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

by

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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.

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

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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,

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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

CHAPTER - 1

1.0 INTRODUCTION

1.1 Background

The concrete is the single most widely used construction material. It provides superior fire resistance and gains strength over lifetime. The concrete structures can have a long service life without maintenance. Nowadays, development of infrastructure growth in construction becomes in large scale. Therefore, it is extremely hard to cast the entire structure at once. Subsequently, the joints in construction are essential to maintain the continuity of the structure.

Construction joints are required for construction sequences according to the volume of the concrete, placing time, height of structure, man power and other facilities required for the site conditions. The construction joints and movement joints are intentional joints in structures which are correctly designed and located in construction drawings. The accurately planned, positioned and constructed joints don't impact the quality of the concrete and expected purpose of the structure. These properly implemented construction joints give restrictions for consequent concrete casting, without adversely impact the structural reinforcement. The pre-planned joints can be treated with a special preparation of the concrete surface.

However, there can be a joint which is formed unintentionally. Such locations, form a plane of weakness or discontinuity where the initial setting time of underlaying concrete layer exceeds when pouring the next concrete layer. It is called as cold joint. Even within the initial setting time period, cold joint can be formed if the successive layers of concrete are not vibrated together. In practice, cold joints are formed unintentionally due to various reasons such as;

- Delay in casting due to unforeseen reasons
- Delay in transportation due to distance between plant and site
- Unexpected break down at plant or site
- Improper planning mainly in large scale concrete
- Retarders not functioning properly
- Not proper compaction of concrete
- Weather conditions – hot weather, etc.

A cold joint is usually characterized as weak joint and affect the strength parameters and durability of the structures. It causes the reduction in strength parameters such as tensile strength, compressive strength and shear capacity. Furthermore, the presence of cold joints leads to water leakage in water retaining structures. The presence of moisture in the cold joint affects the durability of the structure due to the corrosion of reinforcement. Figure 1-1 shows the visible cold joint in the concrete wall.

Figure 1-1 Cold Joint (https://inspectapedia.com/)

To avoid formation of cold joint in concrete layers due to unforeseen long delays, the last concrete layer should be kept alive by doing revibration periodically. However, over vibration should not be carried out because, it may cause segregation in the concrete layer. When concrete setting time approach to initial setting time, the concrete should be allowed to harden without any disturbance. Then the resultant cold joint will be treated as a construction joint. However, it is not acceptable in some structures such as post tensioned beams, pile caps, bridge deck, etc.

In general, the cold joints occur mainly due to initial setting time of concrete. The setting of concrete is defined as the transitional period between states of true fluidity and true rigidity as explained in Figure 1-2 below.

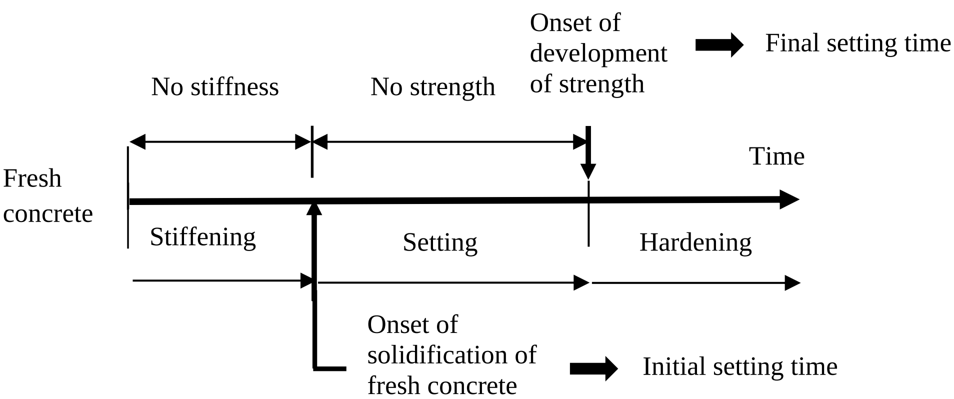

Figure 1-2 Setting of Concrete

The time when cement paste completely loses its plasticity is called initial setting time of concrete, while time when cement paste has hardened sufficiently is called final setting time of concrete. Setting times are measured in a laboratory condition as per ASTM C 403 [4]. However, the laboratory test results are not completely valid in field condition since many external factors other than properties of materials influence the setting times of concrete. Those are;

- Concrete temperature at time of mixing and pouring
- Ambient air temperature
- Ambient humidity
- Wind speed
- Solar radiation, etc.

Therefore, there is a high probability of forming unintentional joints in the structural elements. Hence, it is importance to find a way of preparing the joints to ensure the proper load transfer.

Therefore, it was decided to carry out research to find out the possibility to eliminate of cold joint in concrete by applying the bonding agent at the joint interface.

1.2 Problem Statement

- The presence of cold joint affects significantly on reduction of tensile strength, compressive strength, shear strength and the flexural strength
- The cold joints contain voids. It affects durability of concrete elements due to corrosion of reinforcement resulting from entrapped moisture
- This is critical in water retaining structures due to water leakage
- Even though, the elimination of cold joints is impossible, the joints can be continued as a construction joint but limited to small structures and the methods of constructing construction joints for effective load transfer, durability, performance and proper continuity are important
- The repairing of cold joint is expensive even though some structures the repairing cannot be accepted

1.3 Aim

The main aim of this study is to investigate the performance of cold joint prepared with alternative methods.

1.4 Objectives

- To conduct literature review and identify the cold joint preparation techniques
- To experimentally investigate the effect of bonding agent on performance of cold joints
- To analysis and compare the data
- To provide recommendation on preparing of cold joints

CHAPTER - 2

2.0 LITERATURE REVIEW

2.1 General Introduction

Concrete is most commonly used as structural material due to its' cost benefit, stable material supply and high durable. However, defects in the concrete structure cause for profit loss, affect the durability and appearance of the structures. Nowadays, structures are increasing in size and required large volume of concrete productions. Massive concrete pouring may be faced delay in the time period for many reasons that causes the stoppage of the casting process for a period that can produce a forced separation in concrete layers. It is called "cold joint" and leads to defects in the concrete structures. Figure 2-1 shows the visible cold joint at foundation.

Figure 2-1 Cold Joint in top layer of the foundation (at wind power project during the construction in 2020)

2.2 Formation of Cold Joints

Cold joint is formed when a concrete layer hardens before the next layer of concrete cast against and its cause discontinuity in between two layers or a plane of weakness. In other words, pouring the second layer after passing the initial setting time of the first layer of concrete. However, Researchers found that, the cold joint can be formed even within the conventional initial setting time of concrete which measured as per ASTM C*403*/C403M [4] (Illangakoon et al.,2019).

Cold joint is also formed when successive layers of concrete are not vibrated together. Further, it may happen even within the conventional initial setting time of the first layer which measured as per ASTM C*403* [4] (Jatheesan, et al., 2010).

The cold joint is possibly going to form due to the absence of intermixing of layers, leading a weak bond between two concrete layers. The main factor that effect the occurrence of cold joints is that the setting of the underlying concrete layer (JSCE Concrete Committee, 2014).

When the concrete is placing under hot weather condition, the rate of slump loss, moisture loss from concrete and concrete temperature are increased. Therefore, setting time of concrete is elastically reduced and it cause reduce the pouring time gap between two consecutive concrete layers, which governs cold joint formation (Ham & Oh, 2013).

According to the concrete mix proportion, setting time is completely varied. Therefore, the cold joint forms, in the penetration resistance range of 0.1 and 1.0 N/mm^2 (JSCE Concrete Committee, 2000).

“The dominant factor for the formation of cold joint is concrete temperature at time of casting since it is reducing the casting time between two consecutive layers (Illangakoon, et al., 2019).

Therefore, formation of cold joint only depend on two factors which are setting time of the underlaying concrete layer (1^{st} layer) and vibration limit of the top layer (2^{nd} layer) of concrete. But high concrete temperature at time of mixing & pouring, high ambient air temperature, low relative humidity, excessive solar radiation, high wind speed, w/c ratio, grade of concrete, admixtures, re-vibration, etc., which affect the conventional setting time period.

2.3 Pour Lines and Cold Joints

In concrete construction, pour lines and cold joints are common. But, the cold joints have more serious issues and consequences. As shown in Figure 2-2, pour lines are “dark lines on the formed surface at the boundary between adjacent batches of concrete” and typically “indicate that the vibrator was not lowered far enough to penetrate the layer below the one being vibrated”. Cold-joint lines, on the other hand, indicate “the presence of joints where one layer of concrete had set before next concrete was placed” and are typically revealed by “visible lines on the surfaces of formed concrete” (Volz et al., 1997).

Figure 2-2 Signs of a pour lines: interface exhibits a rough surface with aggregate protruding between lifts and no voids (Volz et al., 1997)

The distinction between the two conditions is usually not apparent at the concrete surface. To the Engineer, a surface line may indicate an unanticipated cold joint and a weakened plane for shear and tension. To the Contractor this surface imperfection may only be a pour line that will behave as if the concrete were monolithic, and the flaw can be dismissed as structurally unimportant. Therefore, further investigation to be conducted (Volz et al., 1997).

2.4 Effect of Cold Joint on Structures

Many researchers found that the effect of cold joint on structures on various conditions as described below. Rathi and Kolase (2013) stated that the cold joint impact the concrete strength in different scale from minor to major reduction. The most significant issues with cold joints are moisture intrusion into the joints and result in degradation of the concrete due to availability of the water in cold joint.

Ham & Oh (2013), Yoo & Kwon (2016) and Illangakoon et al. (2019) stated that the cold joint affects concrete structures including lower long-term strength, increasing the uncontrolled cracking, strength reduction, deterioration concrete structure, chloride diffusion, weakened durability and affects the aesthetic appearance.

Further, Farzad et al. (2019) studied about chloride intrusion in concrete element with cold joint and bulk concrete and stated that the comparison with bulk concrete, chloride intrusion was faster in concrete member with cold joint.

Koh et al. (2019) investigated about influence of carbonation depth in concrete member with cold joint under different stress conditions and found that the carbonation depth was high in concrete member with cold joint under tension. The effects of carbonation and chloride intrusion lead to affect the durability and service life of the concrete structure.

Qian & Xu (2018) stated that the cold joints between concrete layers lead to decrease the bond strength and increase the permeability which considerably affects its structural performance and safety of the dam.

Therefore, the presence of cold joint affects not only the strengths (compressive, tensile, shear and flexural) but also durability and appearance of the concrete structures.

2.5 Factors Effect on Cold Joint Properties

2.5.1 Delay Time

Qian and Xu (2018) examined the properties of cold joint corresponding to different casting time lags, they conducted different type of test such as tensile strength, chloride intrusion, UPV & attenuation of first arrival, water permeability test and alternating current resistance. The results reveal as follow;

- As shown in Figure 2-3, splitting tensile strength gradually decreases with delay time
- As shown inFigure 2-4, Ultrasonic pulse velocity is not sensitive with interval time. However, amplitude decline as interval time increases
- As shown in Figure 2-5, Chloride resistance decreases continuously with interval time
- As shown in Figure 2-6, Current resistance drops slowly but progressive as the time lag increases
- As shown in Figure 2-7, Water permeability increase with interval time

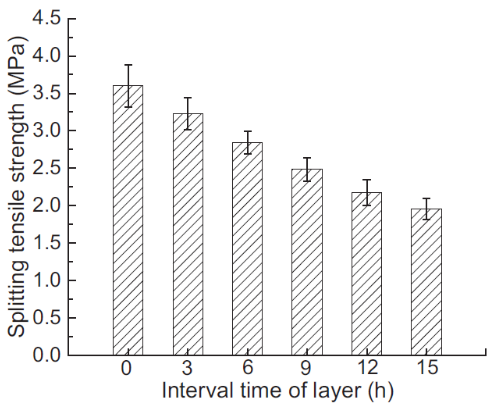

Figure 2-3 Tensile strength with different delay times (Qian and Xu, 2018)

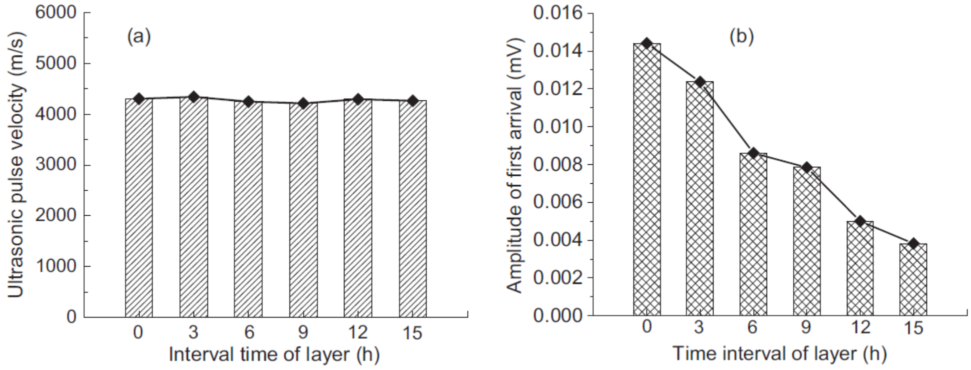

Figure 2-4 UPV test results: (a) velocity; (b) amplitude of first arrival (Qian and Xu, 2018)

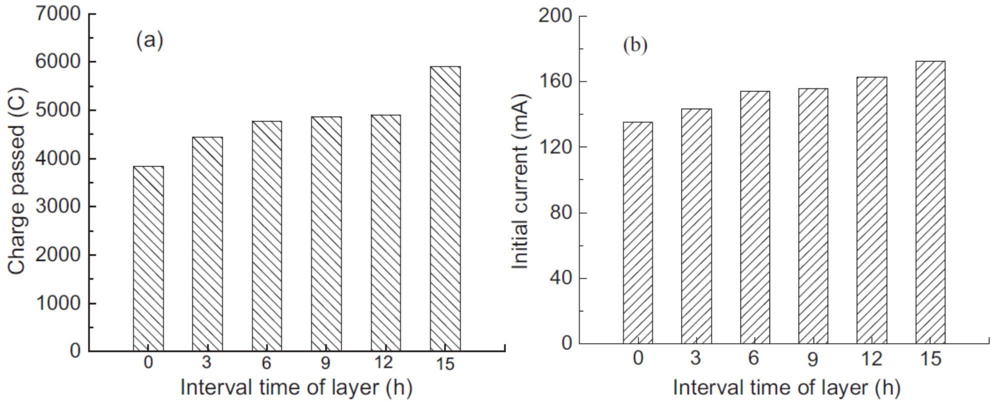

Figure 2-5 Chloride penetration: (a) charge passed; (b) initial current (Qian and Xu, 2018)

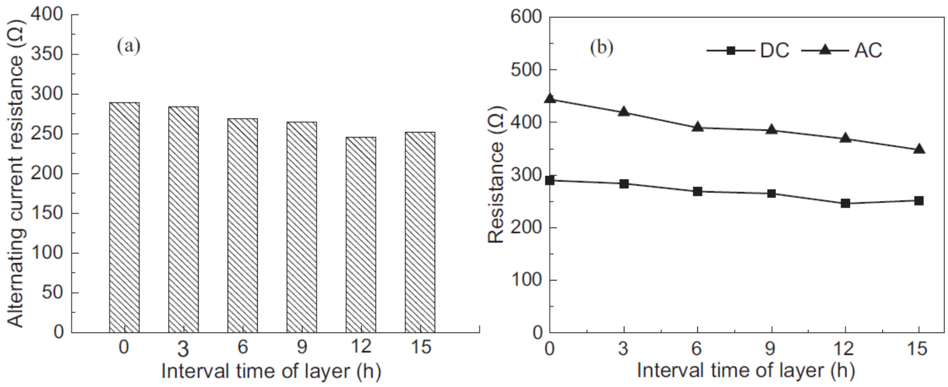

Figure 2-6 Result of alternating current resistance (Qian and Xu, 2018)

