

**INVESTIGATION OF EFFECTS OF BONDING AGENT
ON PERFORMANCE OF COLD JOINT IN CONCRETE
MEMBER**

by

Mr. Panchadcharam Pushparuban

168922X

Supervised by: Dr. (Mrs.) J.C.P.H. Gamage

Thesis submitted in partial fulfilment of the requirements for the degree
of Master of Science

Department of Civil Engineering

University of Moratuwa
Sri Lanka

February 2021

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 dissertation, 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).

.....

P. Pushparuban
Department of Civil Engineering
University of Moratuwa

.....

Date

The above candidate has carried out this research for the Masters Dissertation under my supervision.

.....

Dr. (Mrs.) J.C.P.H. Gamage
Senior Lecturer (Building and Structural)
Department of Civil Engineering
University of Moratuwa

.....

Date

Acknowledgement

May this be a gratitude for those who offered me encouragement, valued cooperation, advices and assistance for achieving my objective.

It is my foremost duty to give special thanks to my supervisor Dr. (Mrs.) J.C.P.H. Gamage for valued guidance and support offered with her busy schedules.

I pay my sincere thanks to Dr. K. Baskaran, PG Research coordinator, Department of Civil Engineering for motivates us to complete my research.

I pay my sincere thanks to the Structural Unit of the Department of Civil Engineering, University of Moratuwa for organizing the structural engineering course which is very useful for young engineers engaged in the emerging infrastructure projects in Sri Lanka.

I would like to thank to Access Engineering (Pvt) Ltd. for providing laboratory and equipment facilities to carry out the experiment of my research work. Further I would like to thank to Mannar Wind Power Project team for guiding me to develop my career.

Ultimately, I make this an opportunity to appreciate each and every person who gave their assistance in every mean to achieve successful completion of this research.

Abstract

One of the most common difficulties in the execution of concrete structures is cold joint because of delay in concrete casting due to several circumstances as well as improper casting sequence. The discontinuity in concrete element leads to structural weakness, increasing the permeability, corrosion of the reinforcement, reducing the durability and bad appearance of concrete. In this research, the aim to eliminate the cold joint by applying the bonding agent.

In order to evaluate the effect of the bonding agent on cold joint, 76 number of cubes were cast using grade 30 concrete. Out of them, 36 specimens contain cold joint with 20° degree of inclination to the horizontal plane for compressive strength with and without applying bonding agent other 36 specimens had cold joint in the horizontal plane for splitting tensile strength with and without applying bonding agent and considered delay time of one hour interval up to 5 hours.

After 28 days of curing, all specimens were tested as per standard method. The experimental result of compressive strength shows that cold joint with applying bonding agent give 6% improvement as compare to without applying bonding agent. But, the experimental result of splitting tensile strength shows that no considerable influence on cold joint as applying bonding agent compare to without applying bonding agent. However, there is considerable reduction in the compressive strength (30.50%) and tensile strength (33.14%) compare with initial specimens with applying bonding agent.

Further, observation based on failure surface of tested specimens clearly indicated that, there are no aggregate inter logged in between two layers when delay time past the initial setting time of the first layer. So, the reduction in strength due to the cold joint purely depends on aggregate interlocking.

The better options are to avoid the cold joint by using admixtures (retarders) to increase the initial setting time, adopt proper casting sequences and vibrate the layers together even within the initial setting time.

Key words: aggregate interlocking, bonding agent, cold joint, initial setting time, strength,

TABLE OF CONTENTS

Declaration of the Candidate & Supervisor	i
Acknowledgement	ii
Abstract	iii
Table of Content	iv
List of Figures	vii
List of Tables	x
List of Abbreviation	xi
1.0 Introduction	1
1.1 Background	1
1.2 Problem Statement	3
1.3 Aim	4
1.4 Objectives	4
2.0 Literature Review	5
2.1 General Introduction	5
2.2 Formation of Cold Joints	5
2.3 Pour Lines and Cold Joints	6
2.4 Effect of Cold Joint on Structures	7
2.5 Factors Effect on Cold Joint Properties	8
2.5.1 Delay Time	8
2.5.2 Water-Cement Ratio	11
2.5.3 Grade of Concrete	12
2.5.4 Surface Roughness of Substrate Concrete	14
2.5.5 Orientation of the Cold Joint/Loading Direction	15
2.5.6 Re-vibration	17
2.5.7 Ambient Temperature	18
2.5.8 Moisture	19
2.5.9 Curing	19
2.5.10 Additives	19
2.6 Traditional Techniques of Preparation of Cold Joints	19
2.7 Modern Techniques of Preparation of Cold Joints	20
2.8 Previous Studies on Eliminating Cold Joint (old to new)	22
2.9 Setting Time of Concrete	27
2.10 Mix Design (DOE Method)	29
2.11 Bonding Agent	32

