Investigation on durability of concrete exposed to chloride, sulfate attack and steel corrosion

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Abstract. In the present age, the concrete material is playing an increasingly important role in construction. But in the meantime, environmental features have serious damaging influence on the concrete. Consequently, this damage will decline the long-time persistence and serviceability of concrete structures. This review paper discusses recent research activity on the permanence of concrete, including: a) main durability problem including sulfate attack, steel corrosion and alkali aggregate reaction, b) durability of concrete in nautical location such as seawater, groundwater, Salt Lake; and c) mix with effects of environmental items and mechanical loads on persistence of concrete. This report is based on results of many realistic experiments which happened by scientist. Consequently, it’s important to follow these methods to improve service life of concrete and durability would be superior.

1. Introduction
With a worldwide construction over ten thousand million tons every year [1], nowadays the concrete is one of the most popular material in civil engineering. With the increasing of concrete tech, it is therefore clear that the concrete material has deep impact on construction structures, which is exposed to the diverse conditions (saline area, cold areas) [2-3]. However, since the durability is not solid enough to endure loads in sulfate environment after the concrete structure created in the marine environment about (6-10) years, the structure need to changed or repaired [4-5]. In the marine environments such as groundwater, seawater, sulfate soil and salt lake are attacking to concrete construction which influence the long-time persistence and service life of concrete construction and cause massive financial aspects, mean while marine include high co-centration of chlorides and sulfates. Durability of Portland cement concrete can be resist to weathering action, abrasion resistance, the process of failure to continue its original form, quality and usability when considered for service environment [6]. At the beginning persistence problems typically seem as the materials deteriorate. This vicious cycle will continue indefinitely and will gradually leading structural damage. There is three group of Concrete deterioration that including chemical, mechanical, and physical which from main durability problems such as steel corrosion are started and advanced [7]. The solving of the durability problems is that an increasing number of researchers have showed comprehensive studies on durability problem. The recent studies showed that separate issues of Alkali aggregate reaction, carbonation, reinforcing steel corrosion, and sulfate attack. A study run by researchers showed that environmental factors and loading have deep impact on the degradation of a
concrete structure. An environmental item and a mechanical loading can combine an effect on different sectors which many realistic experiments happened by scientist[8–19]. Consequently of durability studies, an increasing number of countries have offered [20–22]. Durability loading carrying ability joined service life design method or durability-based design guidelines [7]. This review paper began with the argument on recent about to decrease concrete deterioration according to corresponding activities. The result of previously studies on persistence issues for concrete in nautical environment such as salt lake, ground water, seawater, methodology are introduced and the durability based design philosophy.

2. Main challenges of durability
Sulfate attack, Alkali–aggregate reaction, and steel corrosion are the main persistence issues in concrete.

2.1. Alkali aggregate reaction
in concrete on concrete quality including impermeability, stiffness, Loss of strength, Affect concrete appearance and durability, and previous failure of concrete structures. Furthermore Preserve cost increased the service life of concrete structures is reduced can be a major item of main economic costs. At the end result Some concrete structures and members were destroyed because of ASR. No concrete structures had distorted due to ASR damage.

The reaction in concrete between the alkali hydroxides, which create generally from the Portland cement and certain kinds of aggregate is Alkali aggregate reaction (AAR). There is Two types of AAR including: Alkali Carbonate reaction and Alkali Silica reaction[23]. The scientist by using methods to consider the AAR are: quick testing methods (ASTM C289), autoclave test method, mortar bar trial (ASTM C227), rock cylinder method (ASTM C586), accelerated mortar bar method (ASTM C1260) [24], chemical constriction test [25], testing the concrete prism (RILEMAAR-3) [26], stiffness damage trial [27], Dynamic modulus and gel fluorescence testing[7]. Typically, the degree of AAR is influence by the type and amount of the reactive silica in the aggregate, amount of alkali in the cement, the disposal of temperature and moisture and Conforming, there are some methods for preventing the attack of AAR, using low-alkali cement, utilization of non-deleteriously reactive aggregates and addition of nitrate salts and the by using pozzolans to handle damaging ASR can be useful.