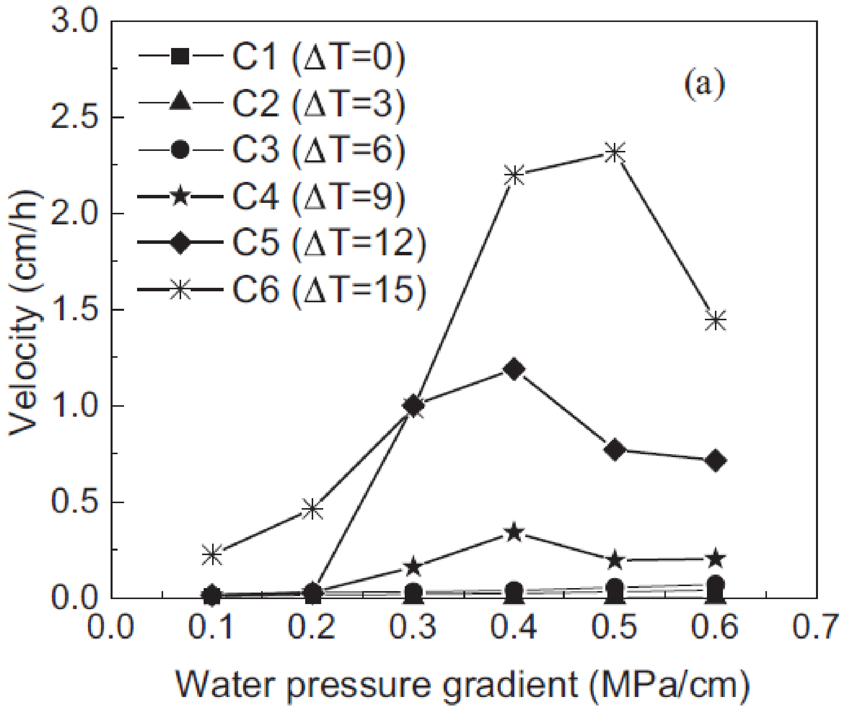

Figure 2-7 Result of water permeability test (Qian & Xu, 2018)

In addition, Rathi and Kolase (2013) stated that the tensile strength, compressive strength and flexural strength of concrete decrease with the delay in casting and irrespective to loading direction as shown in the Figure 2-8 to Figure 2-10. They conducted two different methods to identify the strength variation which are;

Stain concrete: - The concrete is prepared and immediately filled the half volume of moulds and balance volume of the mould is filled with a same mix as per the time lags.

Fresh concrete: - The concrete is prepared and immediately filled the half volume of moulds and balance volume of the mould is filled with concrete that prepared freshly as per the time lags.

The key difference between fresh and stained concrete is fresh concrete is mixed each time lags but strained concrete is mixed at once and fill the mould according to time lags.

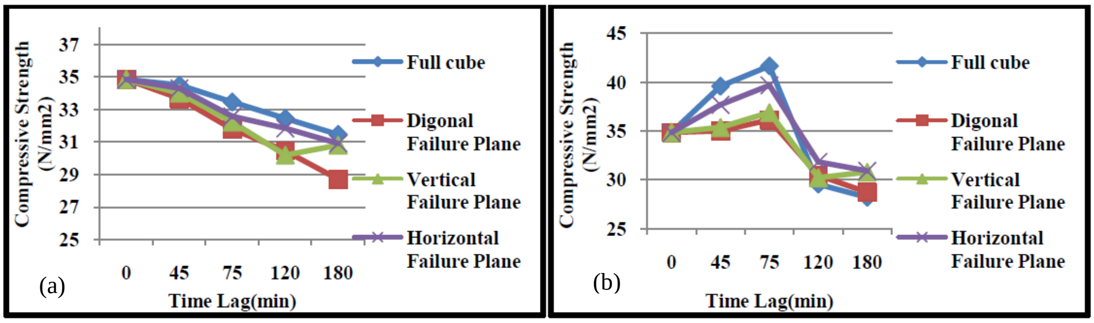

Figure 2-8 Comparison of compressive strength of (a); fresh and (b); strain concrete with delay time and different plane (Rathi and Kolase, 2013)

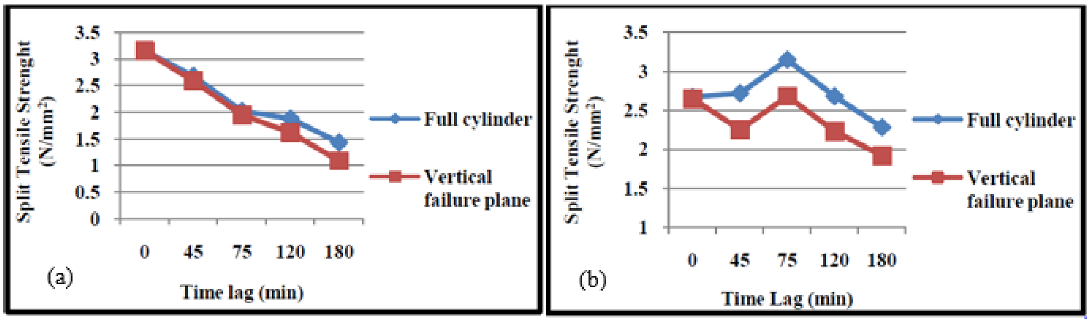

Figure 2-9 Comparison of split tensile strength of (a); fresh and (b); strain concrete with delay time (Rathi and Kolase, 2013)

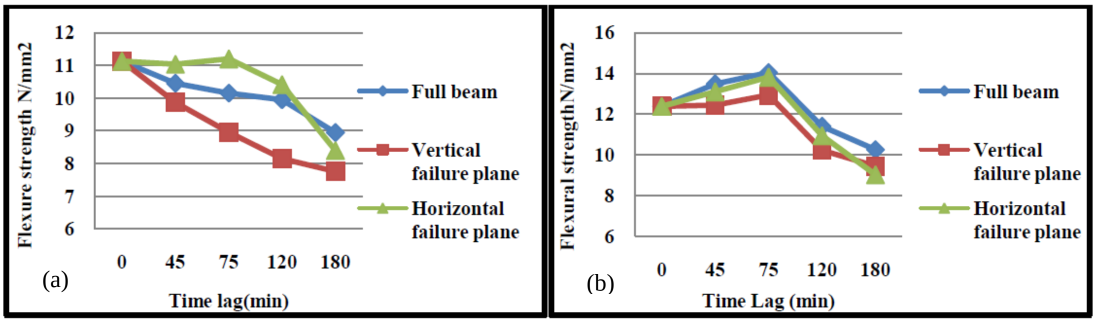

Figure 2-10 Comparison of flexural strength of (a); fresh and (b); strain concrete with delay time and different plane (Rathi and Kolase, 2013)

2.5.2 Water-Cement Ratio

Kyo and Uomoto (2001) reported that the flexural strength at cold joint in self compacting concrete decreases more rapidly when elapsed time is increased and especially when the water cement ratio (w/c) is low and the progress of carbonation depth at the cold joint is larger especially at low water cement ratio as shown in Figures 2-11 and 2-12 below.

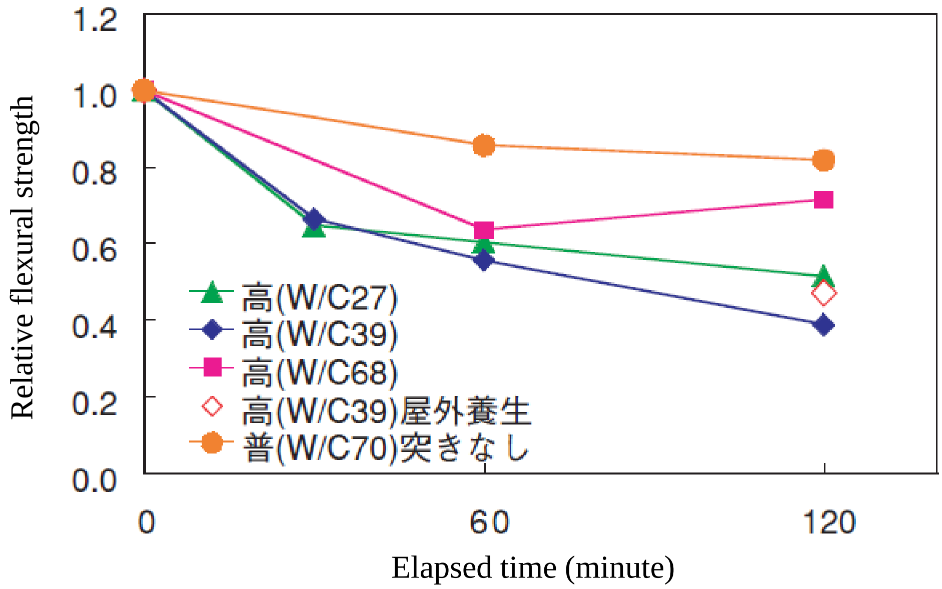

Figure 2-11 Effect of w/c ratio on relative flexural strength with elapsed time (Kyo and Uomoto)

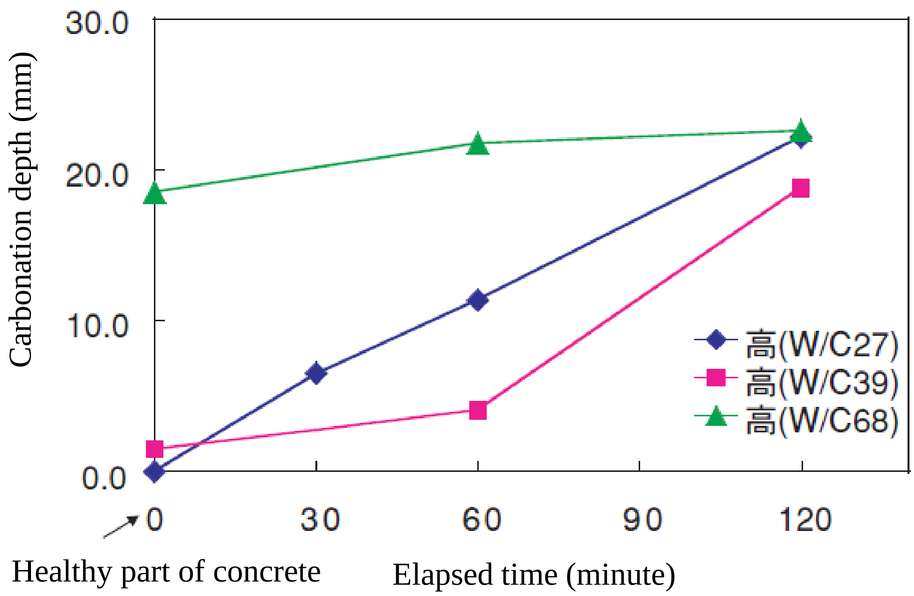

Figure 2-12 Effect of w/c ratio on carbonation depth with elapsed time (Kyo and Uomoto)

2.5.3 Grade of Concrete

Mohamadien (2013) reported that the tensile strength, flexural strength and compressive strength reductions are more influence in higher grade as shown in Figure 2-13, 2-14 and 2-15 below.

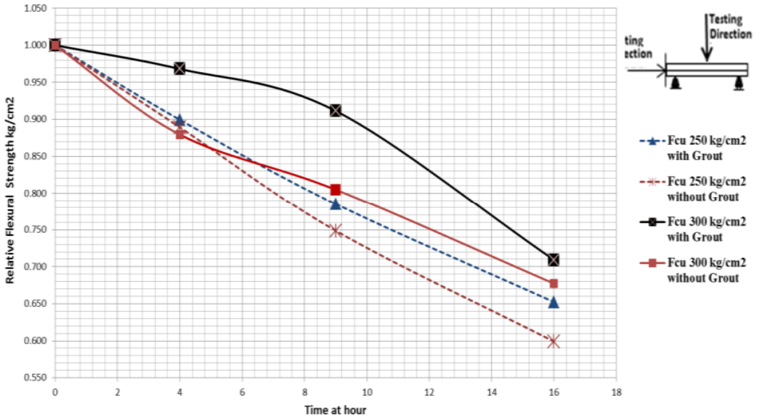

Figure 2-13 Relative flexural strength and lag time with different grade of concrete (Mohamadien, 2013)

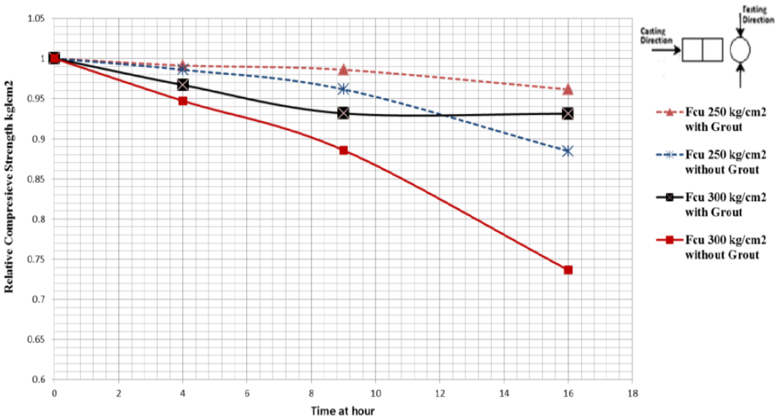

Figure 2-14 Relative splitting tensile strength and delay time with different grade of concrete (Mohamadien, 2013)

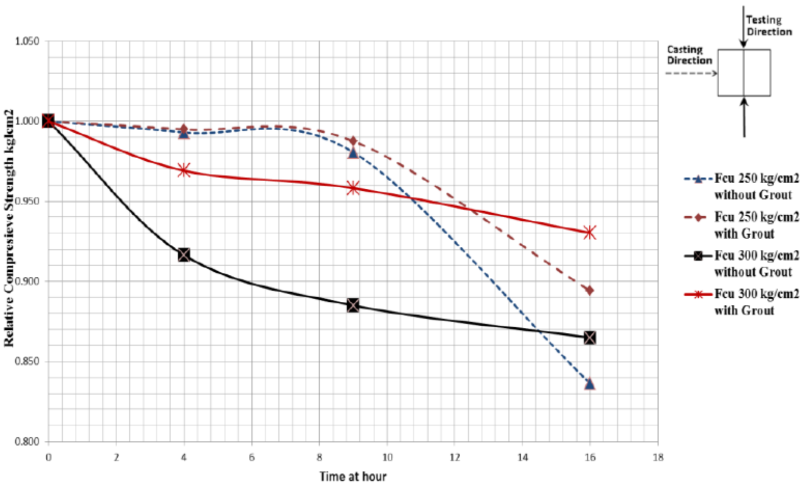

Figure 2-15 Relative compressive strength and lag time with different grade of concrete (Mohamadien, 2013)

2.5.4 Surface Roughness of Substrate Concrete

Courard et al. (2014) reported that the concrete layers interface bond behaviour highly influenced by cleanliness of the substrate as depicted in below Figure 2-16. The interface bond strength is increased when increasing the substrate roughness due to increasing the friction between interface layers.