2.11.1	Applications	32
2.11.2	Features and Benefits	32
2.11.3	Application Method	33
2.12	Testing	33
2.13	Calculations for splitting tensile strength	34
2.14	Summary of Literature Review	35
3.0	Experimental investigation	36
3.1	Introduction	36
3.1.1	Methodology	37
3.2	Materials	37
3.3	Characteristics of Materials	38
3.3.1	Cement	38
3.3.2	Aggregate	39
3.3.3	Water	41
3.3.4	Bonding Agent	41
3.4	Experiment Methodology	42
3.4.1	Mix Design	43
3.4.2	Identification of Specimens	44
3.4.3	Specimens Setup	44
3.4.4	Preparation of Bonding Agent	45
3.4.5	Concrete Batching	46
3.4.6	Concrete Casting	48
3.4.7	Curing	53
3.4.8	Testing	54
4.0	Analysis and Discussions of Results	57
4.1	General Introduction	57
4.2	Compressive Strength	57
4.3	Splitting Tensile Strength	60
4.4	Failure Plane of Specimens Under Splitting Tensile Test	63
4.5	Discussions	64
4.5.1	Compressive strength	64
4.5.2	Tensile Strength	66
4.5.1	Comparison of Bond Strengths	68
5.0	Conclusions and Recommendations	70
5.1	General Introduction	70
5.2	Conclusions	70

5.3 Recommendations	70
5.4 Recommendations for Future Works	71
References	72
Annexes	75
Annex 1 - Material Test Reports	76
Annex 1.1 - Test Reports of Coarse Aggregate	77
Annex 1.2 - Test Reports of Fine Aggregates	80
Annex 1.3 - Technical Data Sheet of Bonding Agent	82
Annex 2 - Mix Design	84
Annex 2.1 – C30/37 Concrete Mix Design	85
Annex 3 – Experimental Test Results	86
Annex 3.1 - Compressive Strength	87
Annex 3.2 - Splitting Tensile Strength	88

LIST OF FIGURES

Figure 1-1 Cold Joint	2
Figure 1-2 Setting of Concrete	2
Figure 2-1 Cold Joint in top layer of the foundation	5
Figure 2-2 Signs of a pour lines: interface exhibits a rough surface with aggregate protruding between lifts and no voids	7
Figure 2-3 Tensile strength with different delay times	8
Figure 2-4 UPV test results: (a) velocity; (b) amplitude of first arrival	9
Figure 2-5 Chloride penetration: (a) charge passed; (b) initial current	9
Figure 2-6 Result of alternating current resistance	9
Figure 2-7 Result of water permeability test	10
Figure 2-8 Comparison of compressive strength of (a); fresh and (b); strain concrete with delay time and different plane	11
Figure 2-9 Comparison of split tensile strength of (a); fresh and (b); strain concrete with delay time	11
Figure 2-10 Comparison of flexural strength of (a); fresh and (b); strain concrete with delay time and different plane	11
Figure 2-11 Effect of w/c ratio on relative flexural strength with elapsed time	12
Figure 2-12 Effect of w/c ratio on carbonation depth with elapsed time	12
Figure 2-13 Relative flexural strength and lag time with different grade of concrete	13
Figure 2-14 Relative splitting tensile strength and delay time with different grade of concrete	13
Figure 2-15 Relative compressive strength and lag time with different grade of concrete	13
Figure 2-16 Factors influence the bond between substrate concrete and repair material	14
Figure 2-17 Slant shear test	14
Figure 2-18 Test result: (a) Slant shear test; (b) Pull off test for different roughness	15
Figure 2-19 Testing of cylinders with cold joint at different orientation	15
Figure 2-20 Compressive strength reduction with time: (a) diagonal; (b) horizontal	16
Figure 2-21 Axial stresses on an intact cylinder (left), with diagonal cold joint (centre) and horizontal cold joint (right)	17
Figure 2-22 Compressive strength vs re-vibration time lag	17

Figure 2-23 Damaged and undamaged concrete surface with different elapsed time	18
Figure 2-24 Application of bonding agent	21
Figure 2-25 Composite specimens and bond strength test	23
Figure 2-26 Schematic diagrams of interface bond strength test	23
Figure 2-27 Possible failure modes of specimens	24
Figure 2-28 Comparison of split tensile strength on bulk and composite specimens	24
Figure 2-29 Comparison of bi-surface shear strength on bulk and composite specimens	24
Figure 2-30 Bond strength in shear	26
Figure 2-31 Setting time of concrete	28
Figure 2-32 Stages of hardening process of cement paste	28
Figure 2-33 Normal distribution	29
Figure 2-34 Standard deviation	29
Figure 2-35 Relationship between compressive strength and w/c ratio	30
Figure 2-36 Relationship between wet density of concrete and free water content	31
Figure 2-37 Relationship between fine aggregate and W/C ratio	32
Figure 2-38 Alternative apparatuses for splitting cubes	34
Figure 2-39 Specimens for splitting tensile strength	34
Figure 3-1 Overview of test program	36
Figure 3-2 Methodology flowchart	37
Figure 3-3 Nippon cement	38
Figure 3-4 Fine and Coarse aggregates	39
Figure 3-5 Sieve analysis for coarse aggregate	40
Figure 3-6 Bonding agent -Emaco 157D	42
Figure 3-7 Specimens' labelling scheme	44
Figure 3-8 Wooden frame for making cold joint in an angle plane: (a) Schematic diagram; (b) Preparation of moulds arrangement for compressive strength test	45
Figure 3-9 Preparation of moulds arrangement for splitting shear test	45
Figure 3-10 Preparation of bonding agent	45
Figure 3-11 Moisture check for fine aggregate	46
Figure 3-12 Mixing the concrete	48
Figure 3-13 Cube specimens casting plan for compressive strength	48
Figure 3-14 Casting and compacting the first layer of concrete	49
Figure 3-15 Applying the bonding agent	49

