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EFFECTS OF CLIMATE AND CORROSION ON CONCRETE BEHAVIOUR

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Abstract. Corrosion of steel is a damaging agent that reduces the functional and structural responsibilities of reinforced concrete structures. Accordingly, reinforced concrete members in the environments that are prone to concrete carbonation or chloride attack coupled with high temperature and relative humidity suffer from accelerated corrosion of reinforcing material. Also, literature proves that climate influences corrosion of concrete, and suggests investigation of impact of corrosion on concrete based on climate zone. Therefore, this paper presents the effects of climate and corrosion on concrete behavior, using bond strength of concrete as a case study. Concrete specimens were prepared form concrete mix that was infested with 3.5 kgm-3 of sodium chloride to accelerate corrosion. The specimens were cured sodium chloride solution 3.5% by weight of water for 28 days before placing them in the exposure conditions. Pull-out tests were conducted at time intervals for one year to measure the impact of exposure condition and corrosion on bond strength of concrete. The results show reduction of bond strength of concrete by 32%, 28% and 8% after one year of subjection of the specimens to the unsheltered natural climate, sheltered natural climate, and laboratory ambient environment respectively. The findings indicate that the climate influences corrosion, which reduces the interlocking bond between the reinforcing bar and the adjacent concrete.

INTRODUCTION

Corrosion is an indisputable deterioration process. It has become one of the major issues in reinforced concrete structure durability assessment. The action of calcium carbonate and chloride ion at the protective oxide film on reinforcing steel in concrete has been identified as the root cause of corrosion (Ann *et al*. 2009, Wang and Lee 2009). The activity of the harmful compounds that are formed because of the reaction between the ions and the embedded reinforcing steel generates tensile stress that produces cracks and degenerate to concrete spalling.

Although the passive film on the reinforcing steel protects concrete against corrosion, reinforced concrete structure exposed to moist area are liable to corrode especially, at the presence of carbon dioxide and chloride ion (Egba *et al*., 2016). Nevertheless, the initiation and progress of corrosion depends of numerous factors (Song *et al*., 2004). The dependency of reinforced concrete corrosion activity on several factors makes the analysis of corrosion of reinforcing steel in concrete a complex task. Be that as it may, the study of the influence of the numerous factors on reinforced concrete corrosion could boost the knowledge of concrete deterioration.

Accordingly, researchers across the globe have made enormous contributions to concrete corrosion investigation and its associated challenges. Such challenges comprise of the following namely;

1. The complexity of the mechanism of diffusion of carbon dioxide, and chloride ion through reinforced concrete, including the effect of the oxide and ion on the concrete(Ismail *et al*. 2008, Jang *et al*. 2011, Park *et al*. 2012, Muthulingam and Rao 2015).
2. The intricate task of forecasting corrosion initiation time, corrosion rate, including the analysis of corrosion propagation process ((Mao *et al.*, 2015; Yu and Caseres, 2012).
3. The rigorous process of the development of reliable corrosion sensors is a challenge also (Yu and Caseres 2012, Mao *et al*. 2015).

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4. The complicate nature of the study of influence of corrosion on mechanical, and modal properties of reinforced concrete structures (Song and Yu 2015, Zhu, François *et al*. 2015, Bazán, Cobo *et al*. 2016, Ghanooni-Bagha, Shayanfar et al. 2016).
5. The challenge encountered in the study of concrete corrosion repair and inhibition (Abdulrahman and Ismail, 2011).
6. The influence of the environmental parameters on concrete corrosion is another pressing challenge (Hu *et al.*, 2015; Huet *et al.*, 2007; Trocónis de Rincón *et al.*, 2007).

