BOND STRENGTH OF CORRODED HIGH YIELD STEEL BARS EMBEDDED IN NORMAL STRENGTH CONCRETE

THOMAS TAN

THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTER OF ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITY MALAYSIA SABAH
2019

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Disahkan Oleh,

THOMAS TAN
MK1521020T

(Tandatangan Pustakawan)

Tarikh : 10th September 2019

(Prof. Ir. Dr. Abdul Karim Mirasa)
Penyelia Utama

(Dr. Ahmad Nurfaidhi Rizalman)
Penyelia Bersama

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I declare that this thesis submitted to the University Malaysia Sabah, in fulfillment for the degree of Master of Engineering (MEng) in Civil Engineering. This thesis has not been submitted, to any others university for any degrees. I also certify that this works described herein entirely is my own, except for equations, quotations and references as the sources have been duly acknowledged and this thesis may be available within the university library and can be photocopied or loaned to other libraries for purposes of consultation.

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THOMAS TAN
MK1521020T

CERTIFICATION

NAME : **THOMAS TAN**

MATRIX NO : **MK1521020T**

TITLE : **BOND STRENGTH OF CORRODED HIGH YIELD STEEL BARS EMBEDDED IN NORMAL STRENGTH CONCRETE**

DEGREE : **MASTER OF ENGINEERING (CIVIL ENGINEERING)**

VIVA-VOCE : **25th JULY 2019**

CERTIFIED BY:

1. MAIN SUPERVISOR
Professor Ir Dr Abdul Karim bin Mirasa — Signature

2. CO-SUPERVISOR
Dr Ahmad Nurfaidhi bin Rizalman — Signature

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to my main supervisor Professor Ir. Dr. Abdul Karim bin Mirasa without his expertise and his guidance are provided, I would not have been able to complete this study. I would like to thanks to my co-supervisor Dr. Ahmad Nurfaidhi bin Rizalman for his insight, expertise, and valuable comments while reviewing this thesis.

I am so gratefully and would like to acknowledge the generous support I received from the University Malaysia Sabah and the Government of Public Works Department Sabah for their assistance in completed my study in their Laboratory, without such support I could not complete this thesis: Professor Ir. Dr. Abdul Karim bin Mirasa of University Malaysia Sabah, Faculty Engineering (Dean) and Datuk Ir Hj. Amrullah bin Hj. Kamal (Director) and Mr. Vyner Sikodol (Chief Assistant Director) of Public Works Department Sabah.

I would like to express my appreciations to Mr. Ismail bin Usop (Assistant Engineer) of Public Works Department Sabah, Material Testing Laboratory Kota Kinabalu and staffs of University Malaysia Sabah, for their advice and technical support throughout my experiments program. In addition, my deepest appreciations to Mr. Chia Min Kong (Contractor), Mr. Jamealy bin Abdullah (Contractor), Mr. Vun Soo Kong, Director of Pemborong Seri Jindo and Mr. Tan Kia Hong, Operation Manager of Kontraktor Fokus Niaga Sdn. Bhd. who helped throughout the completion of this works both physically and technically with my analytical works and emotions throughout the whole process.

Finally, I would like to give my deepest heartfelt thanks to Madam Angielina David, Miss Vivilen Langsi, Miss Stella Myfey John, Miss Danielle Myfey John, and my family for their constants support and encouragement.

