

**PERFORMANCE OF TMT AND CTD STEEL BARS, OPC AND
BLENDED CEMENTS AGAINST CHLORIDE INDUCED REBAR
CORROSION IN CONCRETE**

by

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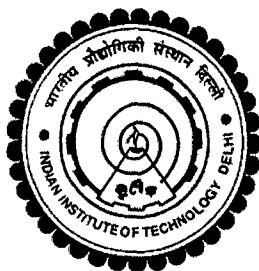
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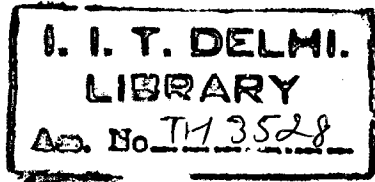
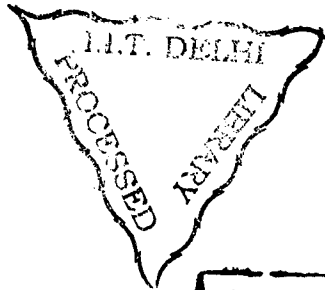
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CERTIFICATE

This is to certify that the thesis entitled “**Performance of TMT and CTD Steel Bars, OPC and Blended Cements against Chloride Induced Rebar Corrosion in Concrete**”, being submitted by **Mr. Bulu Pradhan** to the Indian Institute of Technology Delhi, India, for the award of the degree of “**DOCTOR OF PHILOSOPHY** in Civil Engineering”, is a record of original bonafide research work carried out by him under my guidance and supervision. To the best of my knowledge, the thesis has reached the requisite standard. The material contained in this thesis has not been submitted, in part or full to any other University or Institute for the award of any degree or diploma.



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ABSTRACT

The corrosion of steel in reinforced concrete (RC) structures is a worldwide problem. It is of great importance while considering the safety and durability of reinforced concrete structures. Chloride ions are considered to be the primary cause of rebar corrosion in RC structures than other factors. The critical chloride level at which the initiation of rebar corrosion takes place is not a unique value. In addition to critical chloride content, there is no consensus on the critical parameters indicating the rebar corrosion initiation. The corrosion behaviour of rebar varies significantly in concrete containing internal chlorides compared to that exposed to external chlorides. The corrosion performance of the steel reinforcement in concrete depends on the performance of both the cement and steel types. In the present research work a comprehensive experimental investigation has been carried out to critically evaluate the performance of different types of cement, different types of steel and concrete mixes in terms of rebar corrosion in concrete exposed to both internal chloride and external chloride. In addition, an attempt has been made to identify a stable and reliable indicator of rebar corrosion initiation in concrete. A potentiodynamic study on bare steel specimens in concrete powder solution extracts has been conducted to obtain polarization curves and these have been further used to identify different zones of corrosion

of corrosion

In order to investigate the suitability of the half-cell potential as a stable and reliable indicator of corrosion initiation, a preliminary test was carried out on beam specimens similar to that specified in ASTM G 109. On the basis of the results obtained from the preliminary test, in the main experimental scheme, the same methodology was

adopted with different types of steel, cement and mix parameters. Three types of cement namely, ordinary Portland cement (OPC), Portland pozzolana cement (PPC) and Portland slag cement (PSC), were used in the present investigation. Three different types of steel bars of diameter 12mm, namely cold twisted deformed bars (CTD), and two different types of thermo-mechanically treated (TMT) such as Tempcore TMT and Thermex TMT bars were used as the steel reinforcement. The concrete mixes were made with three w/c ratios of 0.45, 0.50 and 0.55 and two different clear cover depths to the top steel bar. A total of 162 beams were prepared and tested. The specimens were subjected to alternate wetting and drying cycles with 3 days of ponding with 3% sodium chloride solution followed by 11 days of drying. The half-cell potential of the top steel bar with reference to saturated calomel electrode (SCE) and the potential difference between the top steel bar and the bottom common terminal across a 100 Ohm resistor were measured at the beginning of both wetting and drying periods. The exposure of specimens to alternate wetting and drying cycles and potential measurements were continued and there was a sudden drop in the half-cell potential of top steel bar after certain period of exposure and at the same time a reversal in the direction of current between the top steel bar and bottom common terminal had occurred. After the sudden drop in half-cell potential of the top steel bar, the specimens were further subjected to another three cycles of wetting and drying to see the variation in the dropped half-cell potential value. The macrocell corrosion current values and the critical free and total chloride contents were determined for all the specimens after the sudden drop.

In order to evaluate the performance of different types of cement and steel against internal chloride exposure, slab specimens with a centrally embedded steel bar were

prepared with above mentioned steel types, cement types and w/c ratios. The specimens were admixed with sodium chloride concentrations of 0%, 1.5%, 3% and 4.5% by mass of cement at the time of preparation. A total of 432 slabs were prepared and tested. The corrosion rate of the embedded steel reinforcement was determined using two non-destructive methods, namely linear polarization resistance (LPR) and AC impedance spectroscopy. In addition the corrosion rates determined by LPR technique were compared with those obtained through gravimetric (mass loss) measurement that is performed at the end of test period. Furthermore, the half-cell potential, relative resistivity values, free and total chloride contents, and the pH value of all specimens were also determined. In order to identify the factors that affect the half-cell potential and corrosion current density significantly, an analysis of variance (ANOVA) was carried out.

