Advanced Materials Research Vol. 95 (2010) pp 69-72
© (2010) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.95.69

Influence of the Interfacial Transition Zone Properties on Chloride Corrosion in Reinforced Concrete-Characterization of ITZ

Amit Kenny[1, a], Amnon Katz[1,b]

[1]National Building Research Institute, Department of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa, Israel

[a]amitk@tx.technion.ac.il, [b]akatz@tx.technion.ac.il

Keywords: Corrosion, Concrete, Interfacial Transition Zone.

Abstract

Large part of life cycle cost of reinforced concrete structures, especially infrastructures, is maintenance costs, where steel corrosion induced by chlorides is the major part [1, 2]. Normally, concrete provides the reinforcing steel an environment that preserves it in its passive state. High chloride concentration in the vicinity of the steel can lead, however, to steel activation [3]. The chloride threshold for steel activation was found to be significantly different in variety of the closely related environments of concretes, mortars, and simulated pore solution. In concretes and mortars the chloride threshold was found to be significantly higher than that in simulated pore solutions [4].
Two parameters can be the underlying mechanism for this observation: 1. Concrete chemistry is different than that of the paste and common simulated pore solutions, or 2. the micro-structure of the concrete-steel interface is different [5, 6].
Soluble silicate ions in the pore solution, which may arise from the cement, pozzolans or aggregates, also influence the chloride threshold. Several studies showed that the passivation film formed in the presence of dissolved silicate is significantly different from that created in its absence. Hence, chemical differences in concrete composition, especially in the presence of pozzolans, can influence the chloride threshold [7-10].
Localized corrosion is explained by a mechanism of local concentration polarization across a pit or crevice. This mechanism is closely related to the local geometry. Thus, the micro-structure of concrete-steel interface may influence the levels at which concentration polarization occurs, thus affecting the chloride threshold and the localized corrosion development. Results from various studies on concrete reinforcement corrosion, support the model that explains localized corrosion by concentration polarization [11].
In this work, the concrete-steel interfacial transition zone (ITZ) is quantitatively characterized from back scattered electron microscopy images and pullout test, and is used for correlation with chloride threshold. A series of different concretes with different ITZ structure in the concrete-steel interface have been prepared. for each mix, specimens prepared for corrosion experiment, ITZ characterization, and pullout test.
Corrosion experiment for chloride threshold is performed by unidirectional diffusion and capillary suction of 6% NaCl solution. Steel activation is monitored by half cell potential measurement; potential measurement of the tested bar against a second bar, located farther from the NaCl solution, as an internal reference; and electrochemical impedance spectroscopy (EIS). When steel activation is observed, the concrete is drilled at the bar depth for chloride analysis.
The method for quantification of the ITZ by image analysis is composed of three stages: image acquisition by SEM (Scanning Electron Microscope) on BEI (Backscattered Electron Image) mode, image classification into phases, and ITZ character quantification.
Image classification is done by transforming the image, which contain only a scalar for any pixel, into multi-dimensional image, which contain a vector of properties scalar for any pixel. Transformation into multi-dimensional image is accomplished by filtering through various filters, to

calculate pixel neighborhood parameters as average and texture. Than the Mean-Shift algorithm [12] is used for unsupervised image clustering, followed by classifying the clusters into physical phases.

ITZ characters quantified are: ITZ thickness, and average and maximum of the minimal distance between steel and concrete for every pixel on the steel perimeter. In this work, ITZ thickness is defined by two separate algorithms: 1. the distance from the steel where porosity sharply decline, and 2. the distance from the steel where the porosity decreases to the average porosity 300 micrometers away from the steel surface. Minimal distance between steel and concrete is defined for any pixel on the steel surface as the closest solid concrete pixel.

Pullout test is used for physical-performance characterization of the ITZ. Those physical characteristics are: slop at the linear region, bonding strength, maximum stress, and de-bonding energy.

Not enough data obtained so far, for chloride ITZ relationship determination. Thus, this paper deals with the ITZ characterization and its relationship with the concrete mix properties.

Because, no standard method exists for ITZ measurements and characterization, correlation between characters of the ITZ as obtained by the different methods listed above is needed in order to establish confidence. Low co-linearity between methods can result from: high variation of the ITZ among specimens from the same mix, nonlinear relationship, method inaccuracy, method measure different and unrelated characters, or the measured parameter is not a representative characteristic of the ITZ.

Parameters of the minimum distances between steel and concrete were found to correlate with each other. Those parameters were found to be better correlated for vertical bars, while for the horizontal bars, ITZ thicknesses are better correlated. A combination of the different nature of the ITZ around vertical and horizontal bar with miss-classification of some pixels seems to be the cause for that.