THOMAS TAN
10th September 2019

ABSTRACT

Strength and performance of reinforced-concrete depend on the good bond strength, between high yield steel bars and concrete, and the effects of corrosion on high yield steel bars in a range of 12 mm, 16 mm and 25 mm diameter reinforced the concrete for its bond strength and are debated endlessly on-site. To investigate the effects of corrosion on the bond strength between the high yield steel bars and concrete, 36 specimens of tensile test, 72 specimens of pullout test and 12 specimens of flexural test conducted. Descriptions of specimen data taken an average of three reading for tensile test and pullout test except for flexural test, uncorroded as control specimen and corroded as a final specimen. High yield steel bars ranges from 12 mm, 16 mm and 25 mm diameter 600 mm long used for tensile test, high yield steel bars ranges 12 mm, 16 mm and 25 mm diameter 800 mm long used as reinforcement bars and embedded vertically in a concrete mold 150 mm x 150 mm x 150 mm concrete grade 20 and concrete grade 30 for pullout test and 1500 mm x 150 mm x 200 mm beam concrete grade 20 for the flexural test. Results show, weight of high yield steel bars reduced by 0.13%, 0.07% and 0.02%, area reduced by 0.13%, 0.07% and 0.02% on 8 months and 12 months reduced by 0.13%, 0.04%, and 0.03%, the area reduced by 0.12%, 0.04% and 0.03% for high yield steel bars 12 mm, 16 mm and 25 mm diameter for the tensile test. The weight of high yield steel bars reduced by 0.14%, 0.05%, and 0.02%, area reduced by 0.13%, 0.06%, and 0.02% on 8 months and 12 months for high yield steel bars 12 mm, 16 mm and 25 mm diameter for pullout test concrete grade 20 and concrete 30. Weight of high yield steel bars reduced by 0.08%, 0.05% and 0.01%, area reduced by 0.08%, 0.04% and 0.01% for 8 months and 12 months for the high yield steel bars 12 mm, 16 mm and 25 mm diameter for flexural test concrete grade 20. Weight and area of high yield steel bar 12 mm, 16 mm and 25 mm diameter unchanged for the 4 months for pullout test concrete grade 20 and concrete grade 30, and flexural test concrete grade 20. In sum, the researcher discovered the uncleaned corrosion on high yield steel bars surface influences the bond strength on 4 months of corrosion and the cleaned corrosion on the high yield steel bars surface did not influence the bond strength on the 8 months and 12 months of corrosion for pullout test and flexural test conducted.

ABSTRAK
KEKUATAN IKATAN BESI WAJA BERKARAT DI TANAM DALAM KEKUATAN KONKRIT BIASA

Kekuatan dan prestasi konkrit bertetulang bergantung kepada kekuatan ikatan yang sempurna antara besi waja dan konkrit. Kesan karat pada besi waja bersaiz 12 mm, 16 mm, 25 mm untuk tetulang pada konkrit selalu menjadi perbahasan ditapak bina. Penyiasatan terhadap kesan karat pada kekuatan besi waja dan konkrit bertetulang, sebanyak 36 spesimen untuk ujian regangan, 72 spesimen untuk ujian tarik keluar dan 12 spesimen untuk ujian lenturan telah dilaksanakan. Keterangan data daripada spesimen diambil berdasarkan purata daripada tiga bacaan untuk ujian regangan dan ujian tarik keluar kecuali ujian lenturan. Besi waja tidak berkarat digunakan sebagai spesimen rujukan ujian, manakala besi waja berkarat diuji untuk dapatan perbezaan kekuatan ikatan antara besi waja dan konkrit untuk diperbandingkan. Besi waja saiz 12 mm, 16 mm dan 25 mm 600 mm panjang digunakan untuk ujian regangan. Besi waja saiz 12 mm, 16 mm dan 25 mm 800 mm panjang digunakan sebagai tetulang konkrit dengan kaedah diletak menegak dalam acuan 150 mm x 150 mm x 150 mm berkonkritkan gred 20 dan 30 untuk ujian tarik keluar. Besi waja saiz 12 mm, 16 mm dan 25 mm 1400 mm panjang digunakan sebagai tetulang konkrit gelagar 1500 mm x 150 mm x 200 mm gred 20 di dalam ujian lenturan. Keputusan ujian menunjukkan, berat besi waja menurun 0.13%, 0.07% dan 0.02%, ukurlilit menurun 0.13%, 0.07% dan 0.02% pada 8 bulan dan pada 12 bulan berat besi waja menurun 0.13%, 0.04% dan 0.03%, ukurlilit menurun 0.12%, 0.04% dan 0.03% pada besi waja saiz 12 mm, 16 mm and 25 mm untuk ujian regangan. Pada 8 bulan dan 12 bulan berat besi waja menurun 0.14%, 0.05% dan 0.02%, ukurlilit menurun 0.13%, 0.06% dan 0.02% pada besi waja saiz 12 mm, 16 mm and 25 mm untuk ujian tarik keluar pada konkrit gred 20 dan konkrit gred 30. Pada 8 bulan dan 12 bulan berat besi waja menurun 0.08%, 0.05% dan 0.01%, ukurlilit menurun 0.08%, 0.04% dan 0.01% pada besi waja saiz 12 mm, 16 mm dan 25 mm untuk ujian lenturan konkrit gred 20. Pada 4 bulan, berat dan ukurlilit besi waja bersaiz 12 mm, 16 mm dan 25 mm tidak berubah, digunakan di dalam ujian tarik keluar konkrit gred 20 dan konkrit gred 30, dan ujian lenturan konkrit gred 20. Kajian menunjukkan karatan yang tidak dibersihkan pada permukaan besi waja mempengaruhi kekuatan di dalam ikatan antara besi waja dan konkrit pada 4 bulan tetapi tidak mempengaruhi kekuatan dalam ikatan antara besi waja dan konkrit pada 8 bulan dan 12 bulan pengkaratan setelah karatan dibersihkan pada permukaan besi waja.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