Environmental parameters such as temperature, relative humidity, sunshine, rainfall, wind, and air content affect functional capability of concrete (Egba *et al*., 2017). Daily and seasonal fluctuations of the environmental parameters have been identified as part of the major causes of concrete corrosion, deterioration, and service life reduction of concrete structures (Alhozaimy *et al.*, 2012; Lyons *et al.*, 2005; Nguyen *et al.*, 2009; Oh and Jang, 2007; 2005; Xia *et al.*, 2006). Furthermore, the findings of the study conducted by Haque *et al.*, (2007) on design of durable concrete structures in reference to climate zones indicates the necessity of proper characterization of environmental parameters in the natural climate, and concrete microenvironment based on climate zones.

On the other hand, past studies indicate that researchers have always used the pull-out test for experimental determination of bond strength of concrete during concrete behavior evaluation (Bhargava *et al*., 2007). Nevertheless, limited number of literature exists on the impact of climate on bond strength degradation of concrete due to corrosion effect. Therefore, this present paper seeks to describe the effects of climate of the tropical rainforest on bond degradation of reinforced concrete.

MATERIALS AND METHOD

Materials that were in conformity to the quality standard requirements were sourced, and used in the research. The materials were as follows, namely: cement, fine aggregate, coarse aggregate, reinforcing steel bar, water, and salt.

Specimen Preparation

The materials for the concrete were itemized and presented in Table 1. One batch of concrete with 0.6 w/c was prepared. The concrete mix contains sodium chloride (NaCl) to assist in acceleration of corrosion. Sixty-three numbers of 100 mm3 concrete cubes were used for the study. They were cast into moulds, demoulded after 24 hours and cured in 3.5% NaCl water solution for 28 days before subjecting them to exposure conditions.

TABLE 1: Quantity of materials for concrete production

Material	Quantity (Kgm^{-3})
Cement	350
River sand	717.6
Crushed granite	1122.4
Water	210
Sodium chloride	3.5

Specimen Exposure

The specimens were subjected to five different exposure conditions. They include, namely:

1. Laboratory environmental condition at ambient temperature of 24 ± 2 ℃, and relative humidity of 55 ± 5%, denoted by the notation 'NBL-Pull'.
2. Wet and dry alternate cycle process, 7 days in 3.5 % sodium chloride solution by weight of water, plus 7 days of sheltered natural environment exposure, denoted by the notation 'NBP_s-Pull'.
3. Wet and dry alternate cycle process, 7 days in 3.5 % sodium chloride solution by weight of water, plus 7 days of unsheltered natural environment exposure, denoted by the notation 'NBP_u-Pull'.
4. Unsheltered natural environment, denoted by the notation 'NBU-Pull'.

Sheltered natural environment, denoted by the notation ‘NBS-Pull’.

Data Mining

The direct tension pull-out test was conducted using the Dartec M9500 Universal Testing Machine as shown in Figure 1. The test was designed to determine the coupled effect of corrosion of reinforcing bar and exposure condition on the bond strength at the interface of concrete and the reinforcing steel. The test conformed to the specification of ASTM C-234:91, except there was no bond breaker at the bar end.

FIGURE 1. Experimentation setup for direct tension pull-out test

The bond force got from the test was converted to bond stress, using equation 1.

$$b = \frac{P}{\pi \times D \times L} \tag{1}$$

Where b = bond stress MPa, P = load gauge reading attaching with jack N, L = length of steel embedded into the concrete mm, and D = diameter of embedded steel mm.

RESULTS AND DISCUSSIONS

The results of pull-out load as a function of displacement for the concrete specimens are presented in Figure 2 to show changes of the pull-out load due to exposure condition.

