

**COMPARISON OF CORROSION BEHAVIOR OF STEEL
REINFORCEMENT BARS IN ORDINARY PORTLAND
CEMENT AND PORTLAND POZZOLANA CEMENT
ENVIRONMENTS**

K.B.M.V. Sarojani de Costa

(179428F)

Degree of Master of Materials Science

Department of Materials Science and Engineering

University of Motatuwa

Sri Lanka

April 2022

**COMPARISON OF CORROSION BEHAVIOR OF STEEL
REINFORCEMENT BARS IN ORDINARY PORTLAND
CEMENT AND PORTLAND POZZOLANA CEMENT
ENVIRONMENTS**

Kottal Badda Maha Vidanage Sarojani de Costa

(179428F)

Thesis submitted in partial fulfillment of the requirements for the
degree of Master of Materials Science

Department of Materials Science and Engineering

University of Motatuwa

Sri Lanka

April 2022

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa, the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Masters in Materials Science, under my supervision.

Name of the supervisor:

Signature of the supervisor:

Date:

ABSTRACT

In the Sri Lankan cement market present time blended hydraulic cement which is composited with fly ash or blast furnace slag are given a noticeable marketing share as supplementary cement. It has obtained more popularity for incorporating higher workability and achieving a higher lateral strength in the construction industry. But due to the pozzolanic reactivity of blended cement, there is a possibility of reduction of pH of concrete or cement mortar which may be detrimental to the passivity of reinforced steel.

In this study, the comparison of corrosion effect was researched with 15% fly ash blended cement as the pozzolanic cement (Bag-cement of Blended hydraulic cement) and Ordinary Portland cement. Coarse aggregates were excluded to get a clearer picture of the corrosion effect with the change of cement type. The cement mortar mixtures with 1.0: 3.0: 0.5 of cement: sand: water respectively, from both cement types were prepared. Specimens were cast in moulds with reinforcement bars to prepare the specimens for the pull-out test, Half cell potential test, compression test & loss of mass (due to corrosion). After casting test specimens were salt-conditioned by dipping in 5% NaCl solution for 30 minutes per day for 180 days.

Pull-out and compression test results acknowledge that pozzolanic cement contributes higher lateral strength than ordinary Portland cement. After the compression test, reinforced steel bars were removed from the cubes and it was observed that no corrosion has happened in bars that were fully enclosed with (both types of: PPC and OPC) cement covers. Therefore, it reveals that 15% of fly ash blended hydraulic cement does not disturb the passivity layer of steel reinforcements as a result of consumption of Ca(OH)_2 . This study can be extended for further research with 25% or higher ratios of fly ash blended hydraulic cement.

Keywords: Ordinary Portland cement; Portland Pozzolanic Cement; corrosion of TMT steel bars; passivity of steel bars

ACKNOWLEDGEMENTS

I would like to express my gratitude, first of all, to Prof. S.M.A. Nanayakkara who cleared doubts about this research idea and for giving me the initial guidance. I would like to express my sincere thanks to my research supervisor Eng. Mr. S. P. Guluwita, senior lecturer for his coordination, encouragement, and guidance throughout this research. His instructions were highly fruitful and encouraging during the research study. I also express my acknowledgement to the M.Sc. research coordinator for the guidance offered.

I am much thankful to Sri Lanka Standards Institution for granting me a part funding to get registered to the degree of Master in Materials Science.

I highly appreciate Mr. M.A.K Jayatilaka, Director, and National Centre for Non-Destructive Testing, who permitted me to use the instrumentations and testing facilities. My sincere thanks also go to Eng. M.J.M. Hassandeen, General Manager, Melbourne Metal (Pvt.) Limited, Ja-Ela, for granting me the permission to use the laboratory facilities. I would like to acknowledge my gratitude to Mr. Yasendra Abegunawardhane, INSEE Cement, Paliyagada for permitting me to use their testing facilities. I would like to thank my dear husband for his support and encouragement throughout the research work to complete it successfully.

Finally, I would appreciate every person who supported me, encouraged me throughout this research work time which I remind with great gratitude.

K.B.M.V.S. De Costa

TABLE OF CONTENTS

Declaration	i
Abstract	ii
Acknowledgements	iii
Table of contents	iv
List of Figures	vi
List of Tables	vii
List of abbreviations	viii
List of Appendices	ix
1. Introduction	1
2. Literature Survey	6
2.1 Mechanism of Corrosion of steel in concrete	6
2.2 Concrete and the Passive Layer	8
2.3 Carbonation	10
2.4 Ionic transport mechanisms	11
2.5 The Half-Cell Potential Technique	14
2.6 Rebound hammer testing	15
3. Experimental Procedure	17
3.1 List of raw materials and apparatus	17
3.2 Procedure	17
3.2 Compression testing on Cement cubes	21
3.3 Pull out resistance	21
3.4 Loss of mass at the ends of steel	22
4. Test Results and discussion	23
4.1 Results of Half-cell voltages	23
4.2 Results of Rebound hammer testing	26
4.3 Compression test results	28
4.4 Pull out resistance test results	31
4.5 Weight losses at the ends of each steel bars	34
5. Conclusion	36
6. Suggestions	37
Reference List	38