CHAPTER 2: LITERATURE REVIEW

CHAPTER 3: METHODOLOGY 66

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

°	-	Degree
Ø	-	Diameter
ℓ	-	litres
%	-	Percentage
±	-	Plus or Minus
ε	-	Strain
σ	-	Stress
μm	-	micrometer or micron

LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
MS	-	Malaysian Standard
N/mm^2	-	Newton millimetre square
N	-	Newton
mN	-	milliNewton
kN	-	KiloNewton
MN	-	MegaNewton
Mm	-	millimetre
mm^2	-	millimetre square
mm^3	-	millimetre cubic
mm/s	-	millimetre per second
m^2	-	meter square
m^3	-	meter cubic
kg	-	Kilogram
ft^2	-	feet square
ft^3	-	feet cubic
F	-	Fahrenheit
C	-	Celsius
hy	-	high yield
hysb	-	high yield steel bar

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Introduction

One of the most significant currents of discussions is regarding the corrosion of the high yield steel bars. Corrosion of high yield steel bars are commons problem faced by contractors and constructors, and becoming increasingly difficult and sometimes been ignored in practices of keeping the material in the construction site. High yield steel bars are common material characterized by iron and an important component that reinforces the concrete for better and stronger bond strength. The corrosion of the high yield steel bars becomes an issue in a structural buildings industry for past developments. Corrosion of high yield steel bars has been thoughts of the factors in giving bad bond strength to reinforces the concrete, and which is most widely used in a constructions development industry. Corrosion of high yield steel bars occurs because it is placed on the ground and expose to weathers for the long periods of time, presented in Figure 1.1 and Figure 1.2 respectively.