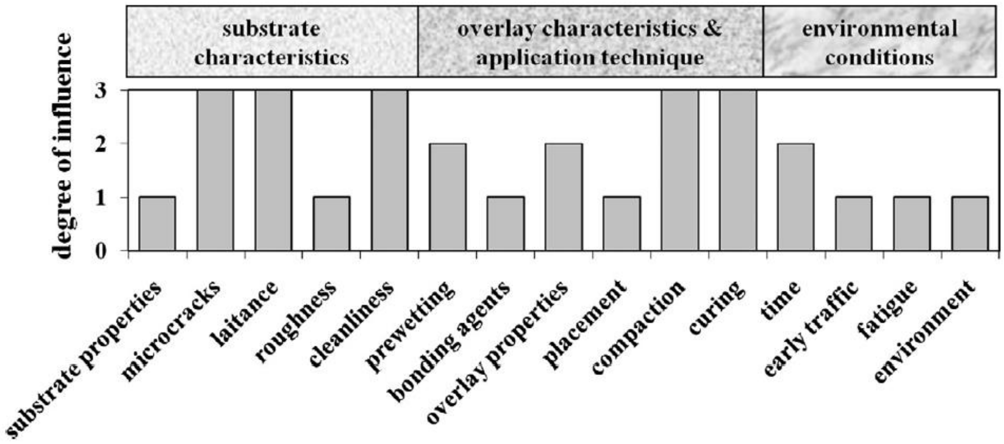

Figure 2-16 Factors influence the bond between substrate concrete and repair material (Courard et al., 2014)

Santos et at. (2006) examined about influence of substrate surface roughness on bonding strength between two concrete layers. They conducted slant shear test and pull off test on different substrate roughness. As shown in Figure 2-18, the results clearly indicate that, sand blasting gives high bond strength.

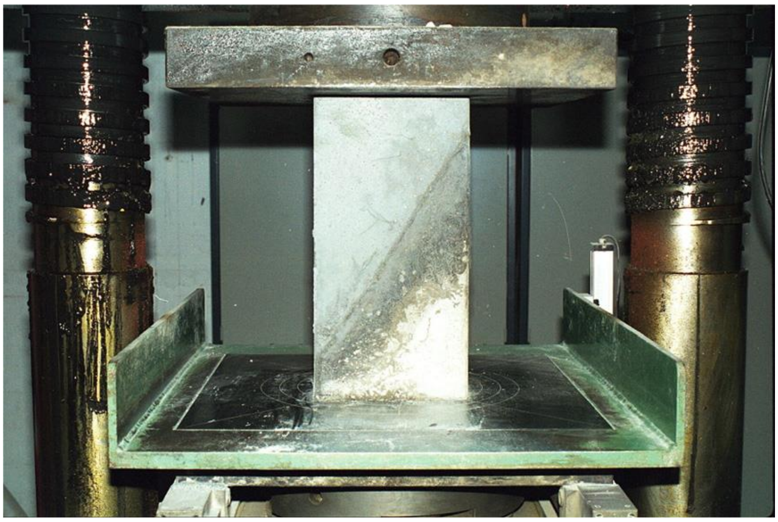

Figure 2-17 Slant shear test (Santos et al., 2006)

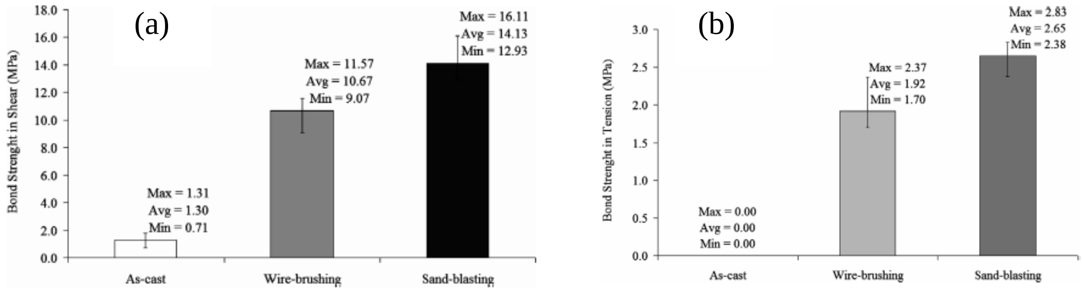

Figure 2-18 Test result: (a) Slant shear test; (b) Pull off test for different roughness (Santos et al., 2006)

Substrate concrete roughness normally assessed qualitatively by watching the concrete surface and by categorizing it from exceptionally smooth to exceptionally rough. However, different codes from different counties suggest different classification methods. As per EC 2, concrete substrate surfaces may be categorized as *"exceptionally smooth, smooth, rough or indented*" when concrete cast different time lags for shear strength. But, as per BS 8110 suggests the equipment which used to prepare the desired surface roughness on the substrate concrete surface. ACI 318 also mentioned two roughness categories.

2.5.5 Orientation of the Cold Joint/Loading Direction

Many researchers reported that the reduction in strength depends on inclination of cold joint and the direction of the state of the stresses (Torres et al., 2016, Tapkire & Kumavat, 2015, Rathi & Kolase, 2013 and Rafiei & Karimi).

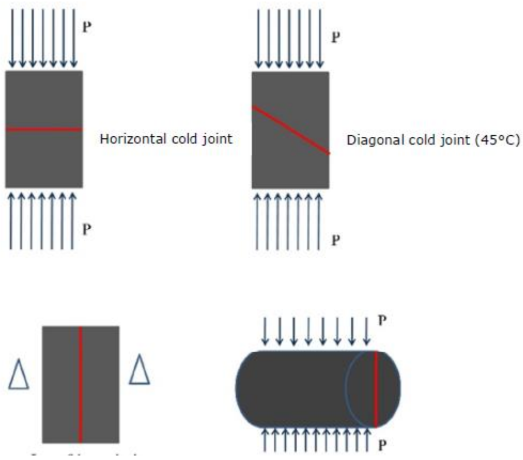

Figure 2-19 Testing of cylinders with cold joint at different orientation (Torres et al., 2016)

Torres et al. (2016) examined that the mechanical properties of cold joints under two complementary perspectives. a) a board experimental investigation conducted using cylinder specimens to quantify the loss of resistance because of formation of cold joints and b) the time dependent behaviour under load or without load of concrete simulative model is proposed, performed and analyzed. The smooth cold joints were formed in different plane such as horizontal, vertical and diagonal as well as different time intervals two to eight hours in the standard cylinder specimens. All the specimens were tested 3 days, 7 days and 28 days for compressive strength, indirect tensile strength.

As shown in Figure 2-20, cylinder specimens with horizontal cold joints do not affect the compressive strength. However, specimens with diagonal cold joints show 30% reduction in compressive strength.

Figure 2-21 shows stress and strain concentrations along the cold joint with different orientation (bulk, diagonal, horizontal) under compressive strength.

According to study based simulative model conducted by Torres et al. (2016), following conclusion were made specimens under compressive strength;

- Resistance in between two layers is less when concrete age is lower
- Resistance in between two layers is less when delay time is higher
- Resistance in between two layers is lesser when orientation of cold joint is 45° degree
- Resistance in between two layers is higher when orientation of cold joint is 0° degree (horizontal plane)

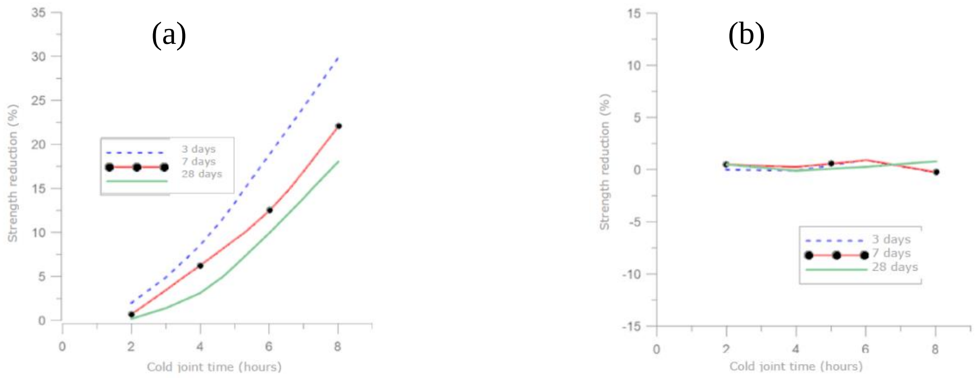

Figure 2-20 Compressive strength reduction with time: (a) diagonal; (b) horizontal (Torrer et al., 2016)

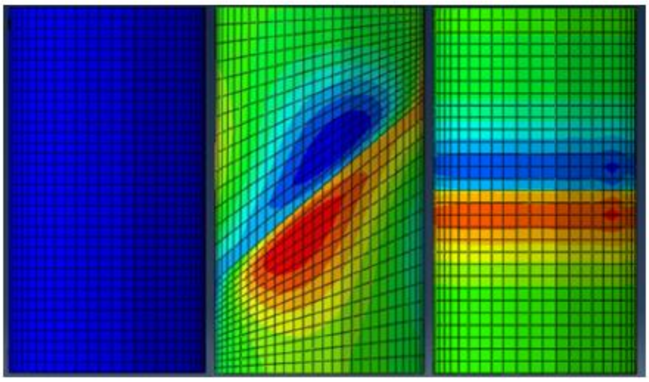

Figure 2-21 Axial stresses on an intact cylinder (left), with diagonal cold joint (centre) and horizontal cold joint (right) (Torrer et al., 2016)

Jafari et al. stated that there is a substantial association between the compressive strength and orientation of cold joint, with the most suitable angle of the cold joint being at 0° and the most unsuitable angle being at 45°, providing the highest and the least compressive strengths, respectively.

2.5.6 Re-vibration

2.5.6.1 Effect of Re-vibration on Compressive Strength

Rao et al. (2008) have done extensive experimental investigation on re-vibration with different water cement ratio changing from 0.35 to 0.7 and re-vibration interval of half an hour up to four hours and concluded that for certain delay time i.e., within the initial setting time of concrete, the compressive strength increases irrespective to water cement ratio. Figure 2-22 shows the variation of compressive strength with re-vibration interval.

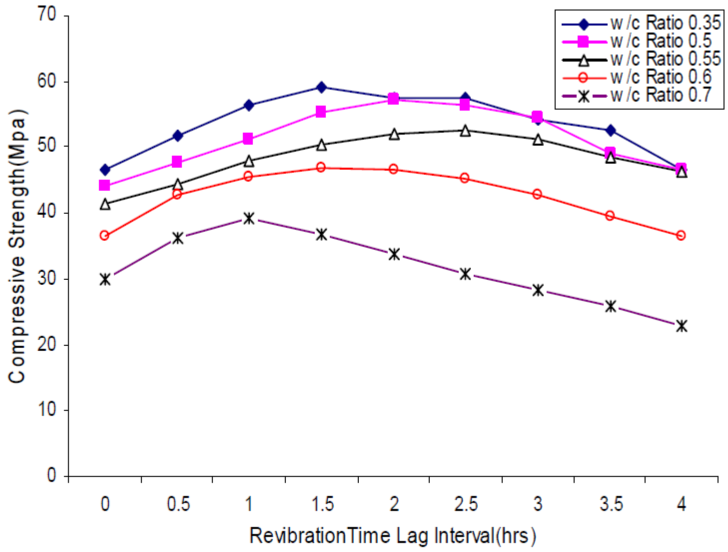

Figure 2-22 Compressive strength vs re-vibration time lag (Rao et al., 2008)

Experimental study done by Rahman (2007) influence of strength of concrete on re-vibration, delaying vibration and repeated vibration to understand the effects and processes involved and concluded that the concrete should be vibrated immediately after casting. The compressive strength improves when revibration carried out within the first one hours. Further, repeated vibration at closer time lags produced positive effects on concrete strength.

2.5.6.2 Effect of Re-Vibration on Cold Joint

Illangakoon et al. (2019) reported that the damageability of 1^{st} layer due to the re-vibration is highly influence the bond strength after the initial setting time. It means re- vibration after the initial setting time increasing the surface roughness of 1^{st} layer. However, the bond strength can be improved when re-vibration should be done before the final setting time of first layer. Figure 2-23 shows the damageability of first layer due to vibration.

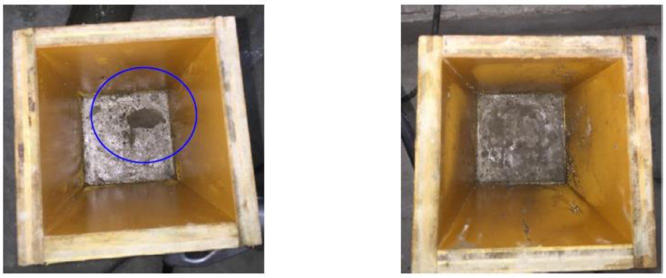

Figure 2-23 Damaged and undamaged concrete surface with different elapsed time (Illangakoon et al. 2019)

The revibration can be carried out when penetration resistance of concrete between 0.4 and 0.6 N/mm^2 and this penetration resistance range is not depending on the ambient temperature. After the penetration resistance of 0.6 N/mm^2, concrete should not be allowed to revibration by means of a poker vibrator. Therefore, cold joint can be formed when overlaying done after the penetration resistance of 0.6 N/mm^2 (Illangakoon et al. 2019).

2.5.7 Ambient Temperature

Illangakoon et al. (2019) reported that at high ambient temperature over 35 ° C, time interval for casting overlay was reduced. However, final outcome of strength reduction does not affect by the ambient temperature. Therefore, the voids formed due to the cold joints does not depend on the ambient temperature; instead, it depends on the setting process. The cold-jointed surface 's undesirable void structure does not rely on the ambient temperature; instead, it depends on the setting method.

2.5.8 Moisture

The moisture in the subgrade is also influence the bond strength. Past and present practice also advises that the substrate concrete be saturated in 24 hours to achieve the good bond strength prior to place the fresh concrete layer. However, bond strength decreases in case of free water or high moisture at the substrate surface (Santos et al., 2012).

2.5.9 Curing

There are no specific requirements for the curing process of composite members cast at various ages specified even in current standards and, thus, the effect of differential shrinkage is often ignored. This is a crucial parameter because in composite components there are different concrete element with different age of curing conditions. In order to increase the bond strength, it is generally suggested to start curing immediately after casting the added concrete, continued it for at least 3-7 days (Santos et al., 2012).

2.5.10 Additives

Until now a lot of additive materials are used for increase the bond strength of old to new concrete connection such as cement paste, bonding agent with different minerals, epoxy, fibers, etc. Additives are used on harden to harden concrete or fresh to harden concrete. But the outcomes of additives are not generally accepted by researchers (Rashid et al., 2019). The detail elaboration of effective additives given clause 2.6 to 2.8.

2.6 Traditional Techniques of Preparation of Cold Joints

There are many techniques adopted to improve the bond strength when adding fresh concrete to an existing harden concrete member. Generally, interface bond strength is improved by increase the surface roughness of substrate concrete. Usually, substrate surface treatment is adopted by means of chipping, wire brushing, water jetting, sand blasting, etc. Experimental investigation conducted by Julio et al., (2004), stated that the bond strength is improved when substrate surface treatment adopted using sand blasting compare with chipping or wire brushing. In addition to surface roughness treatment, the widely used traditional method for connecting old to fresh concrete or repair material and column jacketing are applying cement paste as additives in developing countries like Sri Lanka.

However, under loading different types of stresses induced at the interface of the composite element and under this loading condition, suitability of cement paste is as an adhesive have not been studied and researchers found that, due to its brittle nature, cement paste is poor in tensile resistance even after the substrate roughness surface treatment (Rashid et al., 2019 and Tapkire and Parihar, 2014).

There are some traditional measures to prevent cold joints in concrete:

(a) In the event of concrete recently cast in a fresh state, fresh concrete can be poured directly against the recently cast concrete if poker vibrators can penetrate the surface without much effort. Care should be taken that recently cast concrete surface should be covered as soon as possible by fresh concrete and both layers should be vibrated systematically.