Appendix A: Physical, mechanical and chemical test results of sampled OPC and PPC (Blended hydraulic Cement)	42
Appendix B: The fine aggregate gradation	43
Appendix C: Properties of TMT bars used for the research study	44
Appendix D: Composition of OPC and PPC (Blended Hydraulic cement)	46

LIST OF FIGURES

	Page	
Figure 1.1	Composition of hardened OPC paste	3
Figure 2.1.1	Types and morphology of the corrosion in concrete	7
Figure 2.1.2	Schematic diagram for steel reinforcement corrosion	8
Figure 2.2.1	Schematic diagram for destruction of passivity layer by Cl^-	9
Figure 2.5.1	Half-cell potential measurement	14
Figure 2.6.1	Schematic diagram of Rebound hammer operating principle	16
Figure 3.1.1	OPC and PPC specimens (for pull out test), after casting	19
Figure 3.1.2	OPC and PPC specimens (for compression test), after casting	19
Figure 3.1.4	Test specimens for salt conditioning	20
Figure 3.1.5	Test specimen in salt baths	20
Figure 3.1.6	Testing with Corrosion Analyzer Detector meter	20
Figure 3.1.7	Testing with Rebound Hammer instrument	21
Figure 3.2.1	Compression testing of cement motor cubes	21
Figure 3.4.1	Chemical treatment to remove rust	22
Figure 4.1	Voltage readings of cement cubes Vs. Time	25
Figure 4.2.1	Rebound hammer test of cement cubes	27
Figure 4.3.1	Compressive strength of OPC and PPC cement cubes	29
Figure 4.3.2	Average compressive strengths of OPC and PPC cement cubes	29
Figure 4.4.1	Pull out test results of OPC and PPC mortar cubes	31
Figure 4.4.2	TMT steel bars after pull out test	32
Figure 4.4.3	Pull out test results of OPC and PPC samples	33
Figure 4.5.2	Ribbed Steel bars after separating from the cubes	35
Figure 4.5.3	Steel bars after the chemical treatment	35

LIST OF TABLES

	Page	
Table 2.5	Typical ranges of half-cell potentials of rebar in concrete	15
Table 3.1	Identification numbers of cement motor specimens	18
Table 4.1.1	Half-cell voltage test results	24
Table 4.1.2	Summarized test results of Half-cell voltage	24
Table 4.1.3	Standard deviations of Half-cell voltage	24
Table 4.2.1	Rebound hammer test results	26
Table 4.2.2	Summarized Rebound hammer test results	26
Table 4.2.3	Standard deviations of Rebound hammer test	27
Table 4.3.1	Compression Test Results of OPC cement mortar cubes	28
Table 4.3.2	Compression Test Results of PPC cement mortar cubes	28
Table 4.3.3	Compressive strengths of the two types of cement samples	29
Table 4.4.1	Pull out Test Results of OPC mortar cubes	31
Table 4.4.2	Pull out Test Results of PPC mortar cubes	31
Table 4.4.3	Pull-out results of OPC and PPC samples	33
Table 4.5.1	Weight losses at the ends of steel bars with OPC mortar cubes	34
Table 4.5.2	Weight losses at the ends of steel bars with OPC mortar cubes	34

LIST OF ABBREVIATIONS

Abbreviation	Description
BHC	Blended Hydraulic Cement
C ₃ A	Tricalcium aluminate, 3CaO.Al ₂ O ₃
C ₃ AF	Tetra-calcium aluminoferrite, 4CaO.Al ₂ O ₃ .Fe ₂ O ₃
C ₂ S	Dicalcium silicate, 2CaO.SiO ₂
C ₃ S	Tricalcium silicate, 3CaO.SiO ₂
CADR	Corrosion Analysis Detector Reading
CH	Calcium Hydroxide, Ca(OH) ₂
C-S-H	Calcium silicate hydrate, 3CaO.2SiO ₂ .3H ₂ O
CSH ₂	CaSO ₄ .2H ₂ O, Gypsum
H	H ₂ O
HCV	Half-Cell Voltage
NaCl	Sodium Chloride, Salt
OPC	Ordinary Portland Cement
PPC	Portland Pozzolanic Cement
ppm	parts per million
RHT	Rebound hammer test results
SLSI	Sri Lanka Standards Institution

LIST OF APPENDICES

Appendix	Description	Page
Appendix- A	Physical, mechanical and chemical test results of sampled OPC and PPC (Blended Hydraulic Cement)	41
Appendix- B	Fine aggregate gradation	42
Appendix-C	Properties of TMT bars used for the research study	43
Appendix- D	Composition of OPC and PPC samples	44