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

by

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Reinforced concrete
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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 the 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 corrosior

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 the 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.

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