(b) If the concrete has become a little tougher, but by a light hand pick, the top concrete area still easily removed, then the concrete top surface should be thoroughly racked and loose concrete particle should be removed without disturbing the balance part of concrete in depth. after that, a rich 12 mm thickness mortar layer is placed on that racked surface, then fresh concrete is placed on the rich mortar layer and vibration should be carried out fresh to old deep into the recently cast concrete layer.

(c) A simple test can be used to assess at site using poker vibrate whether can continue the concrete pouring or not if recently cast concrete becomes hard. Concrete pouring should not be continued when running poker vibrator penetrate into the recently cast layer, make distinct holes after removing the vibrator. In the above situation, concrete layer should be allowed to harden for at least 24 hrs. Then the harden concrete surface should be treated as a regular construction joint.

2.7 Modern Techniques of Preparation of Cold Joints

In addition to substrate surface treatment, "*styrene butadiene rubber (SBR)-latex, epoxy bonding agent and carbon fibre reinforced polymer (CFRP)*" are used for improve the bond strength of old to fresh concrete connection in modern life. Figure 2-24 shows application of bonding agent on old to repair mortar connection.

Figure 2-24 Application of bonding agent (http://www.cormix.com/)

Several binders and other material such as silica fume, metakaolin are being used at the interface of old to new layers as the repair material to increase the bond strength or improve the overly transition zone (Mohammadi et al., 2014).

Due to its extensive adhesive property as well as reducing the porosity at the interface of layers, polymer cement mortar is a well-known interface repair material (Rashid et al., 2015). when applying the polymer cement mortar on the harden substrate concrete, it forms a film layer and provide more adhesion in between the old to new concrete layer connection (Ohama, 1995). In the construction industry, many types of polymers are used: polymer acrylic ester (PAE) and styrene butadiene rubber (SBR)-latex are widely used for enhance the interface bond strength (Rashid et al., 2015). SBR-latex is applied at the interface to improve the bond strength as an adhesive. However, the cost of SBR-latex is very expensive.

Not only the polymers but also different kind of bonding agents are used to improve the interface bond connection between old to fresh concrete layers. Epoxy is the common organic bonding agent that can be strengthened by any fiber to improve the adhesion (Frigione et al., 2006). Epoxied joints under shear forced, effect of environmental conditions and moisture were studied on precast concrete box girder and the results are shown that epoxy bonding agent can be used as an adhesive layer (zhou et al., 2017).

Carbon fiber-reinforced polymer (CFRP) has been broadly used to improve the adhesion properties between concrete to concrete or concrete to steel and also used strengthening of concrete structures externally. Therefore, strength of the composite element significantly depends on bond between CFRP and concrete (Naphon et al., 2016). Adhesive with CFRP at interface of the layer may improve the structural capacity of member but failure of debonding is a real time issue in the composite elements. The main failure of composite member is debonding of adhesive layer. The interface bond strength between precast and in situ cast members or between precast members can also be enhanced by CFRP. However, CFRP together with additive for interface bonding characteristic has not been studied yet.

However, the connection between whether old to fresh or old to old concrete layers are still recognized as the weakest zone and should be strengthened (Rashid et al., 2019). Further, fresh to old or precast to precast concrete parts but the outcomes of advantages are not generally accepted by researchers.

Therefore, prevention is better than cure. To avoid the cold joint formation rather than rectifying cold joint, following methods are practices;

- Conduct the trail mix at site and ensure the slump retention according to site weather condition
- Cool the ingredients prior to mixing
- Locate the batching plant to reduce the transport time and place and complete the concrete as soon as possible
- Chose the concrete placing time at night or favorable weather
- Prepare the pouring schedule/patterns if mainly large volume concrete
- Make the shading arrangement for direct sunlight and wind barriers to limit the moisture loss during the concrete placement
- The retarding agent in concrete to extent the setting time
- Backup arrangements for plant and tools to ensure the continues operation during the unforeseen breakdown of plant or tools

2.8 Previous Studies on Eliminating Cold Joint (old to new)

Rashid et al. (2019) has done a broad experimental investigation to assess the effect of adhesive layers while the concrete member subjected to tensile and shear stresses. The experiment was conducted on old to freshly cast concrete. In this investigation, different type of adhesive material (carbon fibre reinforced polymer, cement paste, styrene butadiene rubber-latex and epoxy bonding agent) which often used in the construction industries were used.

Split tensile strength, bi-surface shear strength and slant shear strength tests were conducted on these composite specimens to evaluate their performance under different stress conditions such as shear, tension and tension-shear stress. The detail of experiments shown in Figure 2-25 and Figure 2-26.

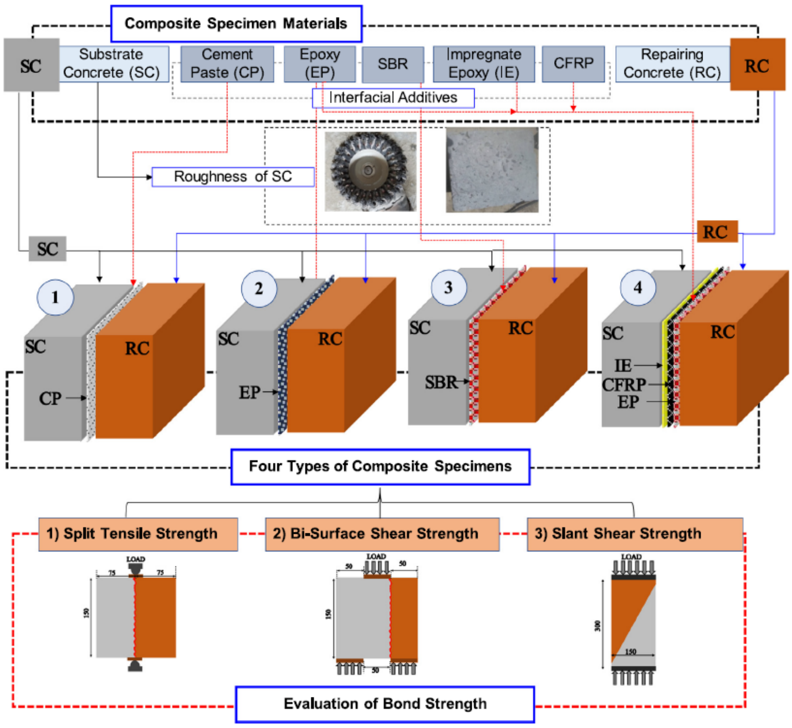

Figure 2-25 Composite specimens and bond strength test (SC= Substrate and RC= Repairing concrete) (Rashid et al., 2019)

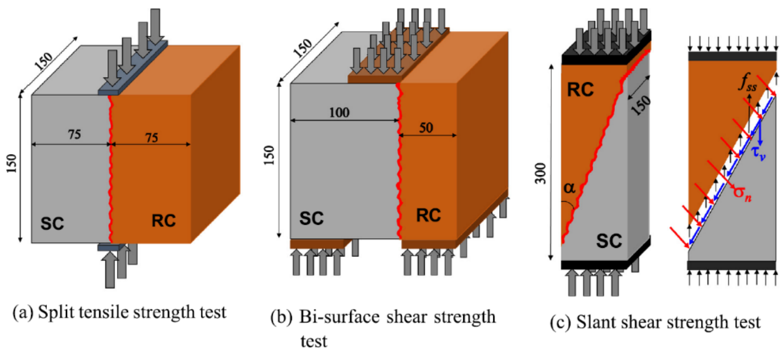

Figure 2-26 Schematic diagrams of interface bond strength test (Rashid et al., 2019)

The bond strength is mainly depending on the repair material. The mechanical anchorage between the new matrix and the old substrate concrete along with the chemical adhesion forces define the ‘‘adhesive” process. Figure 2-27 shows chance of failure modes of composite specimens.

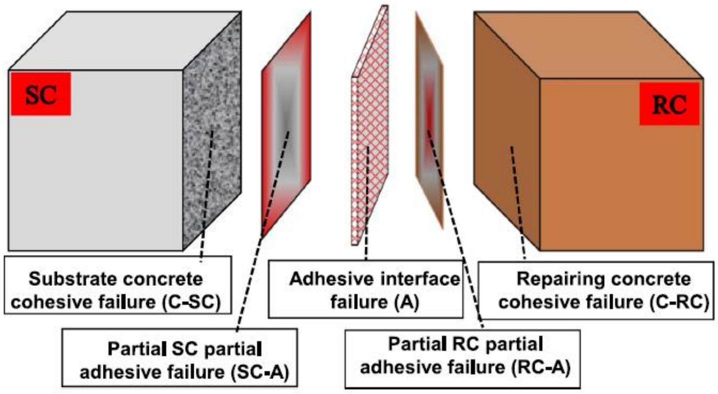

Figure 2-27 Possible failure modes of specimens (SC= Substrate and RC= Repairing concrete) (Rashid et al., 2019)

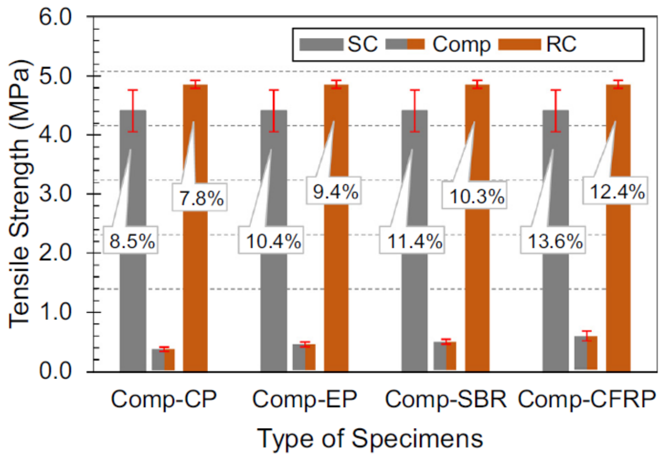

Figure 2-28 Comparison of split tensile strength on bulk and composite specimens (Rashid et al., 2019)

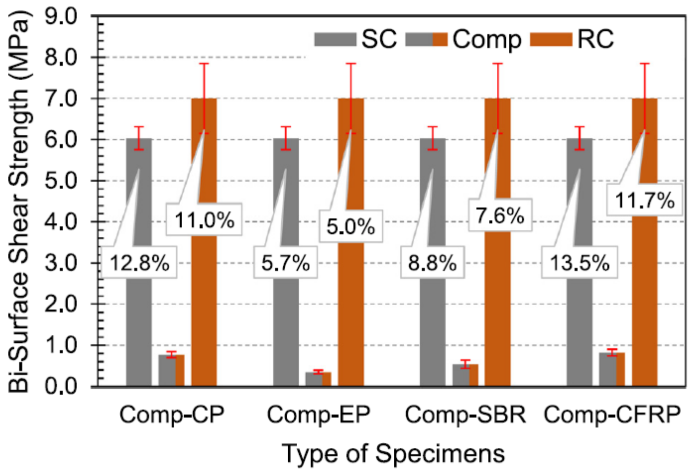

Figure 2-29 Comparison of bi-surface shear strength on bulk and composite specimens (Rashid et al., 2019)

As per test result shown in Figure 2-28 and Figure 2-29, following conclusions have been extracted by them.

- Cement paste as an adhesive gives brittleness and sufficient interlocking at interface of concrete layer, resulting in poor in tension and strong in shear strength, respectively
- The epoxy bonding agents exhibited strong resistance against tension but against shear stress had lower value compare with other three composite specimens. According to the failure mode, reason of lower value was proved. Since, epoxy was attached to the substrate concrete
- Under all types of interface bond strength experimentation, SBR-latex exhibited good mechanical performance and observed tensile strength was 33.3% and 9.8% higher than that of cement paste and epoxy, respectively. The composite specimens under combined shear-tensile stresses, SBR-latex exhibited good performance
- When the composite specimens under shear/ tensile stress, CFRP as an adhesive exhibited the finest performance. The shear strength and tensile strength are improved due to the good interlocking

Santos et al. (2012) has done experimental investigation to evaluate the influence of surface roughness treatment and epoxy bonding agent on the interface bond strength of concrete layers under two different distinctive situations harden concrete against harden concrete part and fresh concrete overlaid against hardened concrete. They conducted bi-surface shear test on specimens and test result is shown in Figure 2-30. As per test result, they concluded as follows;

- When concrete layers cast at different time lags for a member, surface roughness, moisture and use of bonding at the interface of the layers have a significant impact on interface bond strength as well as mode of failure
- The surface roughness of substrate with epoxy provides good interface bond strength when old to fresh concrete connections
- When the substrate concrete surface treatment carried out by sand blasting, the role of bonding agent on bond strength is less pronounced
- The effect of substrate surface preparation is less impact when the substrate is saturated or has moisture content, even though its surface is dry. In these

circumstances, improvement of bond strength when use of epoxy bonding agent is high. However, above conditions with a dry substrate, the influence of epoxy boding agent is low

- The effect of surface preparations is not important when two precast elements are bonded together using the bonding agent

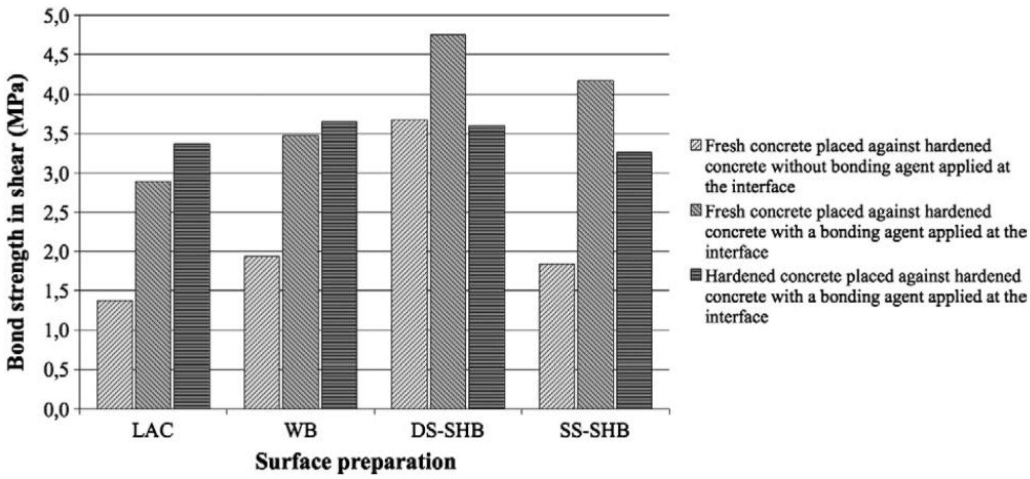

Figure 2-30 Bond strength in shear (Substrate conditions; left as-cast (LAC), wire brushed (WB), Shot blasting (SHB), dry (DS) and saturated (SS)) (Santos et al., 2012)

Julio et al. (2005) also has done study about effects of the surface preparation and epoxy bonding agent on the interface concrete bond strength as the same as done by Santos et al. (2012). They conducted slant shear test and pull off test and concluded that if substrate surface roughness is done properly, improvement of the bond strength is not influenced by epoxy bonding agent. It should also be noted that sand blasted concrete surface roughness offers better bond strength than applying the selected epoxy bonding agent.

Tapkire and Parihar (2014) examined the effect on cold joint properties by applying the cement slurry. They conducted "*compressive strength, flexural strength and split tensile strength*" tests with three different planes and different delay times 60 min, 230 min, and 24 hrs. on different types of M20 grade concrete, such as fresh concrete stained concrete and stained concrete with cement slurry. They found that the bond strength shows small improvement when cement slurry applied on stained concrete as compare to stained concrete and fresh concrete in horizontal failure plane.

