier. To assess the prospective durability performance, the durability index (DI) parameters, which consisted of OPI, WSI, and CCI were analyzed. This analysis was conducted on damp concrete that was subjected to a 28-day period. The subsequent results, displayed in Table 1 and depicted in Figure 5, offer understanding into the vulnerability of the concrete to substances that cause corrosion. This finding contributes to a thorough assessment of the concrete's quality in relation to potential risks posed by these substances.

Table 1: Durability Index Test Results at 28 Ddays

Test	PC-NR	PC-R	PC/SL-NR	PC/SL-R	PC/FA-NR	PC/FA-R
OPI	8.67	6.99	9.13	7.91	8.99	7.27
WSI ($mm\sqrt{hr^{0.5}}$)	15.10	31.32	12.15	16.45	13.86	23.75
Porosity (%)	12.10	20.70	10.46	12.78	10.90	14.07
CCI (mS/cm)	1.91	2.28	0.50	0.77	1.40	2.03
Porosity (%)	6.12	7.85	4.90	4.97	5.02	6.09

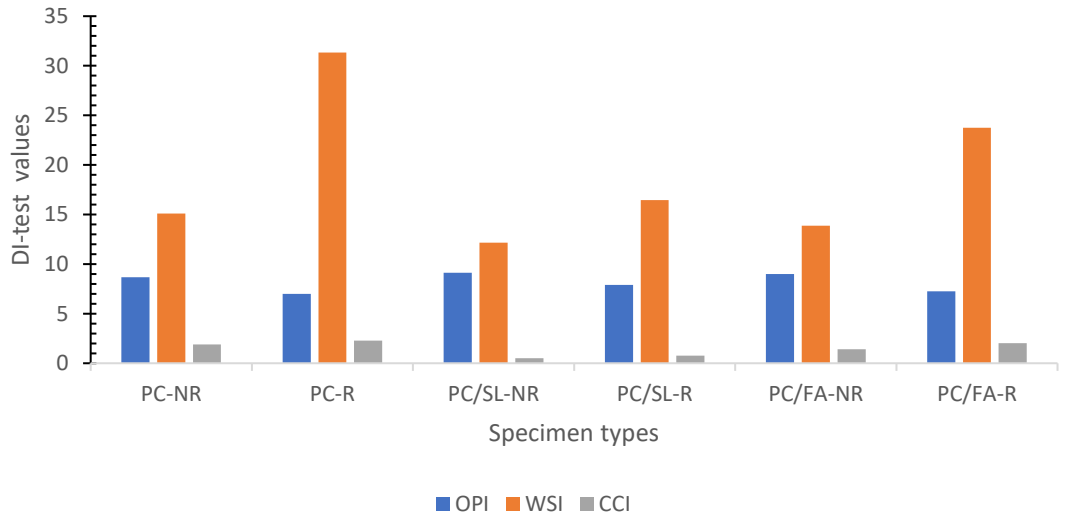


Figure 5: Durability index test results at 28 days

The general trend of the durability index test results for concrete specimens with reactive aggregate and those with non-reactive aggregate indicated that concrete made with non-reactive aggregate is of higher quality. Also, the specimens made with supplementary cementitious materials (SCMs) (i.e., FA and SL) show a higher resistance against the aggressive agents than those made with PC for both reactive and non-reactive aggregate scenarios. The following cause could have contributed to this trend.

A previous study on the determination of different aggregate reactivity indicated that reactive quartz aggregate began exhibiting void formation as a symptom of alkali-silica reaction at 28 days due to the constant moisture supply (Cruz Carlos et al., 2004). This reason was adopted because the reactive aggregate used in this study is composed of quartz, and the concrete cubes were cured in water for 28 days, which served as a constant supply of moisture to the concrete specimens. ASR causes voids and detachment at the cement paste–aggregate boundary, thereby increasing the mortar's overall porosity (Marinoni et al., 2015). The impact of the SCM specimen can be attributed to the advantageous effect of pore refinement in the paste portion of the concrete, which decreases the diffusion rate of species into the concrete (Nikam & Tambvekar, 2003).

5. CONCLUSION

This study critically evaluates the intricate interplay between alkali-silica reaction (ASR) and chloride-induced steel corrosion in reinforced concrete (RC) structures, along with preliminary findings from durability index tests on concrete specimens. This investigation highlights gaps in existing research and presents new insights into the combined degradation mechanisms. From this study, there are five key conclusions are drawn, which include (1) The corrosion rate is crucial in assessing corrosion-induced damage in concrete structures. Accurate evaluation of this rate is essential for structures vulnerable to ASR and corrosion; (2) Understanding the combined effects of ASR and corrosion is vital for the effective repair and maintenance of RC structures. A comprehensive grasp of these deterioration mechanisms is necessary for developing robust; (3) Current studies predominantly focus on the initiation phase of corrosion. Concrete professionals require detailed information encompassing the initiation and propagation phases to prevent misleading assessments, emphasizing key measurable parameters; (4) Enhancing durability involves precise measurement of key parameters, particularly those describing the quality of the

concrete cover layer. Traditional strength parameters are insufficient; a broader approach, such as durability index tests, is crucial for a holistic understanding of concrete deterioration; (5) The practical application of index tests for quality control must be evaluated based on the long-term durability performance of constructed structures. This necessitates a commitment to ongoing, extensive research. These conclusions underscore the importance of a nuanced understanding of ASR and chloride-induced corrosion in RC structures. The study advocates for a shift in the current research focus, urging the incorporation of comprehensive durability assessments in concrete structure analysis.

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