Typical measurements of ITZ thickness are 40 micrometer for vertical bars and 400 micrometer for horizontal ones. Typical maximum distances between steel and concrete are 12 micrometer for vertical bars and 25 micrometer for horizontal ones.

Pullout test results per-se do not correlate due to scattered results. The averages of the results per mix are correlated. These results are better correlated when horizontal and vertical bars are dealt separately. Vertical bars properties are less correlated than the horizontals. The maximum stress during pullout of vertical bars is negatively correlated with the ITZ thickness, and the bonding strength is negatively correlated with the maximum porosity of the ITZ. The maximum stress of horizontal bars is negatively correlated with the ITZ thickness, as well as the bonding strength, and the measurement of the thickness by porosity drop yielded the best correlation. De-bonding energy, on the other hand, is positively correlated with parameters of minimum distance between steel and concrete, and with the ITZ thickness as measured by the average porosity method. Plotting relationships like ITZ thickness (porosity drop method) vs. maximum stress for all specimens demonstrate a relationship which is not linear (Figure 1).

Mix properties influence on ITZ is highly bar orientation depended. For vertical bars, linear correlation with the mix properties is weak. A positive correlation can be found between the slump to the maximum of average distance between concrete and steel, and maximum porosity. This contrasts a reasonable assumption that higher slump will cause better consolidation around the rebar and will result in a denser ITZ. The variability of ITZ around a single bar, as represented by the maximum of the standard deviations of the distances between concrete and steel, increases as the bleeding duration increases. Other ITZ properties have some correlation with the bleeding duration as well. It may indicate some un-measured rheological properties of the fresh concrete, which influence the ITZ formation. Increase of powder content seems to reduce the maximum porosity around vertical bars.

The energy absorbed during pullout is the only parameter that is well correlated with the mix properties for vertical bars. The w/c ratio, total bleeding, and bleeding rate contribute to increase the bonding energy of the vertical bars, while tend to decrease the bonding strength for horizontal bars as those properties increase. This result could be an indication for ITZ structure formation mechanism around vertical bars, which creates a microstructure that influences the fracture mechanism.

For horizontal bars, the mix properties that best correlate with ITZ parameters are: powder content and water content, for the maximum ITZ thickness; and total bleeding, bleeding rate, and water content, for the average ITZ thickness. It can be inferred that raising both powder content and water content make the ITZ smaller. Powder content found to increase the average of the maximum porosity, but not to increase the maximum value itself. That means more evenly distributed porosity around the rebar when powder content is high. Water content is, commonly, associated with higher bleeding, which was found to make the ITZ thicker, but no correlation between water content and bleeding was found in the current work. Bleeding rate and total bleeding are highly correlated with the ITZ. Both found to increase the ITZ thickness. Water to cement ratio is somewhat correlated with the average of the ITZ thickness. That can be a result of negative correlation of the water to cement ratio with the powders content.

Pullout parameters of horizontal bars are well correlated with mix properties. The only pullout parameter, which dose not correlate well with mix properties, is the de-bonding energy. The mix properties which are correlated with the pullout parameters are: total bleeding, bleeding rate, w/c ratio, and powders content. The water content found to have no correlation with all pullout parameters.

The bleeding properties, total bleeding and bleeding rate, are unsurprisingly correlated as could be predicted by bleeding water lens formation phenomenon [5, 13], and as found by using image analysis. Water to cement ratio, is well correlated with the pullout parameters, as could be predicted, because it influences both concrete strength and bleeding. Powder content has lower linear correlation with the pullout parameters, compared with w/c ratio.

Considering observations of other researchers, which emphasized the importance of voids at the steel bar-concrete interface [5, 6], a pronounced difference of chloride threshold is expected for vertical bars, relatively to horizontal, and among horizontal bars. The factor influencing the ITZ thickness around, or more accurately below, horizontal bars is the water bleeding. In practical use, the considered bleeding is the total bleeding below the bar, not the mix bleeding per-se, as was demonstrated by results of pullout tests [14]. It can be concluded that reducing water to powder ratio will reduce bleeding and consequently the ITZ thickness below horizontal bars, which is expected to increase chloride threshold and corrosion resistance.