Figure 1: Alkali-aggregate reaction (AAR)
There is discussion about the effects of nitrate salts and pozzolanic materials

1) The combination between fly ash, with enough reactive siliceous granular skeleton, amount of slag and silica breccia [29] is useful to decrease Alkali Silica reaction development risk [30]. As studied by Wright et al., examined that the lime potential higher the fly ashes, requiring a huge amount of cement replacement to decline Alkali Silica reaction [31]. CaO 27.3 with Fly ash, 2.42% and 13.5 required 31, 13% and 18 by using of Portland Cement against Alkali Silica reaction [31–33]. Besides, mortar plus silica breccia and concrete have an amount less than 30μm indicated a little development than the control mixture with sulfate resistance tests and alkali silica reactivity [34,35].

2) AAR expansion can decrease with adding amount of Lithium nitrate in cement based materials, considerably impact the morphology of the reaction product and the chemical composition. In addition, dense reaction products are served and generated as sulfate attack will be effective protective barrier [36].

Currently, researches showed that initial Alkali Silica reaction gel can a cement matrix will temporarily density.

1) Stukovnik et al. showed that alkali-carbonate feedback, a significantly greater growth in pressure strength was discovered for motivated dolomite aggregates with the mortar, by comparing it with lime aggregate. This event has clarified as better correlation between aggregate grains and Portland cement binder, because of the establishment of a new Aluminum (Al) – Magnesium (Mg) – Silicon (Si) phase both in the along pre-existing cracks and interfacial transition zone [ITZ] in the aggregate grains [37].

2) A recent study showed that by using alkali susceptible aggregates in the alkali activated cement concretes without serious damage although this theory suggests opposition by Krivenko et al. The researcher recommended that the alkali activated cements affected on active alumina in had a satisfactory result allowed the handling the structure establishment method in the ITZ and to diminish expansion down to acceptable completely or levels evade it [38].

3) A recent study showed with the adding amount of alkali reactive brick aggregate didn’t disturb on manufacturing properties of secondary ettringite were noticed by SEM concrete and although alkali silica gel by Bektas [39].

2.2. Concrete structure exposed to sulfate attack
Sulfate corrosion is one of the most important items responsible for increasing deterioration of concrete structure. Sulfate attack can be divided into two main group 'external' or 'internal'.
Investigations on sulfate persistence are mostly carried out through stashing specimens in a solution of magnesium sulfate or a combine of the two or sodium[7]. At present, by effecting of sulfate attack is commonly measured through some points: the mass losing or increasing, length variations, strength and elastic modulus decrease difference of surface hardness [40]. However, these items do not contribute enough info to evaluate chemical reactions and realize the destruction mechanisms [41] and neither these items indications may be related to exposed in extreme conditions.

Detioration of concrete are usually cab be divided into three main group including; (a) Acidic type (b) Expansion type (c) Onion-Peeling type. Acidic type is a process of eating away of the hydrated cement, expansion type is a process of Sulphate reaction to hydrated Alumina, and the last type is onion peeling type which is determined by the concrete level scale in successive layers.

Advanced studies on the deterioration process concrete structure under sulfate attack.

1) By using electrochemical impedance to find the non-destructive sulfate attack investigated by Braganca et al. The resistance tests about using an alternate signal by a range of 25mV at open circuit potential[42]. Sulfate chamber exposed to the (EIS) Electrochemical Impedance Spectroscopy acquired from the reinforced mortar showed that this method can be used to monitor the diminution in the permanence of the primary stages of deterioration. Mono sulfate products were generally showed that the analysis of sulfate profiles gained and equivalent circuits which contended with the founding of cement hydrates through the curing process[42].

2) A recent study by Hachemetal showed that the relation between the insistence to sulfate attack and the specimen size [43]. As shown in Figure [2] bellow, was performed at constant temperature and pH, 20 °C and7.5, respectively. This pH was measured by addition a nitric acid solution. The length and mass of specimens were regulated when the result was improved. From the investigational consequences, they supposed that the effect of increasing the rate of sulfate attack caused an increase in the kinetics of leaching rather than the type of expansive products [43,44].