Figure 3-16 Casting 2 nd layer for zero delay time	50
Figure 3-17 Compaction of 2 nd layer	50
Figure 3-18 Casting and compacting of 2 nd layer for 1 hrs. delay	51
Figure 3-19 Identification labels pasted on cubes	51
Figure 3-20 2 nd layer cast after 2hours (L) and 3hours (R) delay time	51
Figure 3-21 Cube specimens casting plan for tensile strength	52
Figure 3-22 Casting 1 st layer for cold joint with horizontal plane	52
Figure 3-23 Applying bonding agent	52
Figure 3-24 Casting 2 nd layer with delay time	53
Figure 3-25 Curing the specimens	53
Figure 3-26 Cold joint with 20-degree plane	54
Figure 3-27 Cold joint with horizontal plane	54
Figure 3-28 Measuring the weight of specimens	55
Figure 3-29 Testing of compressive strength	55
Figure 3-30 Apparatus for splitting cubes test	56
Figure 3-31 Testing of splitting tensile strength	56
Figure 4-1 Comparison of compressive strength with and without bonding agent	57
Figure 4-2 Comparison on reduction of compressive strength	58
Figure 4-3 Percentage reduction in compressive strength with respect to delay time	59
Figure 4-4 Effect of bonding agent on compressive strength	60
Figure 4-5 Comparison of tensile strength with and without bonding agent	61
Figure 4-6 Comparison on reduction of tensile strength	62
Figure 4-7 Percentage reduction in tensile strength with respect to delay time	62
Figure 4-8 Effect of bonding agent on tensile strength	63
Figure 4-9 Failure surface under splitting tensile strength test	64
Figure 4-10 Percentage reduction of compressive strength of experimental results with previous research results	65
Figure 4-11 Percentage reduction of tensile strength of experimental results with previous research results	67
Figure 4-12 Comparison of bond strength	69

LIST OF TABLES

Table 2-1 Approximate compressive strength (MPa) of concrete mixtures made with a free w/c ratio of 0.5	30
Table 2-2 Approximate water content (kg/m ³) required for corresponding workability	31
Table 3-1 Physical and chemical properties of cement	38
Table 3-2 Standards used for testing	39
Table 3-3 Sieve analysis coarse aggregate	40
Table 3-4 Test results on coarse aggregate	40
Table 3-5 Sieve analysis of fine aggregate	41
Table 3-6 Water absorption and specific gravity of fine aggregate	41
Table 3-7 Properties of bonding agent	42
Table 3-8 Overview of test specimens	43
Table 3-9 Summary of mix design of grade 30 concrete	43
Table 3-10 Moisture in the materials	46
Table 3-11 Adjusted weight after the moisture corrections	47
Table 3-12 Summary of mix design	47
Table 4-1 Average compressive strength with respect to delay time	57
Table 4-2 Reduction in compressive strength with delay time	58
Table 4-3 Percentage reduction in compressive strength with respect to delay time	59
Table 4-4 Influence of bonding agent on compressive strength	59
Table 4-5 Average tensile strength with respect to delay time	60
Table 4-6 Reduction in tensile strength with respect to delay time	61
Table 4-7 Percentage reduction in tensile strength with respect to delay time	62
Table 4-8 Influence of bonding agent on tensile strength	63
Table 4-9 Experimental result of the experiment done by Rathi and Kolase, 2013	64
Table 4-10 Percentage reduction in compressive strength	65
Table 4-11 Test results of the experiment done by Jatheesan et. al, 2010	66
Table 4-12 Comparison of bond strength results	68

LIST OF ABBREVIATIONS

Abbreviation	Description
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Material
BS	British Standard
CERP	Carbon Fiber Reinforced Polymer
Comp	Composite
CP	Cement Paste
DS	Dry Substrate
EC	Euro Code Standard
EP	Epoxy
IS	Indian Standard
LAC	Left as Cast
OPC	Ordinary Portland Cement
RC	Repairing Concrete
SBR	Styrene Butadiene Rubber
SC	Substrate Concrete
SHB	Sand Blasting
SLS	Sri Lankan Standard
SS	Saturated Substrate
T	Time
UPV	Ultrasonic Pulse Velocity
w/c	Water to Cement Ratio
WB	Wire Brushed