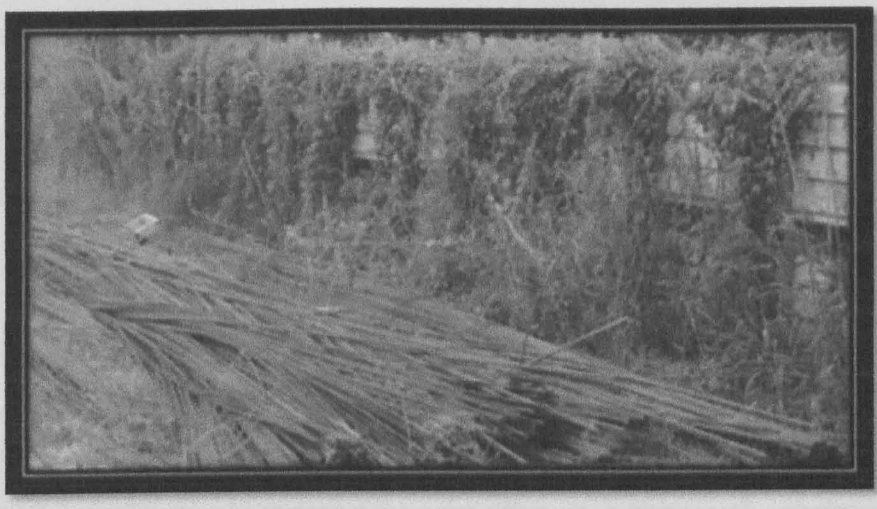

Figure 1.1: Corroded High Yield Steel Bars laid on the Ground

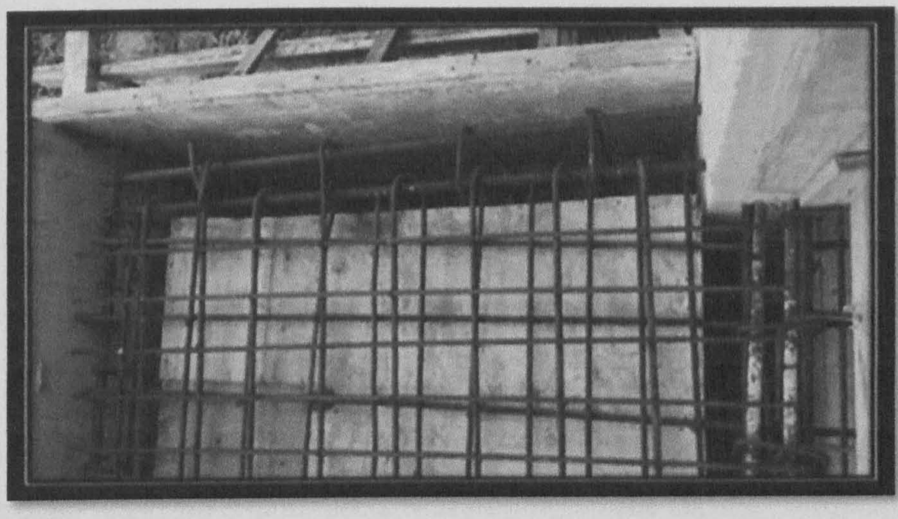

Figure 1.2: Corroded Reinforcement

High yield steel bars, one of the most common and useful materials used to reinforces the concrete in the structural constructions, and it has one major flaw, it corrodes when exposed to oxygen and water. High yield steel bars are most highly manufactured by man-made materials and its subject to corrosion as it is was made almost entirely of iron in its production respectively.

Mechanism of the corrosion occurs when iron (Fe) surface undergoes simple changes as following:

a. First, ($Fe \rightarrow Fe^{n+}$ + n electrons) iron atoms lose some of the electrons and become a positively charged ion, and allow it to bond with another group of the negatively charged atom. The negatively charged atoms combined with electrons and the specimens (high yield steel bars) produce the first rusting reaction (Malaysia Steel Industry).

b. Second, the reaction involves oxygen (O_2) and water (H_2O) or ($O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$) to give a variant of iron oxide to rusted the wet iron (Malaysian Steel Industry).

$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2$

Iron (High Yield Steel Bars) + Oxygen + Water → Iron Hydroxide dissolved in it.

Oxygen dissolves in water and reacts with Iron Hydroxide caused Corrode.

$4Fe(OH)_2 + O_2 \rightarrow 2H_2O + 2Fe_2O_3H_2O$

Iron Hydroxide + Oxygen → Water + Hydrated Iron Oxide (Brown color corrode). (Malaysian Steel Industry).

In this study, high yield steel bars reinforced concrete cubes 150 mm X 150 mm X 150 mm dependent on bar's sizes, concrete covers, and position of high yield steel bars. Its mechanism allowed the anchorage positions and composites actioned which reacts when concrete cube pulled out from high yield steel bar, which causes slips and cracks during the process to separates both of the specimens. High yield steel bars reinforce the concrete beams 1500 mm X 150 mm X 200 mm dependent on bar's sizes, concrete covers, spacing and positions between high yield steel bars and stirrups. Its mechanism allowed the anchorages of the horizontal, parallel and vertical positions of high yield steel bars reinforced concrete for its bond strength, and it also allowed composites action reacts when the loads applied to the concrete beam during flexing respectively.

1.2 Problem Statement

It has been discussed regarding corrosion of the high yield steel bars by contractors and constructors that confused and uncertainty, how corrosion can affects the bond strength between corroded high yield steel bars and concrete. However, there are little attentions has been paid to prevents corrosion for the unstable practicals ways of keeping high yield steel bars. In Sandakan, most of high yield steel bars that are used in the construction abandoned for months and hence, the high yield steel bars exposures to weathers pore to the corrosion and moreover, contractors also tend to purchases corroded steel bars without knowing the actuals strength and therefore, the researcher focuses on the tensile strength and the bond strength respectively.

The critical of the study is to investigate and reveal the finding on high yield steel bars strength on its tensile strength and bond strength between the high yield steel bars and concrete for pullout strength and flexural strength of uncorroded and corroded high yield steel bars which corrosion is uncleaned and cleaned on surfaces of high yield steel bars might be. The limitation of this production for the specimens are all high yield steel bars are new and come in a bundle of each size ranges from 8 mm ø, 12 mm ø, 16 mm ø and 25 mm ø. The brand new high yield steel bars cut 600 mm length of 12 mm ø, 16 mm ø and 25 mm ø, 800 mm length of 12 mm ø, 16 mm ø and 25 mm ø, 1400 mm length of 12 mm ø, 16 mm ø and 25 mm ø and 500 mm length of 8 mm ø mild steel for stirrups of 100 mm X 150 mm X 100 mm X 150 mm which tie with the 1400 mm long high yield steel bars then kept above the ground level of 76 cm under the shed for corrosion process respectively.