Mohamadien (2013) examined the effect on cold joint properties by applying the cement slurry (water/grout 2:1) and splashing water. They conducted compressive, flexural and split tensile strength on concrete of M25 and M30 grade concrete with three different planes and different delay times 4hrs, 9hrs, and 16hrs. They found that use of grout coating material in forced separation has a positive impact on improving its mechanical properties. Figure 2-13, Figure 2-14 and Figure 2-15 presented in clause 2.5.3 show the test results of flexural, splitting and compressive strength of specimens, respectively. Summary of the above experimental results are as follows;

(a) Tensile strength, compressive strength and flexural strength decrease with increasing the casting time of 2nd layer whether coated with grout or water

(b) The use of grout to treat the first layer just before casting the second layer will improve the strength properties of concrete

(c) The mechanical properties of concrete grade 30 are more influence than concrete grade 25 when presence of cold joint

(d) Impact of grout on concrete strength has more effect on grade 30 concrete

2.9 Setting Time of Concrete

Setting time of concrete is a main factor influence the formation of cold joint. Therefore, it is important to understand the setting time of concrete. A typical vicat apparatus is used to be found the setting time of cement in laboratory conditions. Setting time shows the consistency of cement. setting time of concrete and cement are not be same. In other words, Concrete setting time does not coincide with the cement setting time that the concrete is made of. Concrete setting time depends on external factors such as ambient temperature, humidity, solar radiation, wind as well as properties of material such as admixtures, water cement ratio and cement type. For the civil construction works, the concrete setting parameter is more practical importance rather than the setting time of cement. Therefore, keep the concrete in plastic condition, retarding plasticizers are used to increase the setting time of concrete.

The setting time of concrete is conducted by penetrometer test. Testing procedure is covered by ASTM C – 403 [4]. The same testing procedure may also be applied for prepared mortar and grouts.

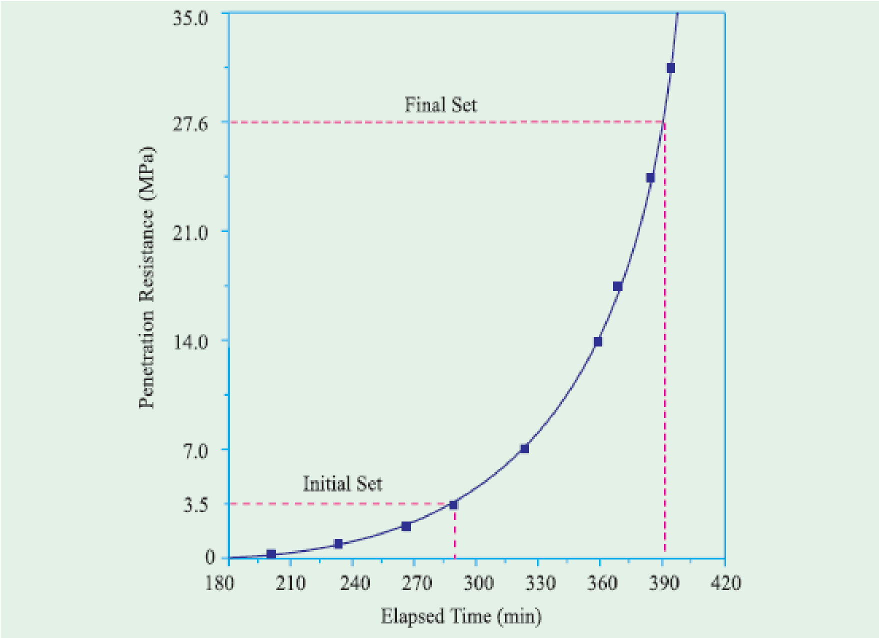

Figure 2-31 Setting time of concrete (Neville, 2011)

The point of intersection of the line parallel to the x-axis and passing through 3.5 MPa of penetration resistance with the smooth curve provides the initial setting time (Figure 2-31). In the same way, a horizontal line is drawn through the 27.6 MPa penetration resistance and point it cuts the smooth curve is read on the x-axis which provides the final set. Figure 2-32 explains the stages of hardening process of cement paste.

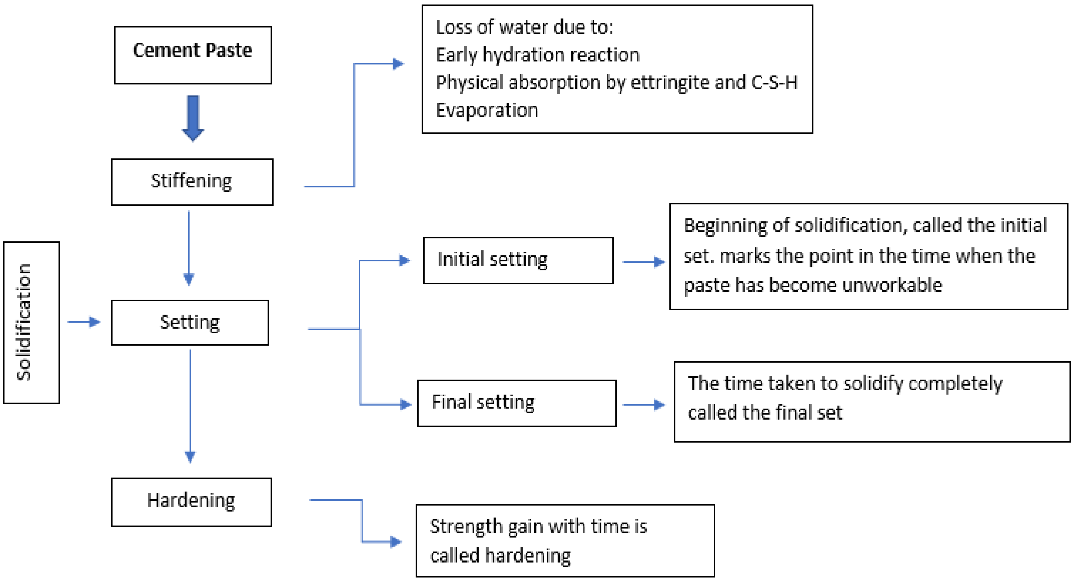

Figure 2-32 Stages of hardening process of cement paste (Neville, 2011)

2.10 Mix Design (DOE Method)

An enhancement of road note No.4 method is the DOE mix design method. This method of concrete mix design or proportioning approach primarily based on the systematic field and laboratory experiment performed by road research laboratory U.K (British (DOE) Method, 1988).

In essence, the DOE method consists of 8 steps, as follows:

Step 1. Determine the target mean strength f_m from the specified characteristic compressive strength at 28 days f_c and the quality control of the materials.

$f_m = f_c + 1.64\ s$ where s is the standard deviation reference to Figure 2-34 (based on past experience)

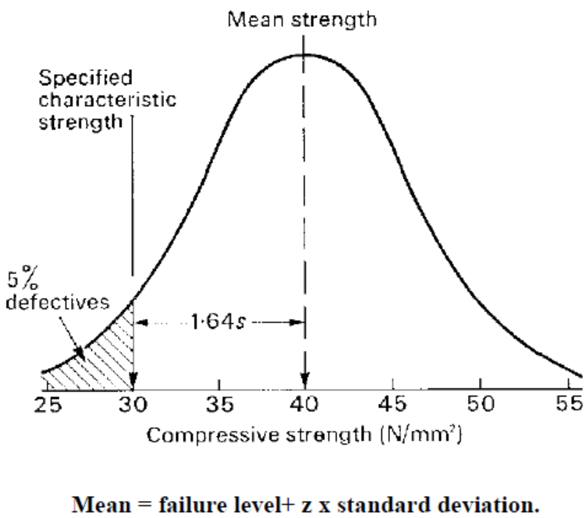

Figure 2-33 Normal distribution (British (DOE) Method, 1988)

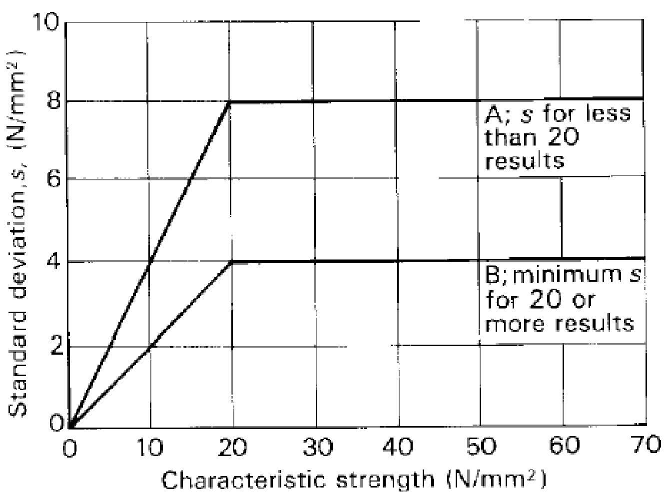

Figure 2-34 Standard deviation (British (DOE) Method, 1988)

Step 2. Obtain the w/c for the desired target mean strength using empirical relationship between compressive strength and w/c ratio according to Table 2-1 and Figure 2-35.

Table 2-1 Approximate compressive strength (MPa) of concrete mixtures made with a free w/c ratio of 0.5 (British (DOE) Method, 1988)

Type of Cement	*Type of C.A*	*Compressive Strength at the age (cube) of days MPa*			
		3	*7*	*28*	*91*
Ordinary Portland cement (Type I) / Sulphate Resisting Cement (Type V)	uncrushed	22	30	42	49
	Crushed	27	36	49	56
Rapid-Hardening Portland Cement (Type III)	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

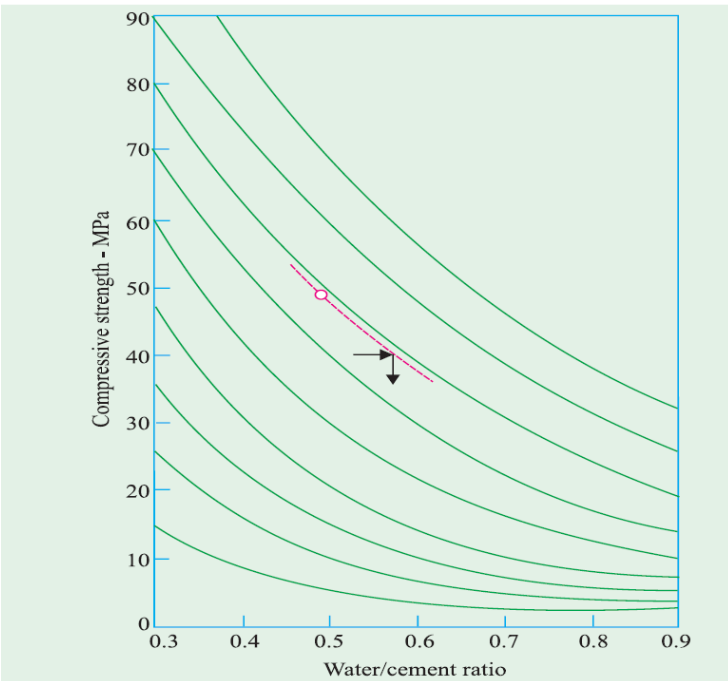

Figure 2-35 Relationship between compressive strength and w/c ratio (British (DOE) Method, 1988)

Step 3. Estimate approximate free water content based on required slump and aggregate type according to Table 2-2.

Table 2-2 Approximate water content (kg/m^3) required for corresponding workability (British (DOE) Method, 1988)

Slump, mm		0-10	10-30	30-60	60-180
V-B time, sec		> 12	6-12	3-6	0-3
Maximum size of aggregate	Type of aggregate				
10 mm	Uncrushed Crushed	150 180	180 205	205 230	225 250
20 mm	Uncrushed Crushed	135 170	160 190	180 210	195 225
25 mm	Uncrushed Crushed	130 166	155 186	175 206	190 221
40 mm	Uncrushed Crushed	115 155	140 175	160 190	175 205

Step 4. Determine cement content from W/C ratio and water content using step 2 and step 3

Step 5. Estimate the wet density for fully compacted concrete using Figure 2-36.

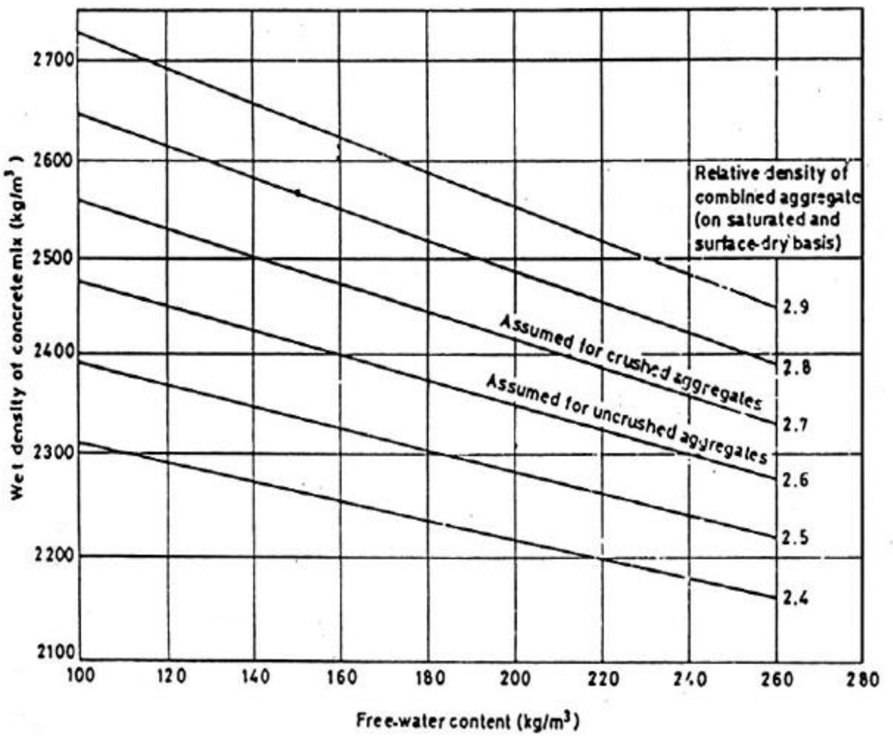

Figure 2-36 Relationship between wet density of concrete and free water content (British (DOE) Method, 1988)

Step 6. Determine the total aggregate content.

Step 7. Determination of fine aggregate content using Figure 2-37.

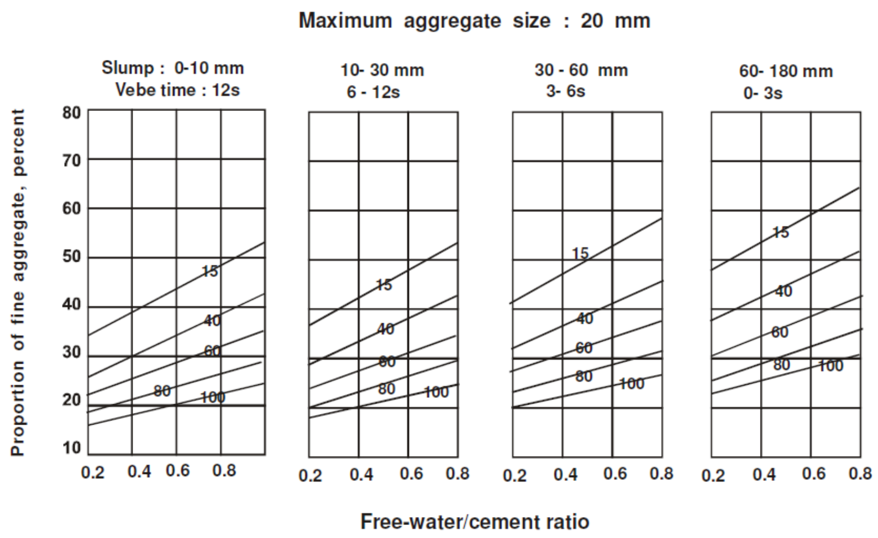

Figure 2-37 Relationship between fine aggregate and W/C ratio (British (DOE) Method, 1988)

Step 8. The difference between total aggregates content and fine aggregate content gives the content of coarse aggregate.