Potentiodynamic study on bare steel specimens in concrete powder solution extracts were carried out to identify different zones of corrosion namely, immune zone, active zone, passive zone and pitting zone for the earlier-mentioned three types of steel reinforcement in chloride contaminated concrete powder solution extracts prepared from three different types of cement, three w/c ratios as stated earlier and two test conditions, i.e. with and without deaeration of the solution extracts. A total of 216 bare steel specimens were prepared and tested. In order to confirm the major factors that govern the different zones of corrosion significantly, an analysis of variance (ANOVA) was carried out.

From the results of potential measurements on beam specimens subjected to external chloride exposure, it is observed that the reliable determining parameter indicating the

initiation of rebar corrosion is the half-cell potential. The observed average value of this indicating half-cell potential is -280mV (SCE) and is independent of steel type, cement type and w/c ratio. The Tempcore TMT steel in concrete with PSC and PPC exhibited lower values of macrocell corrosion current and higher critical chloride contents than other types of steel and cement. From the results of internal chloride exposure, it is observed that the corrosion rate obtained through linear polarization resistance (LPR) measurements is in close agreement with those obtained from gravimetric measurement. AC impedance spectroscopy technique showed slightly lower values of corrosion current density than those obtained from LPR technique. However the variations in corrosion rate with steel type, cement type and mix parameters are similar in the above methods. The Tempcore TMT steel in concrete with PPC and PSC exhibited lower values of corrosion current density as compared to other types of steel and cement. Concretes with blended cements exhibited higher values of resistivity than that exhibited by that with OPC. From the potentiodynamic study on bare steel specimens in concrete powder solution extracts, various zones of corrosion namely semi-immune zone, active zone, passive zone and pitting zone have been identified for different types of steel, cement and w/c ratios. Through ANOVA it is inferred that chloride content has the strongest effect in governing different zones of corrosion of the steel reinforcement. Test conditions, cement type and steel type have some effect on zones of corrosion whereas w/c ratio has no effect on the same. Lastly, through an overall performance appraisal, it is inferred that the Tempcore TMT steel used in the investigation performed best followed by the Thermex TMT and CTD steels in terms of chloride induced corrosion in concrete. Similarly among cement types, PSC performed best followed by PPC and OPC. Looking at steel-cement

combinations, Tempcore TMT-PSC and Tempcore TMT-PPC performed best while Thermex TMT-OPC performed worst against chloride induced corrosion in concrete.

TABLE OF CONTENTS

	Page no.
CERTIFICATE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
LIST OF FIGURES	xiv
LIST OF PLATES	xxvi
LIST OF TABLES	xxvii
LIST OF SYMBOLS AND ABBREVIATIONS	xxix
 CHAPTER 1: INTRODUCTION	 1
1.1 General	1
1.2 Scope and objectives of the present research work	4
1.3 Format of thesis	7
 CHAPTER 2: LITERATURE REVIEW	 9
2.1 General	9
2.2 The Corrosion process with emphasis on rebar corrosion	10
2.2.1 Rebar corrosion: An electrochemical process	10
2.3 Corrosion Tendency: A Thermodynamic Approach	12
2.3.1 Free energy and rate of reaction	13
2.3.2 Free energy change and electrode potential	14
2.3.3 Equilibrium potential/pH (Pourbaix) diagram	16
2.4 Electrochemical polarization	19
2.4.1 Causes of polarization	20

2.4.2 Influence of polarization on corrosion rate	21
2.4.3 Relationship between overpotential and corrosion rate	23
2.5 Rebar corrosion initiation in reinforced concrete – role of chloride	24
2.5.1 Chloride induced rebar corrosion in concrete – an introduction	26
2.5.2 Service life of RC structures against chloride induced corrosion	29
2.5.3 Critical chloride level	29
2.5.3.1 General	29
2.5.3.2 Effect of cement type on critical chloride levels in concrete	30
2.5.3.3 Effect of steel type on critical chloride levels in concrete	33
2.5.4 Ambiguity in critical levels for corrosion initiation/depasivation	36
2.6 Performance of cement and steel type against chloride induced corrosion	40
2.6.1 Performance of cement type	40
2.6.1.1 Effect of other factors – water-binder ratio and grade of concrete	50
2.6.2 Performance of steel type	51
2.7 Chloride induced corrosion of steel reinforcement in simulated pore solutions	54
2.8 Corrosion investigation techniques	59
2.8.1 Potential measurement	60
2.8.2 Corrosion rate measurement	61
2.8.2.1 Linear polarization resistance (LPR) technique	61
2.8.2.2 AC impedance spectroscopy technique	62
2.8.2.3 Tafel plot (TP) technique	63
2.8.2.4 Galvanostatic pulse technique	64
2.8.2.5 Coulstatic method	65