1.3 Objectives

The aimed of this study is to investigate the tensile strength and the bond strength of the high yield steel bars that subjected to different periods of corrosion. In order to achieve the aims the following objectives are set:

Objective 1: To investigates high yield steel bars that exposed to weathers for 4 months, 8 months and 12 months of corrosion for the tensile strength.

Objective 2: To investigates high yield steel bars that exposed to weathers for 4 months, 8 months and 12 months corrosion, high yield steel bars embedded vertically in concrete cubes 150 mm X 150 mm X 150 mm for the pullout test.

REFERENCES

Abrishami, H.H. Mitchell, D., 1992. Simulation of uniform bond stress. ACI Mat. Jl 89(2): 161-168.

Adukpo, E. Oteng-Seifah, S. Manu, P. and Solomon-Ayeh K., 2010. The effect of steel reinforcement corrosion on tensile strength, bond strength and flexural strength. In: Barrett, P., Amaratunga, D., Haigh, R., Keraminiyage, K. and Pathirage, C., 2010. Eds. CIB 2010 World Congress, Salford, UK: 166-175.

Alengaram, UJ, Mahmud, H. and Jumaat, MZ, 2010. Comparison of mechanical and bond properties of oil palm kernel shell concrete with normal weight concrete, International Journal of the Physical Sciences 5(8): 1231-1239.

Alk. Apostolopoulos, T. Matikas, C.A. Apostolopoulos, G. Diamantogiannis, 2013. Pit corrosion examination of bare and embedded steel bar, in: 10th International Conference Advanced Metallic Materials and Technology, Saint Petersburg, Russia: 489-495.

Almusallam A.A., 2001. Effect of degree of corrosion on the properties of reinforcing steel bars, Construction and Building Materials, 15(8): 361-8.

Assaad, JJ & Issa, CA., 2012. Bond strength of epoxy-coated bars in underwater concrete, Construction and Building Materials, 30: 667-674.

Azizinamini, A. Pavel, R. Hatfield, E. and Ghosh, S.K., 1999. Behavior of spliced reinforcing bars embedded in high strength concrete. ACI Str Jl 96(5): 826-835.

Azizinamini, A. Darwin, D. Eligehausen, R. Pavel, R. and Ghosh, S.K., 1999. Proposed modification to ACI 318-95 tension development and lap splice for high strength concrete. ACI Str Jl 96(6): 922-926.

Azizinamini, A.Stark, M. Roller, J.J. and Ghosk, S.K., 1993. Bond performance of reinforcing bars embedded in high strength concrete. ACI Str Jl 90(5): 554-561.

American Concrete Institute (ACI) Committee 365. 2002. Service life prediction state of-art report. ACI 365. 1R-00 American Concrete Institute, Farmington Hills, MI, 44.

ASTM A615-16: Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement. West Conshohocken: ASTM International, 2016.

Bonacci J. and Marquez J., 1994. Tests of Yielding Anchorages under Monotonic Loadings. Journal of Structural Engineering 120(3): 987-997.

Broomfield and J., 1997. Corrosion of steel in concrete: understanding, investigating and repair, E&FN Spon, London, 264.

Cairns J., 1979. An Analysis of the Ultimate Strength of Lapped Joints of Compression Reinforcement. Magazine of Concrete Research 31(106): 19-27.

Cao, J & Chung, DDL., 2001. Degradation of the bond between concrete and steel under cyclic shear loading monitored by contact electrical resistance measurement, Cement and Concrete Research 31(4): 669-671.

C.A. Apostolopoulos, S. Demis, V.G. Papadaksi, 2013. Chloride-include corrosion of steel reinforcement-mechanical performance and pit depth analysis, Constr. Build. Mater. 38(9): 139-146.

C.A. Apostolopoulos and V.G. Papadakis, 2007. Consequences of steel corrosion on the ductility properties of reinforcement bar. Construction and Building Materials 22(2008): 2316-24.

Chana and P., 1990. A Test Method to Establish a Realistic Bond Stress. Magazine of Concrete Research 24(151): 83-90.