3) 3- Stroh et al. Showed high-resolution synchrotron [is an extremely powerful source of X-rays] X-ray diffraction that was in concrete in a crushed soil of sulfate during nineteen years [45], the major crystalline step that recognized by ettringite in the inner gypsum and region was extremely near to the surface of concrete [45].
4) Generally, thaumasite with formula \[ \text{Ca}_3\text{Si}((\text{CO}_3)\text{(SO}_4)\text{(OH)}_6\cdot12\text{(H}_2\text{O)}) \] is typically needed around 1 year using an external storage solution of [MgSO4-].

To avoid the time-consuming exterior method, Li et al. invented a method about internal add method to increase thaumasite establishment at laboratory [46]. This method, cement lime pastes including magnesium sulfate [10%] was preserved for six months keeping in water with [± 2] °C. This experiment showed that a new way could give a noticeably fast way for thaumasite sulfate attack investigation [46, 47].

2.3 Deterioration caused by the corrosion of steel

The corrosion of structural steel is an electrochemical step that needs the simultaneous existence of moisture and oxygen. Recognizing that the most major durability problem in construction engineering is corrosion of the reinforcing steel [49, 50]. The really difficult problem in construction engineering is how to decrease the steel corrosion. The most important factor that controls the frequency of chloride and carbonation entry is the mixing of concrete cover thickness and concrete quality. Consequently, the main protection method that considered is developing the quality of concrete [51, 52]. Including the augmented concrete cover, stainless steel, corrosion inhibitors and coating rebar that considered as protection plans.

1) In general, the quantity of concrete cover over the Reinforcing steel meaningfully affected on the time to corrosion of the entramed reinforcing steel [65]. However, the possibility of cracking caused by tensile stress, thermal effects, and shrinkage increases [7] and the rebar becomes less operative when the cover rises.

2) The durability performance can be improved by the coating of the reinforcing steel and that working as a fence avoiding the entrance of hostile types to the surface of steel and that can provide electrical insulation. Recently study, the performance of epoxy coating clearly offering higher than zinc-primer and red oxide coatings with the corrosion of steel [66], and there are many ways to use it as a powder or as a liquid which merges on the steel surface.

The primary necessities for epoxy-coated-reinforcing steels by the method of electrostatic-spray were addressed by A775M-04a / ASTM A775 (Standard condition for Epoxy-Coated Bars Steel-Reinforcing). The quantity of losses to the epoxy coating before the concrete molding have
been measured as the main supply element to the low execution of reinforcing steel [54]. Therefore, for properly producing traineeship, it is necessary to handle and apply the coating and, fixing of practical damage to epoxy-coated-bars. In addition, the connection characteristics between the epoxy coated rebar and the concrete aren't stronger than among conventional rebar and concrete, which must be enhanced [2].

3) There were not many researchers about using stainless-steel bars [55–59]. The chloride verge amount for initiation of corrosion in non welded AISI304 (one of stainless steel types) has been exposed that reinforcing steel is 3 to 5 times greater than that of normal reinforcing steel. However, the bar welding decreases dangerous chloride level by fifty percent. The stainless-rebar using is a costly resolution and that should be noticed [2].

4) There is another useful instrument for supplying the resistance of corrosion which is galvanized steel (Zinc coating of steel). It performances as a sacrificial and barrier kind coating. However, it has a problem is like other mineral coatings, by time the zinc-coating will erode. The ecological conditions will determine the loss of coating thickness by the rate of corrosion and the time which it will be operative. Mostly, there is a completely linear connection between the metal thickness and the period of its active serving for galvanized steel exposed to an industrial atmosphere [60]. The surrounding solution Potenz Hydrogen (pH) is very important for the stability of zinc-coating where the zinc-coating exposed. Zinc corrosion manufacture can be used on the zinc-coating surface and closed, subsequently led to the zinc coating passivation and hindering the development of hydrogen gas. Particularly, if ungalvanized and galvanized rails are used in a single structure, care must be possessed to make sure complete electrical isolation for both of them [61].