2.11 Bonding Agent

Emaco 157D Primer (barra emulsion 57D) was used as bonding agent of this research work. Since it is quality certified product from BASF as well as this product is being used at every construction site in Sri Lanka.

2.11.1 Applications

Emaco 157D Primer is the ideal SBR-latex recommended for use:

- With cement as a bonding slurry
- In weather resistant exterior or interior renderings
- In floor screeds and toppings, or plasters for improved chemical resistance
- In repair of honeycombed and spalled concrete, beams and precast elements
- In tile or mosaic bedding compounds for bedding tiles or re-fixing slip bricks

2.11.2 Features and Benefits

- Water resistant
- Excellent adhesion to concrete, steel and brick
- High abrasion resistance

- Good resistance to salts, mineral oils and many other chemicals
- Reduces bleeding
- Greatly increased durability
- High flexibility
- Plasticizing effect and reduced shrinkage
- Highly increased tensile strength
- Non-toxic. Can be used in contact with potable water
- Improved corrosion protection
- Lower water/cement ratio
- Promotes high early strength in mortars

2.11.3 Application Method

Bonding slurry (priming) - Apply a slurry onto the still damp substrate, consisting of 1 part EMACO 157D PRIMER and 2 parts by volume of cement, mixed to a lump-free creamy consistency (BASF, 2019). A stiff brush should be used to work the bonding slurry well into the damp surface. This slurry should not be applied in a thickness exceeding approximately 2 mm. The mortar must be placed wet-on-wet. If the slurry does dry, a further slurry coat must be applied (BASF, 2019).

2.12 Testing

Sampling and testing for fresh concrete and harden concrete will be done as follows;

- Sampling of fresh concrete as per BS EN 12350-1:2000 [14]
- Dimensions, shape, and other requirements of moulds and specimens as per BS EN 12390-1:2012 [16]
- Casting and curing specimens for strength test as per BS EN 12390-2:2000 [17]
- Compressive test of test specimens as per BS EN 12390-3:2009 [18]
- Splitting tensile strength as per IS 5816:1999 [28] alternative apparatus for splitting cubes (Refer Figure 2-38)

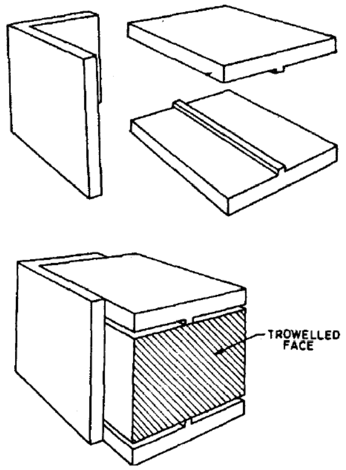

Figure 2-38 Alternative apparatuses for splitting cubes (IS 5816, 1999)

2.13 Calculations for splitting tensile strength

The splitting tensile strength (f_{ct}) of the specimen shall be calculated using following Equation 01;

$$f_{ct} = \frac{2P}{\pi l d} \quad \text{Equation 01}$$

Where; f_{ct} = Splitting tensile strength,

P = maximum load in Newtons applied to the specimens,

l = length as shown in Figure 2-39 (in mm) and

d = cross sectional dimension as shown in Figure 2-39 (in mm)

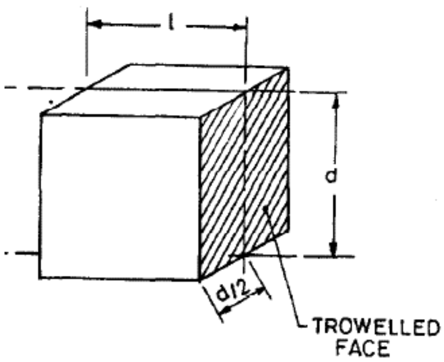

Figure 2-39 Specimens for splitting tensile strength (IS 5816, 1999)

2.14 Summary of Literature Review

In this chapter, relevant information taken from books and research papers for carrying out the research in a systematic manner has been discussed. It covers various theories, definitions and experiments regarding the mechanical properties of cold joints and effect of bonding agent on cold joint, specifications and guidelines of material properties, sampling and testing.

Literature analysis indicates that a variety of studies have been carried out to study the old to new concrete connections along with surface preparations ((Courard, et al., 2012), (Qian & Xu, 2018), (Rao & Kishen, n.d.), (Rashid, et al., 2020), (Santhos, et al., 2012) and (Santos, et al., 2006)). Moreover, most of the studies have been mainly undertaken to understand the effect of cold joints in concrete structures as well as properties of cold joints ((Illangakoon, et al., 2019), (Choi, et al., 2015), (Farzad, et al., 2019), (H.A. Mohamadien, 2013), (Jatheesan, et al., 2010), (Rao, 2013), (Xu, et al., 2001), (Kyo & Uomoto, 2000), (Lee, et al., 2016)). Most of these cold joint elimination studies applied to old to new concrete layers and not just past initial setting time concrete to new concrete without surface preparations. Forming cold joints due to unforeseen reasons and unintentionally, affects structural properties as well as the appearance. However, the method of eliminating these cold joints has not been studied yet.

Based on the literature review, a laboratory testing approach has been adopted for proper understanding on cold joint properties and alternative methods to eliminate the cold joint. Therefore, compressive strength and splitting tensile strength have been tested on specimens which having cold joint with different lag times.

CHAPTER - 3

3.0 EXPERIMENTAL INVESTIGATION

3.1 Introduction

Generally, the development of experimental investigation to find out the properties of cold joints in concrete requires the proper understanding of all related mechanisms and the relationship between the various influencing parameters. The various parameters taken in this experimental programme which based on literature review and related standards are shown in Figure 3-1.

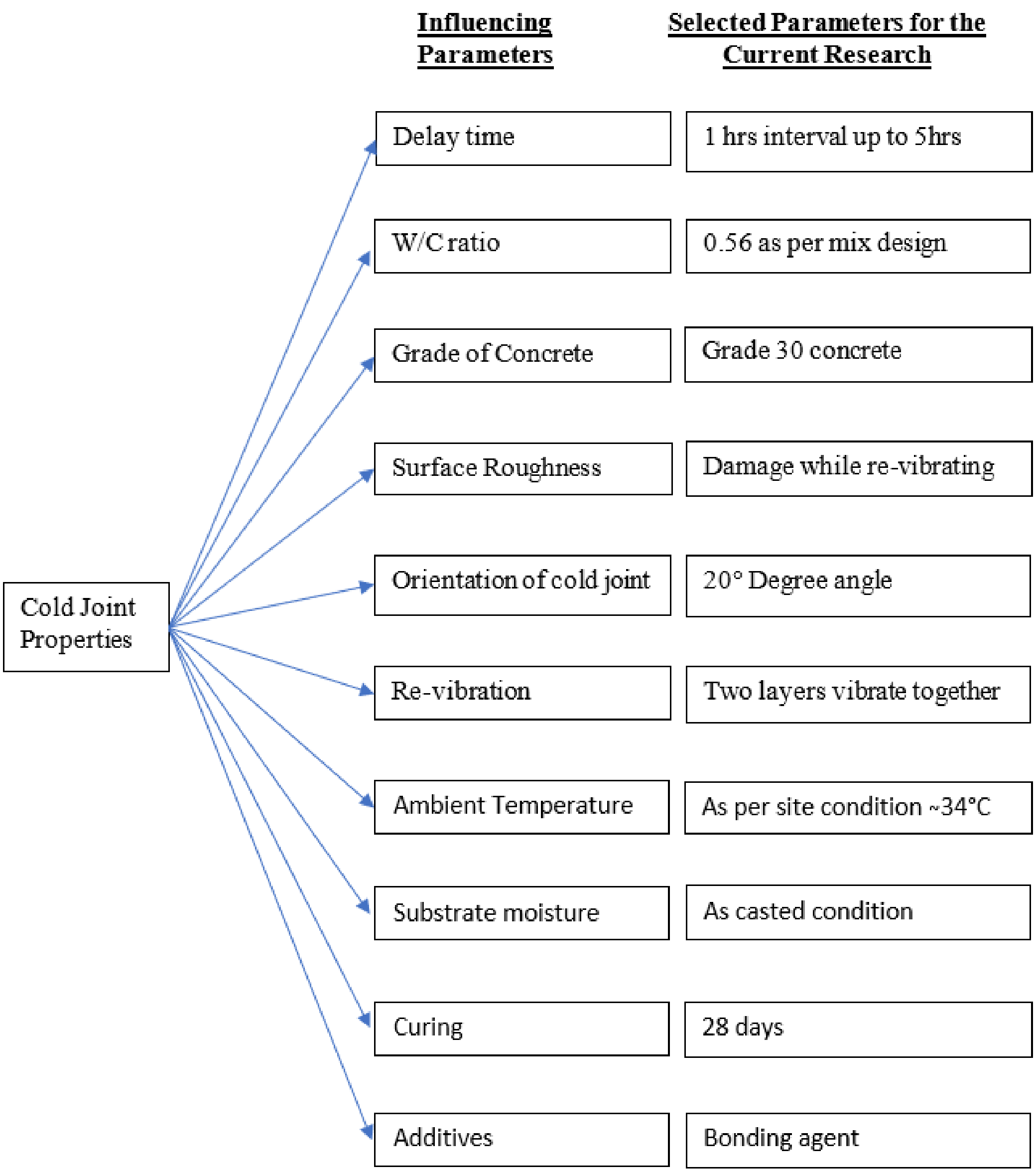

Figure 3-1 Overview of test program

3.1.1 Methodology

The main objectives of this research were to investigate cold joint properties with time lags and alternative method to eliminate the cold joint. The methodology flowchart is shown in Figure 3-2.

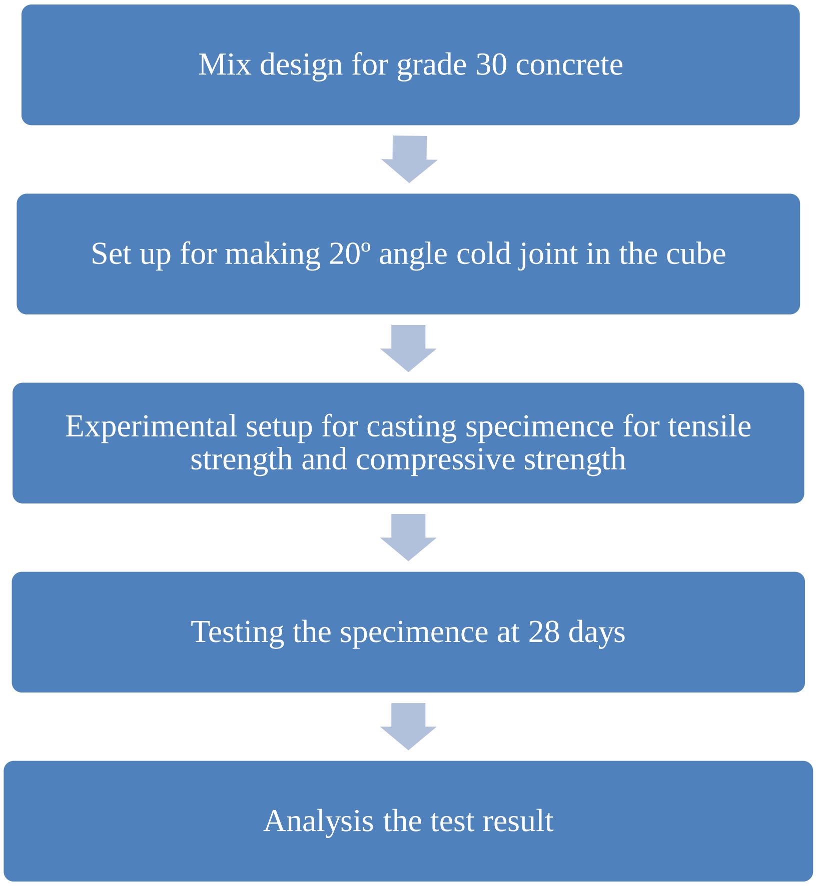

Figure 3-2 Methodology flowchart

3.2 Materials

The materials used in the study were comprised of;

- Cement
- Fine Aggregate
- Coarse Aggregate
- Water
- Bonding Agent – Emaco 157D [7]

3.3 Characteristics of Materials

3.3.1 Cement

Ordinary Portland Cement (OPC) strength class of 42.5N, brand name of Nippon cement was used as shown in Figure 3-3 [56]. The physical properties and chemical composition obtained from manufacture's test report are shown in Table 3-1.

Figure 3-3 Nippon cement

Table 3-1 Physical and chemical properties of cement (Tokyo Cement Company (Lanka) PLC, 2019)

Physical Properties				
	Test/Unit	Test Method	Results	Requirement SLS 107:2015 Strength Class 42.5 N
1	Compressive Strength (N/mm^2) 28 days	SLS:ISO 679:2011	57.2	≥ 42.5 & ≤62.5
2	Setting Time (minutes) (a) Initial	SLS ISO 9597 :2011	125	≥ 60
3	Soundness, mm		0	Not more than 10
4	Standard Consistency (%)		28.8	
Chemical Composition				
	Test/Unit	Test Method	Results	Requirement SLS 107:2015 Strength Class 42.5 N
1	Sulphate Content (expressed as SO_3)/ % by mass	SLS ISO 29581-1 :2011	2.6	≤3.5
2	Insoluble Residue / % by mass		0.5	≤5.0
3	Loss on Ignition / % by mass		1.3	≤5.0
4	Chloride Content / % by mass		0.02	≤0.10

3.3.2 Aggregate

The natural river sand as fine aggregate and crushed granite stone as coarse aggregate were used for this experimental study as shown in Figure 3-4. Both aggregates were tested to ensure the required characteristics of the material. The physical properties namely; water absorption, unit weight, specific gravity, finus modulus, aggregate impact value (AIV), Los angeles abrasion values (LAAV) have been tested according to standards specified in Table 3-2 below.

Figure 3-4 Fine and Coarse aggregates

Table 3-2 Standards used for testing

Type of Test	Standard
Sieve Aalysis for Coarse aggregate	BS812 Part 103:1985
Aggregate Impact Value	BS812 Part 112 :1990
Flakiness Index	BS812 Part 105
Water Absorption	BS812 Part 2 :1985
Specific Gravity	BS812:1985
Sieve Aalysis for fine aggregate	BS882:1992

The laboratory results of sieve analysis (Figure 3-5), aggregate impact value, flakiness index, water absorption are presented below Table 3-3 to Table 3-6, respectively.

Figure 3-5 Sieve analysis for coarse aggregate

Table 3-3 Seieve analysis coarse aggregate (Annex -1.1)

Weight (g)	2832				
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Total Passing (%)	Limits (%)	
63.0	0	0.0%	100.0%	100	100
37.5	0	0.0%	100.0%	100	100
20.0	83	2.9%	97.1%	90	100
14.0	985	34.8%	62.3%	40	80
10.0	744	26.3%	36.0%	30	60
5.0	871	30.8%	5.3%	0	10
Pan	129				

Table 3-4 Test results on coarse aggregate (Annex-1.1)

Test on Coarse Aggregate	Result
Aggregate Impact Value (%)	18.2
Flakiness Index (%)	18.6
Elongation Index (%)	18.5
Water Absorption (%)	0.17
Bulk Specific Gravity	2.82

Table 3-5 Seive analysis of fine aggregate (Annex -1.2)

Weight (g)	1375				
Sieve Size (mm)	Weight Retained (g)	Retained (%)	Total Passing (%)	Limits (%)	
9.5	0	0.0%	100.0%	100	100
4.75	20	1.5%	98.5%	95	100
2.36	113	8.2%	90.3%	80	100
1.18	372	27.1%	63.3%	50	85
0.6	451	32.8%	30.5%	25	60
0.3	213	15.5%	15.0%	10	30
1.5	158	11.5%	3.5%	2	10
Pan	26				

Table 3-6 Water absorption and specific gravity of fine aggregate (Annex-1.2)

Test on fine Aggregate	Result
Water Absorption (%)	0.73
Bulk Specific Gravity	2.89

3.3.3 Water

This experimental investigation, potable was choosed from the water supply network system and confirmed to SLS 522 and clean, free from any impurities, acid, alkali, oil, or other matter which is impact on concrete strength.