Chen, G., Hadi, M.N.S., Gao, D. and Zhao, L., 2015. Experimental study on the properties of corroded steel fibres. Construction and Building Materials 79: 165-172.

Coronelli D. and Gambarova P., 2004. Structural assessment of corroded reinforced concrete beams. Modelling guidelines Jl Struct Eng ASCE. 130(8): 1214-24.

Craig, R.R., ed. Mechanics of Materials. 1996, John Wiley & Sons: New York, NY, ISBN 0-471-50284-7

CEB-FIP Report., 2000. Bond of reinforcement in concrete: state of the art report. FIB Bulletin 10, Sw.

Darwin, D. Zuo, J. Tholen, M.L. and Idun, E.K., 1996. Development length criteria for conventional and high relative rib area reinforcing bars. ACI Str Jl 93(3): 347-359.

Dowling N. E, 1993. Mechanical Behaviour of Materials, Engineering Methods for Deformation, Fracture and Fatigue, Fourth Edition., Marcia J. H., Holly S., Scott D., Somnath B., Ashwitha J., Jayashree A. and Daniel S., Pearson Education Limited 2013, Edinburgh Gate, Harlow, Essex CM20 2JE, England: 190-225.

Eligehausen, R. Popov, E.G. Bertero, V.V., 1983. Local bond stress-slip relationships of deformed bars under generalized excitations. R.No.UCB/EERC 83/23,EERC, Berkeley.

Fang, C, Lundgren, K, Chen, L and Zhu, Ch., 2004. Corrosion influence on bond in reinforced concrete. Cement and Concrete Research 34(11): 2159-2167.

Ferguson, P.M. Breen, J.E. Thompson, J.N., 1966. Pull out tests on high strength reinforcing bars. ACI Jl T.No.62-55: 933-950.

Ferguson, P.M. Robert, I. Thompson J.N., 1962. Development length of high strength reinforcing bars in bond. ACI Jl T.No.59-17: 887-922.

Fernandez et al., 2016. Mechanical model to evaluate steel reinforcement corrosion effects on σ–ε and fatigue curve. Experimental calibration and validation 118: 320-333.

Francois, R., Khan, I. & Dang V.H., Mater Struct., 2013. Impact of corrosion on mechanical properties of steel embedded in 27-year-old corroded reinforced concrete beams. 46:899. doi: 10.1617/s11527-012-9941-z.

Foroughi, A, Dilmaghani, S and Famili, H., 2008. Bond reinforcement steel in self-compacting concrete, International Journal of Civil Engineering 6(1): 24-33.

Gambarova P.G., Rosati G.P., Zasso B., 1989. Steel-to-Concrete Bond after Concrete Splitting. Test Results. Materials and Structures 22: 35-47.

Goto and Y., 1971. Cracks formed in concrete around deformed bars in concrete. ACI Jl: 68(2): 244-251.

H. Kim, S. Tae, H. Lee, S. Lee, T Noguchi, 2009. Evaluation of mechanical performance of corroded reinforcement considering the surface shape. ISIJ Int. 49(9): 1392-1400.

H.S. Lee and Y.S. Cho, 2009. Evaluation of the mechanical properties of steel reinforcement embedded in concrete specimen as a function of the degree of reinforcement corrosion, Int. J. Fract. 157(1-2): 81-88.

H.S. Lee, F. Tomosawa, T. Noguchi, 1996. Effect of rebar corrosion on the structural performance of single reinforced beams C. Sjostrom (Ed.), Durability of Building Materials and Components vol. 1, E & FN Spon, London: 571-580.

Hadi, MNS, 2008. Bond of high strength concrete with high strength reinforcing steel. The Open Civil Jl 2: 143-147.

Hanjari K.Z., Kettil P., Lundgren K., 2011. Analysis of mechanical behaviour of corroded reinforced concrete structures. ACI Struct. Jl 108(5): 532-41.

Hansen, R.J. and Liepins, A.A., 1962. Behaviour of bond in dynamic loading. ACI Jl: 563-583.

Harajli, M.H. Hamad, B.S. and Rteil, A.A., 2004. Effect of confinement on bond strength between steel bars and concrete. ACI Struct. Jl 101(5): 595-603.