5) Corrosion protections are beneficial, not just as a preventive amount for fresh structures but also as a restorative and preventative roof used the mixture to existent structures. Several corrosion protections can be divided into [2]: (a) adsorption-inhibitors, which perform particularly on the partial of cathodic reaction of the operation of corrosion or on the anodic, or on both of them, (b) passivation, which support the reaction of passivation of the steel and (c) forming of the film protections, which prevent the surface less or more fully, for example: the silo-xane instituted corrosion preventer [62–65 thus, The mechanical act of the inhibitors of rust isn't versus regular corrosion but pitting and localized rust of a negative metal because of a decline in pH value or the presence of chloride ions [66].

Corrosion protections mixing with the free concrete can be acting in 2 various ways: - these inhibitors can reduce the rust rate after passivation has occurred and extend the corrosion initiation time [7]. Mixed in inhibitors are more credible because the adding of the inhibitors to the mix is easier and safer. Some research laboratory testing has revealed that definite expressively impact the quantity of chloride ions necessary to begin rust but can decrease the rust percentage. In recent study, sustainable the green application and eco-friendly rust inhibitor becomes an encouraging investigation [67]. A green application inhibitor is Bambuse-Arunindacee extract leaves that offer greater durability to rust of steel comparing with ethanolamine and calciumnitrite. That excerpt able to steady calcium-silicate-hydrates {CSH} gels that avert calcium-hydroxide conversion to carboaluminate phases and calcite to approximately same percentage [67]. There is another distinctive green-inhibitor which is Anthocleiste-djalonensis that is an exceptional type of extractors from root bark, stem-bark, and leaf. The predicted and test info samples by Okeniyi et al. appeared that just 0.4166 % Anthocleiste-djalonensis leaf extractor mixing showed very good inhibition competence [68]. Moreover, Okeniyi, coworkers plus employed electrochemical monitoring techs to evaluate anti-
corrosion act of Phyllanthus Muellerianus leaf excerption on concrete reinforcement of steel in (0.5M) H2SO4 utilize for manufacturing area. In the tests adsorption-isotherm-predictions and the results of electrochemical, the greatest inhibition competence at inhibiting the concrete reinforcement of steel rust was showed the 0.33333 % Phyllanthus Muellerianus-leaf excerption mixing (per-cement-weight) [69].

6) To raise the strength of the ligature from the ordinary steel bars incorporated in the same structures sans any need for real dyeing and demolition, and intensive immunization of concrete based on cement and mortar with ethyl silicate solution and with competence [68]. Moreover, Okeniyi, coworkers plus employed electrochemical monitoring techs to evaluate anti-corrosion act of Phyllanthus Muellerianus leaf excerption on concrete reinforcement of steel in (0.5M) H2SO4 utilize for manufacturing area. In the tests adsorption-isotherm-predictions and the results of electrochemical, the greatest inhibition competence at inhibiting the concrete reinforcement of steel rust was showed the 0.33333 % Phyllanthus Muellerianus-leaf excerption mixing (per-cement-weight) [69].

7) To raise the strength of the ligature from the ordinary steel bars incorporated in the same structures sans any need for real dyeing and demolition, and intensive immunization of concrete based on cement and mortar with ethyl silicate solution and with electrochemical treatments in ways of sodium solution[70]. A group of electrochemical treatments was shown in the figure below. It was described that the rust test in the analysis appeared that the categories of corrosion risk for some mortar takers after the treatment of immersion were acceptable from high to low level [70].

Figure 4. Set-up for electrochemical treatment [70]

3. Conclusion
This review illustrates when concrete exposed to environmental factors and have serious damaging effect on the durability of concrete. According to the review with consider of according usage of pozzolanic materials is an economical aspect to increase concrete serviceability. These reports were reviewed about steel corrosion is that the amount of concrete cover upon the rebar can be decrease of steel corrosion. These codes of designing durability have less intrinsic drawbacks because of the fail to broad consider diverse combination effects of mechanical loading and surrounding elements effects. Consequently, it’s
important to follow these methods to improve service life of concrete and durability would be superior. In
hence we should mention that every day there should be development in field of concrete structure
because by growing the number of people usage of concrete in different fields will increase.

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