3.3.4 Bonding Agent

Emaco 157D Primer (normally called barra emulsion 57D) [7] is an aqueous emulsion of styrene-butadiene copolymer latex was used as a bonding agent shown in Figure 3-6. The properties of bonding agent given in Table 3-7 below. The technical data sheet is attached in Annex - 1.3.

Figure 3-6 Bonding agent -Emaco 157D

Table 3-7 Properties of bonding agent (BASF technical data sheet)

Properties of Bonding Agent	
Supply form	Liquid
Colour	Milky white
Specific gravity	1.01 kg/L
PH value	Approx. 9 – 10.5
Storage temperature	Sensitive to frost
Application temperature	Not below 5°C
Toxicity	Non-toxic

3.4 Experiment Methodology

The interface bond strength between recently cast concrete to fresh concrete are significantly influenced by lag time intervals and adhesive material at the layer interface. The effect of bonding agent at the interface were assessed by indirect spliting tensile sterength and compressive strength. The cubic specimens of size 150 mm were used. This strength test provides many advantages when compared to other tests, namely: (1) normal cube mould can be used since the standard cubic specimens's geometry is the same as the specimens' geometry; (2) The same compression testing machine was used without any specific instrument; and (3) without inducing bending, loads were applied symmetrically.

The research variables included the orientation of cold joint, presence of bonding agent between two layers and time lag of 2nd layer for different periods up to 5 hours. Table 3-8 shows the details of specimens and testing programme.

Table 3-8 Overview of test specimens

Specimens preparation	Presence of bonding agent at interface	Number of specimens	Delay time
Compressive Strength	Yes	3	0 Hrs
	No	3	
	Yes	3	1 Hrs
	No	3	
	Yes	3	2 Hrs
	No	3	
	Yes	3	3 Hrs
	No	3	
	Yes	3	4 Hrs
	No	3	
	Yes	3	5 Hrs
	No	3	
Splitting Tensile Strength	Yes	3	0 Hrs
	No	3	
	Yes	3	1 Hrs
	No	3	
	Yes	3	2 Hrs
	No	3	
	Yes	3	3 Hrs
	No	3	
	Yes	3	4 Hrs
	No	3	
	Yes	3	5 Hrs
	No	3	
Total Specimens	72		

3.4.1 Mix Design

The mix proportion for concrete with the characteristic compressive strength of 30 N/mm^2 at 28 days was determined using DOE method as mentioned in chapter 2 clause 2.10. The summary of the mix design is tabulated in Table 3-9 and detail calculations are attached in Annex -2

Table 3-9 Summary of mix design of grade 30 concrete

Cement (kg)	Water (L)	Fine aggregate (kg)	Coarse aggregate (kg)
366	205	809	1030

3.4.2 Identification of Specimens

The concrete specimens were marked considering following: (1) the specimens prepared for compressive strength or splitting tensile strength; (2) orientation of cold joint; (3) with or without applying bonding agent between the layer interface and (4) lag time of second layer casting.

The specimens were tagged with the capital "C" and "S" when the specimens were prepared for compressive strength and splitting tensile strength, respectively. When the bonding agent was applied at the layers interface, the specimens similarly marked with letter "B". Depending on the lag time interval of the second layer, the specimens were tagged "1" i.e., one-hour lag time.

As an example, the specimens used to evaluate the compressive strength with a bonding agent and the second layer cast at lag time of 2 hrs, then the specimen labelled as C-B-2. Figure 3-7 illustrates the specimens' labelling scheme.

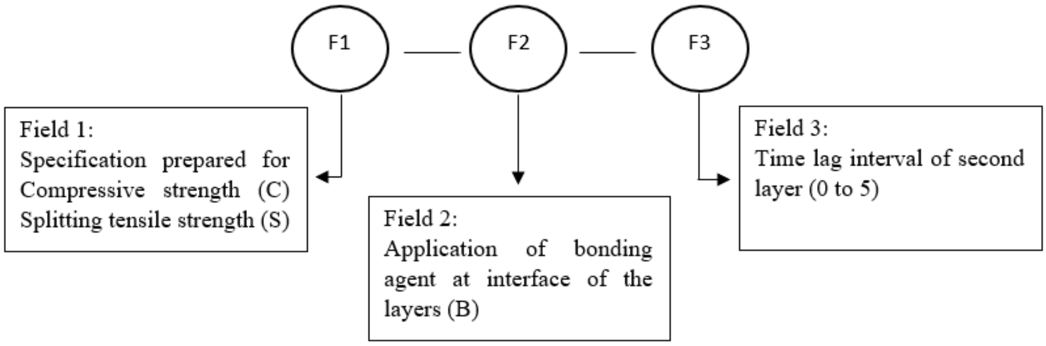

Figure 3-7 Specimens' labelling scheme

3.4.3 Specimens Setup

For compressive strength, cold joint was orientated 20° degress to the horizontal plane. Therefore, wooden frame was set up to making a cold joint of 20° degress as shown in Figure 3.8. For spiling shear test, cold jont was oriented to horizontal plane and arrangement is shown in Figure 3-9. The test setup consisted of 72 number of cubes. These cubes were tested for tensile strength and compressive strength.

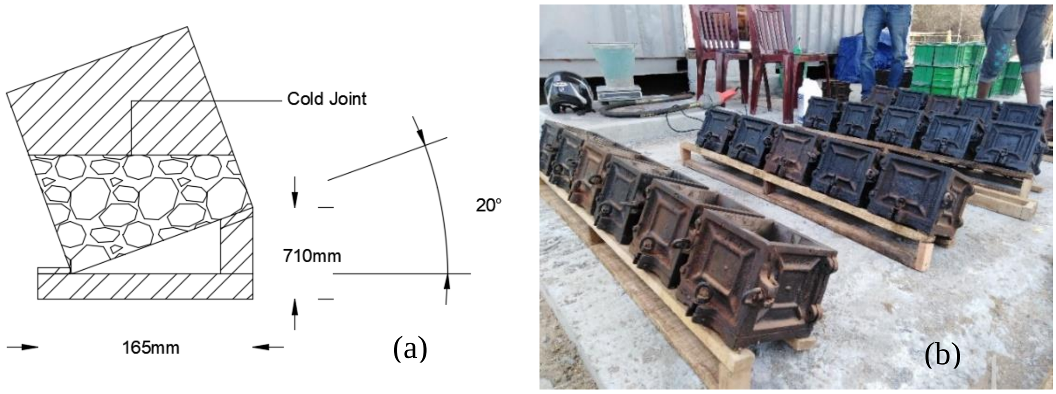

Figure 3-8 Wooden frame for making cold joint in an angle plane: (a) Schematic diagram; (b) Preparation of moulds arrangement for compressive strength test

Figure 3-9 Preparation of moulds arrangement for splitting shear test

3.4.4 Preparation of Bonding Agent

As per the technical data sheet [7], one part of Emaco 157D primer and two parts by volume of cement were mixed. A stiff brush was used to apply the bonding slurry in the interface of the layers. Figure 3-10 shows the prepared bonding slurry.

Figure 3-10 Preparation of bonding agent

3.4.5 Concrete Batching

All materials used for this research project were stored at the batching plant of Mannar Wind Power Project located in the Mannar Island. All concrete batches were mixed and cast at the same place in accordance with BS EN 12350 [14].

(i) Moisture correction

Prior to concrete batch, moisture content of coarse and fine aggregate was checked to find the additional water in the materials. Table 3-10 and Figure 3-11 shows the moisture content of coarse and fine aggregates and testing of moisture for fine aggregate, respectively.

Table 3-10 Moisture in the materials

Moisture			
Material	Initial Weight (g)	Dry Weight (g)	Moisture %
Coarse Aggregate	620	610	1.64%
Fine Aggregate	428	415	3.13%

Figure 3-11 Moisture check for fine aggregate

Table 3-11 shows the corrected weight of coarse aggregates, fine aggregates and water according to the moisture adjustment.

Table 3-11 Adjusted weight after the moisture corrections

Moisture Correction				
Material	Moisture %	Absorption %	Initial Weight (m^3/kg)	Adjusted Weight (m^3/kg)
Coarse Aggregate	1.64	0.17	1030	1045
Fine Aggregate	3.13	0.73	809	829
Water	-	-	205	170

Table 3-12 shows the summary of mix design after the moisture correction as well as the required weight of material according to each time lag batches.

Table 3-12 Summary of mix design (after moisture correction)

Quantities	Cement (kg)	Water (L)	Fine aggregate (kg)	Coarse aggregate (kg)
Per $1m^3$	366	170	829	1045
Initial batch ($0.164\ m^3$)	60	28	136	171
Time lag Batches ($0.027m^3$)	10	5	23	29

(ii) Concrete mixing

Prior to concrete batch, the mixer was dampened to reduce the amount of water absorbed by residue adhered to the walls of the mixer barrel. Then, coarse and fine aggregates, water and cement were added after being weighted as per the required volume specified in Table 3-12. After that, all constituents were added to the mixer as shown in Figure 3-12, the concrete was mixed for 5 minutes.

Figure 3-12 Mixing the concrete

3.4.6 Concrete Casting

3.4.6.1 Specimens for Compressive Strength

As mentioned in chapter 2 clause 2.5.5, the compressive strength properties depend on the cold joint orientation. Therefore, it was decided to select the cold joint orientation 20° due to easy of casting the specimens, properly carry out the re-vibration on the first layer and protect the edge damages while casting and testing.

Before casting samples, the surface of the moulds were cleared and a thin grease layer was applied. This is done to avoid the attachment between the concrete and the inner surface of the moulds.

As shown in Figure 3-13, there were two sets of specimens for with or without applying the bonding agent at the interface of the layers and each time lag, each set contain three numbers of cubes. Therefore, 36 numbers of specimens were arranged as shown in Figure 3-8 (b).

The first batch of concrete was filled half volume of the all 36 cubes, then compaction was done using poker vibrator as shown in Figure 3-14.

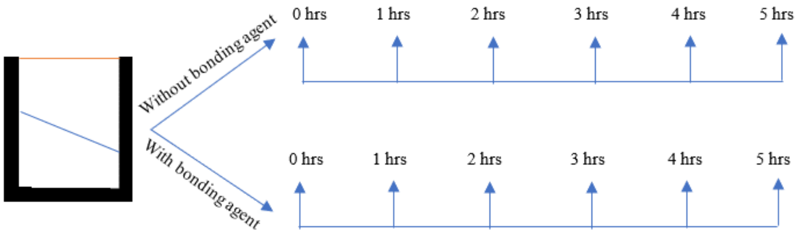

Figure 3-13 Cube specimens casting plan for compressive strength

Figure 3-14 Casting and compacting the first layer of concrete

Then the bonding agent was applied on selected specimens, i.e. each delay time three cubes, just before the casting of 2nd layer as shown in Figure 3-15.

Figure 3-15 Applying the bonding agent

After that, as shown in Figure 3-16, the 2nd layer of concrete was cast in six cubes (3 cubes - with bonding agent other 3 cubes - without applying the bonding agent) with the same concrete as in 1st layers and compacted using a mechanical poker vibrator for ‘0’ delay time (without delaying). The vibration technique was adopted that, the running vibrator sinks by its own weight into both layers as shown in Figure 3-17 regardless intial setting time of 1st layer of concrete passed or not . Therefore, try to eliminate the cold joint formation due to vibration limits to 2nd layer as well as increase the damageabilty of 1st layer to improve the layer bonding properties.

Figure 3-16 Casting 2nd layer for zero delay time

Figure 3-17 Compaction of 2nd layer

In each set, the second layer of concrete was cast by varying the delay time 1, 2, 3, 4 and 5 hours after casting the 1st layer. The concrete mix for the 2nd layer was prepared for each delay time and the bonding agent was applied on three cubes of each delay time just before casting of 2nd layer. Then the both layers were vibrated together. The vibration technique was adopted that running vibrator sink by its own weight into both layers. Figure 3-18 shows the casting of 2nd layer after one-hour delay time of casting the 1st layer.

Figure 3-18 Casting and compacting of 2nd layer for 1 hrs. delay

Each specimen tagged with identification label as per the method described in clause 3.4.2 above and shown in Figure 3-19.

Figure 3-19 Identification labels pasted on cubes

In the same way each hour delay, the cubes were cast as shown in Figure 3-20.

Figure 3-20 2nd layer cast after 2hours (L) and 3hours (R) delay time, respectively

3.4.6.2 Specimens for Splitting Tensile Strength

The casting method for both cases compressive strength and splitting tensile strength was the same except orientation of cold joint. For splitting tensile strength, the cold joint with horizontal plane specimens were prepared and shown in Figure 3-21.

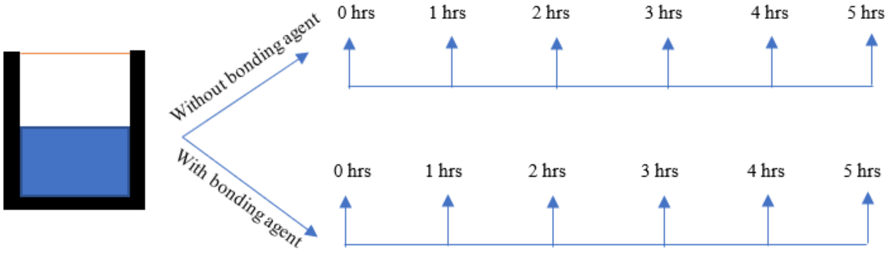

Figure 3-21 Cube specimens casting plan for tensile strength

The mould arrangements and the casting of 1st layer of concrete as shown in Figure 3-22.

Figure 3-22 Casting 1st layer for cold joint with horizontal plane

Figure 3-23 shows the application of bonding agent on top of the first layer just prior to casting the 2nd layer.

Figure 3-23 Applying bonding agent

The completed 2nd layer with varying delay times and labelling on top of the cubes as shown in Figure 3-24.

Figure 3-24 Casting 2nd layer with delay time

3.4.7 Curing

All the specimens were removed from the mould after twenty-four hours of casting. Then, they were immersed in a saturated water tank until the age of testing (28 days) as shown in Figure 3-25.

Figure 3-25 Curing the specimens

The prepared specimens with 20º and 0º horizontal inclination of cold joint are shown in Figure 3-26 and Figure 3-27, respectively.

Figure 3-26 Cold joint with 20-degree plane

Figure 3-27 Cold joint with horizontal plane

3.4.8 Testing

3.4.8.1 Compressive Strength

The compressive strength of specimens which having a cold joint 20º degree to horizontal plane was tested. The compressive strength values obtained by testing of standard cubes with different lag time are tabulated in Annex- 3.1. Figure 3-28 and Figure 3-29 show the measured weight of specimens and compressive testing setup of the specimens, respectively.