Higgins C. and Farrow III W.C., 2006. Tests of reinforced concrete beams with corrosion damaged stirrups. ACI Struct. Jl 103(1): 133-41.

https://en.wikipedia.org/wiki/Flexural-strength

https://www.google.com/imgres=httpFimage.thefabricator.com

https://theconstructor.orgcivilengineering/checkforfixingreinforcementinformworksofconcretestructuralmembers https://www.researchgate.net/figure/local-bond-stress-slip-law-FIB-2000_fig8_286916341

https://www.researchgate.net/figure/schematic-representation-of-the-electrochemical-process-of-chloride-induced-pitting-fig1_319664970

https://www.thefabricator.com/article/matelsmaterials/determining-the-flowstress-curve-with-yield-and-ultimate-tensile-strength-part-i

https://www.thewarren.org/AlevelRevision/engineering/stress-strain

IS 2770., 1997. Method of Testing bond in reinforced concrete part i-pullout test. BIS, New Delhi.

J. Cairns, G.A. Plizzari, Y. Du, D.W. Law, C. Franoni, 2005. Mechanical properties of corrosion-damaged reinforcement, ACI Mater. Jl 102(4): 256-264.

J. Xia, W. Jin, Y. Zhao, L. Li, 2013. Mechanical performance of corroded steel bars in concrete. Struct. Build. 166(5): 235-246.

Johnson, JB., 2010. Bond Strength of Corrosion Resistant Steel Reinforcement in Concrete, MSc Thesis, Faculty of the Virginia Polytechnic Institute and State University.

L.A. Clark and M. Saifullah., 1994. Effect of corrosion rate on the bond strength of corroded reinforcement, in: R.N. Swamy (Ed.), Corrosion and Corrosion Protection of Steel in Concrete, Sheffield Academic Press, Sheffield, United Kingdom.

Larrard F., Schaller I., Fuchs J., 1993. Effect of Bar Diameter on the Bond Strength of Passive Reinforcement in High-Strength Concrete. ACI Materials Jl 90(4): 333-339.

Lutz L.A. and Gergely, P., 1967. Mechanics of bond and slip of deformed bars in concrete. ACI Mat. Jl T.No.64-62: 711-721.

M. Maslehuddin, I.M. Allam, G. Al-Sulimani, A.I. Al-mana, S.N. Abduljauward., 1990. Effect of rusting of reinforcing steel on its mechanical properties and bond with concrete. ACI Mater. Jl 87(5): 496-502.

M. Papadopoulos et. al., 2011. Corrosion of exposed rebars, associated mechanical degradation and correlations with accelerated corrosion tests. Constr. Build. Mater. 25(8): 3367-3374.

Malvar L.J., 1992. Bond of Reinforcement under Controlled Confinement. ACI Materials Jl 89(6): 593-601.

Mathey, R.G. Watstein, D., 1961. Investigation of bond in beam and pull out specimens with high yield strength deformed bars. ACI Jl T.No.57-50: 1071 1089.

M.M. Kashani, A.J. Crewe, N.A. Alexander, 2013. Nonlinear stress-strain behavior of corrosion-damaged reinforcing bars including inelastic buckling. Engineering Struct. 48(3): 417-429.

Moetaz, M and El-Hawary, 1999. Evaluation of bond strength of epoxy-coated bars in concrete exposed to marine environment. Construction and Building Materials 13(7): 357-362.

Nihal Abdelhamid Taha and Mohammed Morsy, 2015. Study of the behavior of corroded steel bar and convenient method of repairing. HBRC Jl 2016. 12(2): 107-113.

O'Flaherty F.J., Mangat P.S., Lambert P., Browne E.H., 2008. Effect of under-reinforcement on the flexural behaviour of corroded beams, Material Struct. 41(2): 311-21.

R. Palsson and M.S. Mirza, 2002. Mechanical response of corroded steel reinforcement of abandoned concrete bridge, ACI Struct. Jl 99(2): 157-162.

S. Morinaga, 1996. Remaining life of reinforced concrete structures after corrosion cracking, in: C. Sjostrom (Ed.), Durability of Building Materials and Components. E & FN Spon, London, United Kingdom.

Schiessl, P., 1988. Corrosion of steel in concrete. Report of the TC60-CSC RILEM, Chapman and Hal, London: 204.

Selvaraj, R & Bhuvaneshwari, B., 2009. Characterization and development of organic coating for steel rebars in concrete. Electrochimica Acta 27(6): 657 670.