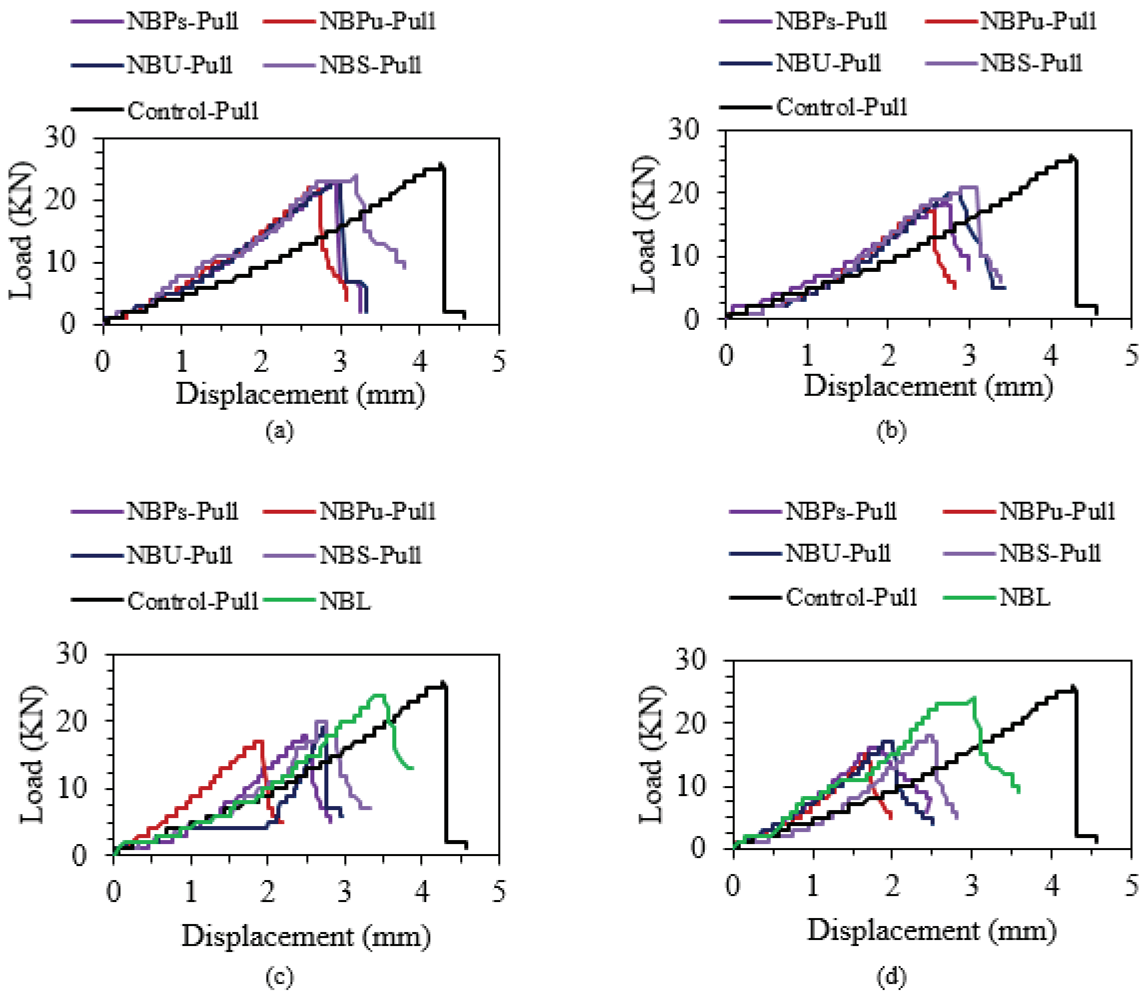

FIGURE 2. Pull-out load as a function of displacement: (a) 3 months exposure, (b) 6 months exposure, (c) 9 months exposure, (d) 12 months exposure

The results show that the pull-out load of the concrete specimens vary with exposure condition. The finding indicates that after three months of specimen exposure to different conditions, the pull-out load for the NBPu specimen was reduced by 12% compared to the control specimen. The NBPs and NBU specimens have pull-out load reduction of 8% each from the control specimen. The NBS specimen has pull-out load reduction of 4%. However, there was no reduction of pull-out load for the NBL specimen.

Also, after six months of specimen exposure to different conditions, the pull-out load for the NBPu specimen was reduced by 28% compared to the control specimen. The NBPs and NBU specimens have pull-out load reduction of 24% and 20% respectively from the control specimen. The NBS specimen has pull-out load reduction of 16%. However, there was no reduction of pull-out load for the NBL specimen.