References

[1] R.G. Pillai, D. Trejo, Surface condition effects on critical chloride threshold of steel reinforcement; ACI Material Journal March-April (2005) 103-109

[2] K. Thangavel, The treshold limit for chloride corrosion of reinforced concrete. Corrosion Reviews 22, 1 (2004) p. 55

[3] V.S. Ramachandran, Corrosion investigation in reinforced concrete, Handbook of analytical techniques in concrete science and technology, (1999) p. 443

[4] C. Alonso, C. Andrade, M. Castellote and P. Castro, Chloride threshold values to depassovate reinforcing bars embedded in a standardized OPC mortar. Cement and Conc. Res. 30 (2000) p. 1047

[5] T.U. Mohammed, H. Hamada, A discussion of the paper "chloride threshold values to depassivate reinforcing bars embedded in a standardized OPC mortar" by C. Alonso, C. Andrade, M. Castellote, and P. Castro; Cement and Concrete Research 31 (2001) 835-838

[6] G.K. Glass, B. Reddy, The Influence of the Steel Concrete Interface on the Risk of Chloride Induced Corrosion Initiation; Luxembourgh : University of Applied Sciences. - In: Corrosion of Steel in Reinforced Concrete Structures, COST 521, Final Workshop, Luxembourgh, 18-19 February (2002), Weydert, R. (Ed.), S. 227-232

[7] S.T.Amaral, E.M.A. Martini, I.L. Müller, An attempt of experimental separation of the potentiodynamic anodic peaks of iron in alkaline solutions and application of the ohmic model for passive film growth; Corrosion Science 43 (2001) 853-879

[8] V. Deodeshmukh, A. Venugopal, D. Chandra, A. Yilmaz, J. Daemen, D.A. Jones, S. Lea, M. Engelhard, X-ray photoelectron spectroscopic analyses of corrosion products formed on rock bolt

carbon steel in chloride media with bicarbonate and silicate ions, Corrosion Science 46 (2004) 2629–2649

[9] Kawamura M., D. Singhal, Y. Tsuji, Effects of interfacial transition zone around reinforcement on its corrosion in mortars with and without a reactive aggregate; Proceeding of the international RILEM conference No. 35 The interfacial zone in cementitious composites (1998) 179-186

[10] Montemor M.F., A.M.P. Simões, M.G.S. Ferreira, Analytical characterization of the passive film formed on steel in solutions simulating the concrete interstitial electrolyte; Corrosion 54, 5 (1998) 347-353

[11] Galvele, Jose R., Transport Processes and the Mechanism of Pitting of Metals, J. Electrichem. Soc. Vol. 123, No. 4, (1976) 464-474

[12] Georgescu, B., I. Shimshoni, P. Meer, 2003, Mean shift based clustering in high dimensions: A texture classification example, Proceedings of the IEEE International Conference on Computer Vision, Volume 1, (2003), Pages 456-463

[13] W. Zhu, M. Sonebi and P. J. M. Bartos, Bond and interfacial properties of reinforcement in selfcompacting concrete, Materials and Structures, Vol. 37, August-September (2004), pp 442-448

[14] P.L. Domone, A review of the hardened mechanical properties of self-compacting concrete, Cement & Concrete Composites 29 (2007) 1–12

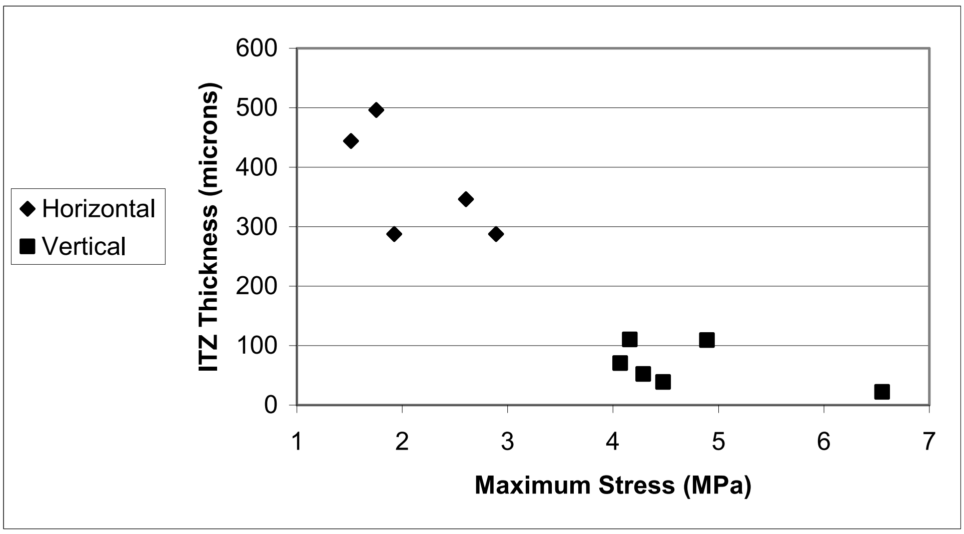

Figure 1 – Maximum stress versus ITZ thickness as measured using the gradient method