2.8.2.6 Gravimetric (mass loss) method	66
2.8.3 Resistivity measurement	67
2.8.4 Chemical testing of concrete	68
2.9 Summary	69
CHAPTER 3: CORROSION INITIATION PERFORMANCE OF STEEL AND CEMENT THROUGH HALF-CELL POTENTIAL	73
3.1 General	73
3.2 Preliminary test	74
3.3 Experimental details	75
3.3.1 Materials	76
3.3.1.1 Cement	76
3.3.1.2 Steel	77
3.3.1.3 Coarse and fine aggregates	79
3.3.1.4 Mixing water	81
3.3.1.5 Concrete mix proportion	81
3.3.2 Cover depth	82
3.3.3 Preparation and preconditioning of steel specimens	83
3.3.4 Preparation of beam specimens and cubes	85
3.3.5 Exposure conditions	86
3.3.6 Corrosion monitoring instrument	87
3.3.7 Potential measurement	88
3.3.8 Collection of concrete powder	91
3.3.9 Determination of free chloride, total chloride and pH value	92
3.4 Results and discussion	94
3.4.1 Results of potential measurement	95
3.4.2 Macrocell corrosion current	102

3.4.3 Free chloride, total chloride and pH value	110
3.4.4 Critical chloride content and corrosion initiation period	116
3.5 Inferences	120
CHAPTER: 4 CORROSION PERFORMANCE OF STEEL AND CEMENT AGAINST INTERNAL CHLORIDE	123
4.1 General	123
4.2 Experimental program	124
4.2.1 Materials used	125
4.2.2 Preparation and preconditioning of steel bars	126
4.2.3 Preparation of slab specimens and cubes	127
4.2.4 Corrosion rate measurement	129
4.2.4.1 Corrosion rate by linear polarization resistance (LPR) technique	129
4.2.4.2 Corrosion rate by AC impedance spectroscopy	132
4.2.4.3 Corrosion rate by Gravimetric (mass loss) measurement	134
4.2.5 Determination of free chloride, total chloride and pH value	137
4.3 Results and discussion	137
4.3.1 Compressive strength	137
4.3.2 Free chloride, total chloride and pH value	139
4.3.3 Results of half-cell potential	142
4.3.3.1 Analysis of variance (ANOVA) for half-cell potential	148
4.3.4 IR drop and relative resistivity value	149
4.3.5 Corrosion current density results by LPR	153
4.3.5.1 Analysis of variance (ANOVA) for corrosion current density	158
4.3.6 Comparison of corrosion rate by LPR and AC impedance spectroscopy	159

4.3.7 Comparison of corrosion rate by LPR and gravimetric measurement	162
4.4 Inferences	172
CHAPTER 5: CORROSION ZONES OF REBAR IN CHLORIDE CONTAMINATED CONCRETE	177
5.1 General	177
5.2 Preliminary test	179
5.3 Experimental program	179
5.3.1 Materials	180
5.3.2 Preparation and preconditioning of steel specimens	181
5.3.3 Preparation of concrete cubes and concrete powder	182
5.3.4 Preparation of concrete powder solution extracts and deaeration	183
5.3.5 Potentiodynamic sweep test	184
5.3.6 Determination of free chloride, total chloride and pH value	186
5.4 Results and discussion	186
5.4.1 Different zones of corrosion of the steel reinforcement	188
5.4.2 Role of experimental factors on zones of corrosion	191
5.4.3 Comparison of zones for experimental factors	220
5.4.4 Analysis of variance (ANOVA)	223
5.4.5 Critical chloride content for higher pitting risk	236
5.5 Inferences	238
CHAPTER 6: OVERALL PERFORMANCE APPRAISAL OF STEEL AND CEMENT TYPE	241
6.1 General	241
6.2 Overall corrosion initiation performance of steel type, cement type and their combinations	241
6.2.1 Performance of steel type against corrosion initiation (external	241

chloride)	
6.2.2 Performance of cement type against corrosion initiation (external chloride)	242
6.2.3 Measures for corrosion initiation performance	243
6.2.4 Critical chloride contents	260
6.3. Performance through macrocell corrosion current: external chloride	265
6.4 Performance through corrosion current density: internal chloride	267
6.4.1 Performance of cement type against internal chloride	271
6.4.2 Performance of steel type against internal chloride	272
6.5 Overall ranking of steel type, cement type and their combinations	272
6.6 Discussion on the results of ANOVA analysis	275
CHAPTER 7: CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK	277
7.1 General	277
7.2 Conclusions from external chloride exposure	277
7.3 Conclusions from internal chloride exposure	278
7.4 Conclusions from potentiodynamic study	280
7.5 Conclusions from overall performance appraisal	280
7.6 Suggestions for further work	281
REFERENCES	283
APPENDIX 1	297
APPENDIX 2	301
APPENDIX 3	315
LIST OF PUBLICATIONS BASED ON PRESENT RESEARCH WORK	321
BIO DATA	323