Somayaji, S. and Shah, S.P., 1981. Bond stress versus slip relationship and cracking response of tension members. ACI Jl 78(3): 217-225.

Soylev, TA & Francois, R., 2006. Effects of bar-placement conditions on steel concrete. Materials and Structures 39(2): 187-195.

Soroushian, P. Choi, K.B. Park, G.H. and Aslani, F., 1991. Bond of def. bars to concrete: effects of confinement and strength of concrete. ACI Mat. Jl 88(03): 227-232.

Soroushian, P. Choi and K.B. 1989. Local bond of deformed bars with different diameters in confined concrete. ACI Str Jl 86(02): 217-222.

Stewart M.G., 2009. Mechanical behaviour of pitting corrosion of flexural and shear reinforcement and its effect on structural reliability of corroding RC beams. Struct Safety 31(1): 19-30.

Tepfers R., 1979. Cracking of Concrete Cover along Anchored Deformed Reinforcing Bars. Magazine of Concrete Research 31 (106): 3-12.

Tepfers, R.A. 1973. Theory of bond applied to overlapped tensile reinforcement splices for deformed bars. Publ 73:2. Department of Concrete Structures, Chalmers University of Technology, Göteborg. 328.

Torres-Acosta A.A., Navarro-Gutierrez S., Teran-Guillen J., 2007. Residual flexure capacity of corroded reinforced concrete beams, Engineering Struct. 29(6): 1145-52.

Tuutti K., 1982. Corrosion of steel in concrete, Report 4, Swedish Cement and Concrete Research Institute, Stockholm, Sweden. P 82.

Val D.V., 2007. Deterioration of strength of RC beams due to corrosion and its influence on beam reliability, Structural Eng. Jl 133(9): 1297-306.

Valcuende, M & Parra C, 2009. Bond behaviour of reinforcement in self compacting concretes. Construction and Building Materials 23(1): 162-170.

Verma, N & Balasubramaniam R, 2011. Corrosion of Steel Reinforcements in Concrete. MME 480 TERM PAPER, Indian Institute of Technology, Kanpur.

Vidal T., Castel A., Francois R., 2007. Corrosion process and structural performance of a 17 year old reinforced concrete beam stored in chloride environment, Cem Concr Res. 37(11): 1551-61.

W. Zhang, X. Song, X. Gu, S. Li., 2012. Tensile and fatigue behavior of corroded rebars, Constr. Building Mater. 34(9): 409-417.

Warner, RF, Rangan, BV, Hall, AS & Faulkes, KA., 1998. Structures. Longman Australia.

Yalciner, H, Eren, O & Sensoy S, 2012. An experimental study on the bond strength between reinforcement bars and concrete as a function of concrete cover, strength and corrosion level. Cement and Concrete Research 42(5): 643-655.

Yankelevsky, D.Z. Adin, M.A. and Farhey, D.N., 1992. Mathematical model for bond slip behaviour under cyclic loading. ACI Str Jl 89(6): 692-698.

Yu Chen Ou and Nguyen Dang Nguyen, 2016. Modified axial-shear-flexure interaction approaches for uncorroded and corroded reinforced concrete beams. Engineering Structure 128: 44-54.

Yu Chen Ou, Yudas Tadeus, Teddy Susanto and Hwasung Roh, 2015. Tensile behavior of naturally and artificially corroded steel bars. Construction and Building Materials 103 (2016): 93-104.

Y. Du, L.A Clark, A.H.C. Chan, 2005. Residual capacity of corroded reinforcing bars, Mag. Concr. Res 57(3): 135-147.

Y. Du, L.A Clark, A.H.C. Chan, 2005. Effect of corrosion on ductility of reinforcing bars, Mag. Concr. Res 57(7): 407-419.

Y. Du, 2001. Effect of reinforcement corrosion on structural concrete ductility (Ph.D. dissertation), University of Birmingham, United Kingdom.

Y.G. Du, L.A. Clark, A.H.C. Chan, 2005. Residual capacity of corroded reinforcing bars Mag. Concr. Res. 57(3): 135-147.

Y.S. Yuan, Y.S. Ji, S.P. Shah, 2007. Comparison of two accelerated corrosion techniques for concrete structures ACI Struct. Jl 104(3): 344-347.

Zhang, R., Castel, A., Francois R., 2009. Serviceability limit state criteria based on steel concrete bond loss for corroded reinforced concrete in chloride environment, Materials Structure 42(10): 1407-21.