In addition, after nine months of specimen exposure to different conditions, the pull-out load for the NBPu specimen was reduced by 32% compared to the control specimen. The NBPs and NBU specimens have pull-out load reduction of 28% and 24% respectively from the control specimen. The NBS specimen has pull-out load reduction of 20%. However, there was 4% reduction of pull-out load for the NBL specimen compared to the control specimen.

Furthermore, after twelve months of specimen exposure to different conditions, the pull-out load for the NBPu specimen was reduced by 40% compared to the control specimen. The NBPs and NBU specimens have pull-out load reduction of 36% and 32% respectively from the control specimen. The NBS specimen has pull-out load reduction of 28%. However, there was 8% reduction of pull-out load for the NBL specimen compared to the control specimen.

On the other hand, the finding indicates that for the NBPu specimen, the pull-out load reduced at the ratio of 1.00:0.88:0.72:0.68:0.60 for 0, 3, 6, 9, and 12 months of exposure duration respectively. Also, the NBPs shows a pull-out load reduction at the ratio of 1.00:0.92:0.76:0.72:0.64 for 0, 3, 6, 9, and 12 months of exposure duration respectively. In addition, the NBU shows a pull-out load reduction at the ratio of 1.00:0.92:0.80:0.76:0.68 for 0, 3, 6, 9, and 12 months of exposure duration respectively. Furthermore, for the NBS specimen, there was a pull-out load reduction at the ratio of 1.00:0.96:0.84:0.80:0.72 for 0, 3, 6, 9, and 12 months of exposure duration respectively.

The results show that corrosion reduces the interlocking bond between the bar and the adjacent concrete. The finding is in line with the submission of other researchers (Al-Sulaimani *et al*., 1990; Cabrera, 1996; Bhargava *et al*., 2007). Also, the findings indicate that exposure condition and climate environment influence corrosion-induced reduction of the interlocking bond between reinforcing bar and the adjacent concrete. The result supports the findings of Oh and Jang (2007), Haque (2007), Alhozaimy *et al*., (2012).

In the same way, bond strength of concrete specimens at different exposure conditions and duration is presented in Table 2.

TABLE 2: Bond strength of concrete specimens at different exposure conditions

Duration (months)	NBPu (MPa)	NBPs (MPa)	NBU (MPa)	NBS (MPa)	NBL (MPa)
0	12.63	12.63	12.63	12.63	12.63
3	11.11	11.62	11.62	12.12	12.63
6	9.09	9.60	10.10	10.61	12.63
9	8.59	9.09	9.60	10.10	12.12
12	7.58	8.08	8.59	9.09	11.62

The results show that the NBPu, NBPs, NBU, NBS and NBL specimens lost bond strength by 40%, 36%, 32%, 28% and 8% after twelve months of subjection to exposure conditions respectively. The results indicate that corrosion decreases the bond strength of concrete as suggested by other researchers (Almusallam *et al*., 1996; Fu and Chung, 1997; Chung *et al*., 2004). Also, corrosion influence on the bond strength of concrete under exposure conditions and natural climate is time dependent. The result supports the findings of other researchers (Fang *et al*., 2004).

CONCLUSION

The effects of the climate environment and corrosion of steel on concrete behaviour were discussed in the paper. One batch of chloride infested concrete with 0.0 w/c was prepared. The concrete mix contains sodium chloride to assist in acceleration of corrosion. Sixty-three numbers of 100 mm^3concrete cubes were used for the study. They were cast into moulds, demoulded after 24 hours and cured in 3.5% NaCl water solution for 28 days before subjecting them to exposure conditions. Pull-out tests were conducted at time intervals for one year to measure the impact of exposure condition and corrosion on bond strength of concrete. The results show reduction of bond strength of concrete by 32%, 28% and 8% after one year of subjection of the specimens to the unsheltered natural climate, sheltered natural climate, and laboratory ambient environment respectively. The findings indicate that the climate influences corrosion, which reduces the interlocking bond between the reinforcing bar and the adjacent concrete.

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