Figure 3-28 Measuring the weight of specimens

Figure 3-29 Testing of compressive strength

3.4.8.2 Splitting Tensile Strength

The splitting tensile strength was checked on specimens which having a cold joint with the horizontal plane to determine the effect of cold joint on tensile strength properties. Splitting tensile strength was carried on 150mm cubes as per IS 5816:1999 standard [27] and detailed results are presented in Annex-3.2. Figure 3-30 shows the made up apparatus for splitting tensile test for cube specimens and Figure 3-31 shows the splitting tensile testing setup on cube specimens.

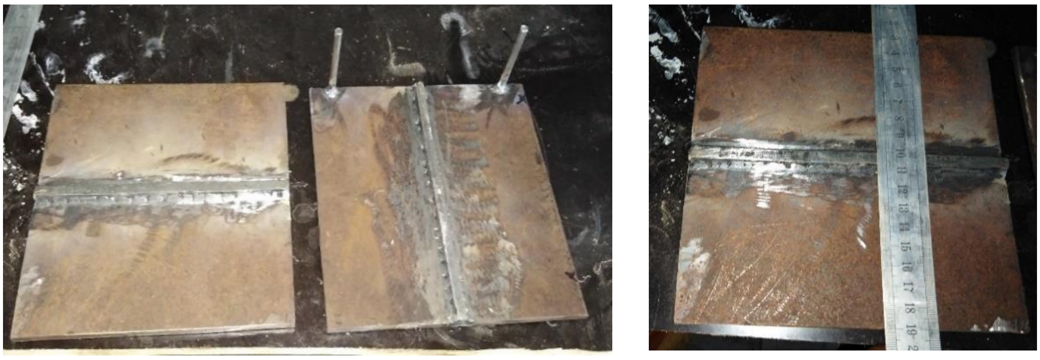

Figure 3-30 Apparatus for splitting cubes test

Figure 3-31 Testing of splitting tensile strength

CHAPTER - 4

4.0 ANALYSIS AND DISCUSSIONS OF RESULTS

4.1 General Introduction

The test results of 72 prepared specimens to evaluate the cold joint properties with delay time and the influence of bonding agents on cold joint properties of grade 30 concrete are analysed in this chapter.

4.2 Compressive Strength

The compressive strength was checked on specimens with the 20° angle of cold joint to understand the impact of cold joint on compressive strength with respect to delay time. Compressive strength was checked at the age of 28 days as per BS EN 12390-2 [17] and detail test results are presented in Annex-3.1. The summary of test results is given in Table 4-1.

Table 4-1 Average compressive strength with respect to delay time

Delay Time (T) (Hrs.)	Average Compressive Strength (N/mm^2)	
	With Bonding Agent	Without Bonding Agent
0	38.09	38.11
1	38.56	38.32
2	32.70	32.64
3	33.41	32.97
4	31.60	29.60
5	26.48	24.98

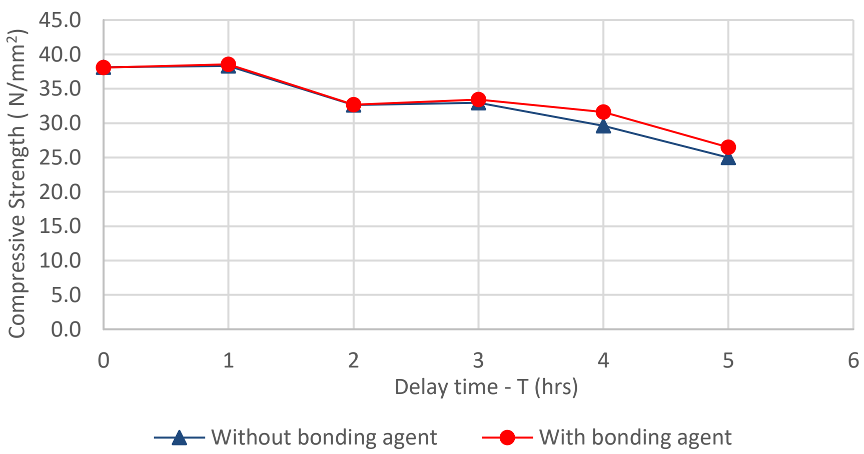

Figure 4-1 Comparison of compressive strength with and without bonding agent

Variations of strength were analyzed to determine the influence of bonding agent on cold joint as well as delay time. The comparison was made based on the initial strengths (at delay time (T) =0) considered as a reference result. The analyzed experimental results of compressive strengths with delay time were presented and plotted in Table 4-2 and Figure 4-2, respectively.

Table 4-2 Reduction in compressive strength with delay time

Delay Time (T) (Hrs.)	Reduction in Average Strength (N/mm^2)	
	With Bonding Agent	Without Bonding Agent
0	0.00	0.00
1	-0.46	-0.21
2	5.39	5.47
3	4.68	5.14
4	6.49	8.51
5	11.61	13.13

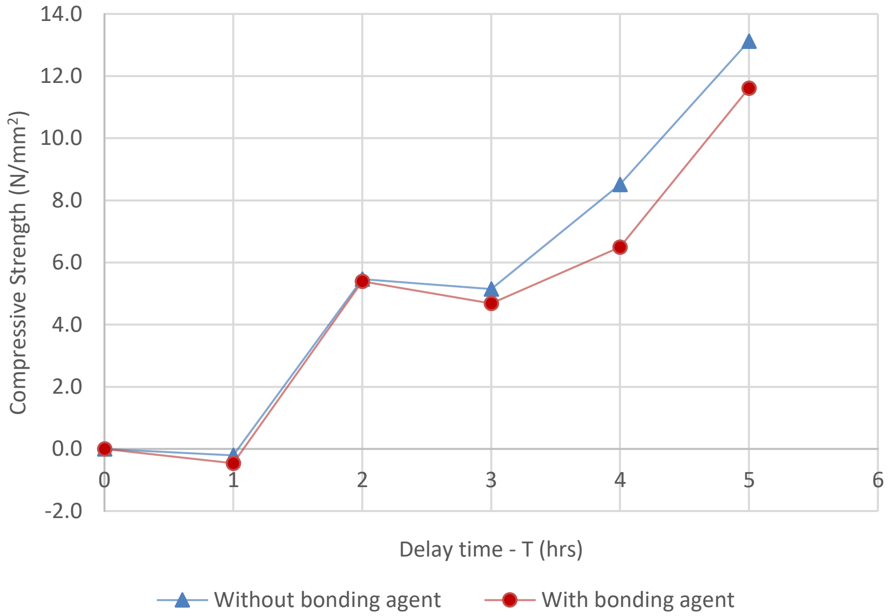

Figure 4-2 Comparison on reduction of compressive strength

From Figure 4-1 and Figure 4-2, the compressive strength decreases with delay time, whether the bonding agent applied or not, but there is a marginal improvement observed when applying the bonding agent at the interface after 3 hours delay. The behaviour of the graph is explained in clause 4.5.1 below.

Table 4-3 Percentage reduction in compressive strength with respect to delay time

Delay Time (T) (Hrs.)	Percentage Reduction in Compressive Strength (%)	
	With Bonding Agent	Without Bonding Agent
0	0.0	0.0
1	-1.2	-0.6
2	14.2	14.4
3	12.3	13.5
4	17.0	22.3
5	30.5	34.4

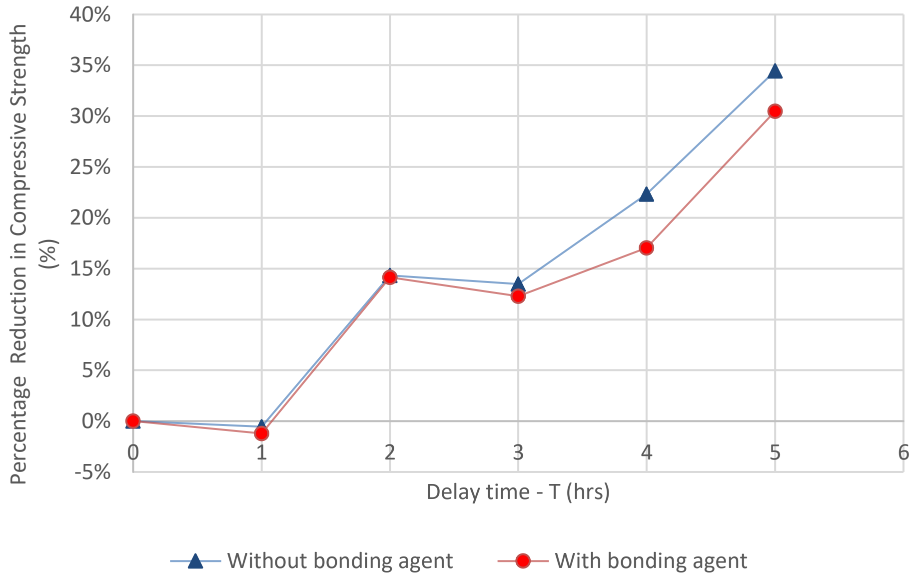

Figure 4-3 Percentage reduction in compressive strength with respect to delay time

Table 4-4 Influence of bonding agent on compressive strength

Delay Time (T) (hrs.)	Influence of bonding agent on compressive strength (%)
0	-0.1
1	0.6
2	0.2
3	1.4
4	6.8
5	6.0

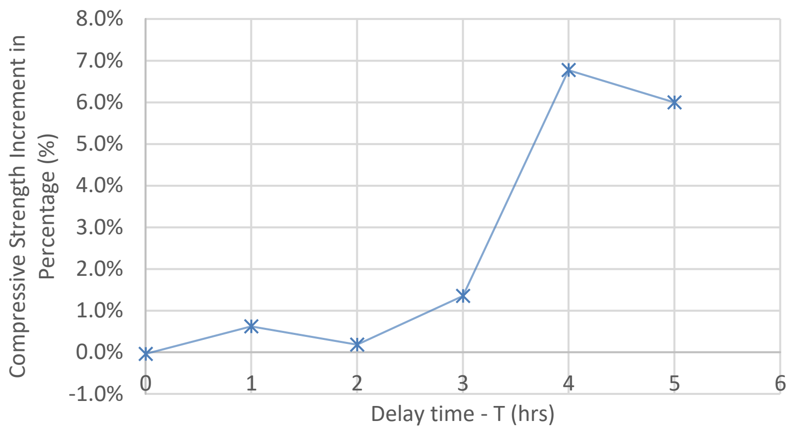

Figure 4-4 Effect of bonding agent on compressive strength

From Figure 4-3 and Figure 4-4, It was observed that, the reduction of compressive strength after 5 hours delays and compare with initial (T=0) compressive strength 30.18% and 34.44% with presence of bonding agent or not, respectively. Further, considerable improvement of the compressive strength (6%) observed when bonding agent presence at the interface after 4 hours delay time with respect to same cube cast without bonding agent. The detail discussion on reduction of compressive strength due to cold joint is presented in clause 4.5 below.

4.3 Splitting Tensile Strength

As stated in the Chapter 2 clause 2.13, the measured splitting tensile strength was calculated using Equation 01 and summary of test results are given in Table 4-5. The detailed results are presented in Annex-3.2.

Table 4-5 Average tensile strength with respect to delay time

Delay Time (T) (Hrs.)	Average Tensile Strength (N/mm^2)	
	With Bonding Agent	Without Bonding Agent
0	2.76	2.76
1	2.79	2.78
2	1.96	1.99
3	2.15	2.09
4	1.87	1.85
5	1.84	1.82

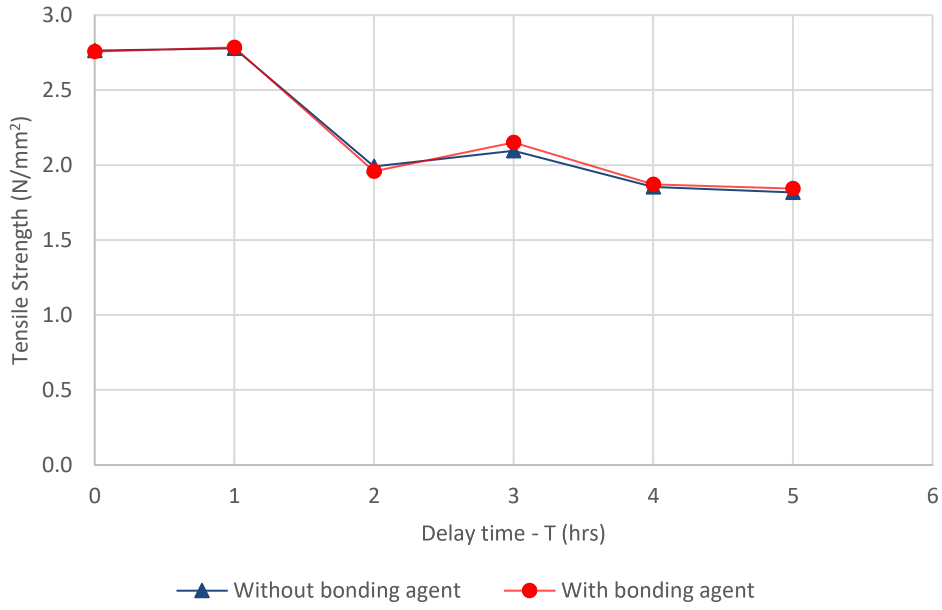

Figure 4-5 Comparison of tensile strength with and without bonding agent

Variations of tensile strength were analyzed to determine the influence of bonding agent on cold joint as well as the delay time. The comparison was made based on the initial strengths (at T=0) considered as a reference result. The analyzed experimental results of tensile strengths with delay time were presented and plotted in Table 4-6 and Figure 4-6, respectively.

Table 4-6 Reduction in tensile strength with respect to delay time

Delay Time (Hrs.) (T)	Reduction in Tensile Strength (N/mm^2)	
	With bonding agent	Without bonding agent
0	0.00	0.00
1	-0.03	-0.02
2	0.80	0.77
3	0.61	0.67
4	0.89	0.91
5	0.91	0.95

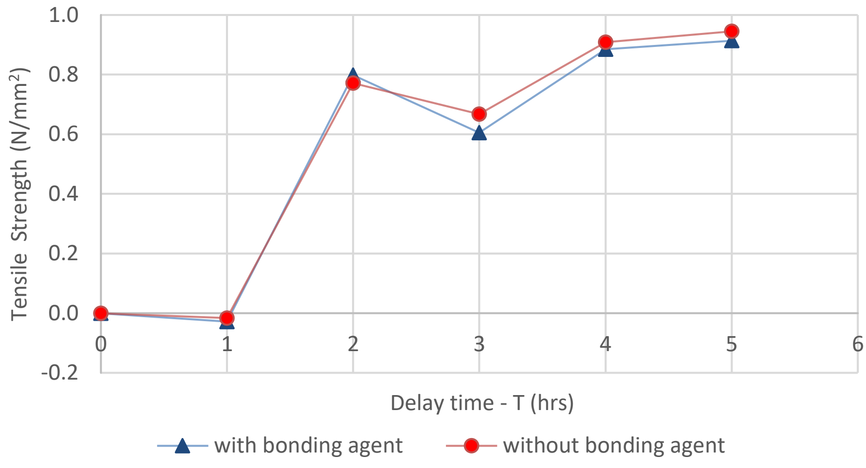

Figure 4-6 Comparison on reduction of tensile strength

From Figure 4-5 and Figure 4-6, the tensile strength decreases with delay time, whether the bonding agent applied or not, but there is no improvement observed when applying the bonding agent at the concrete layers interface. The behaviour of the graph is explained in clause 4.5.2 below.

Table 4-7 Percentage reduction in tensile strength with respect to delay time

Delay Time (T) (Hrs.)	Percentage Reduction in Tensile Strength (%)	
	With bonding agent	Without bonding agent
0	0.0	0.0
1	-1.0	-0.6
2	29.0	27.9
3	22.0	24.2
4	32.1	32.9
5	33.1	34.2

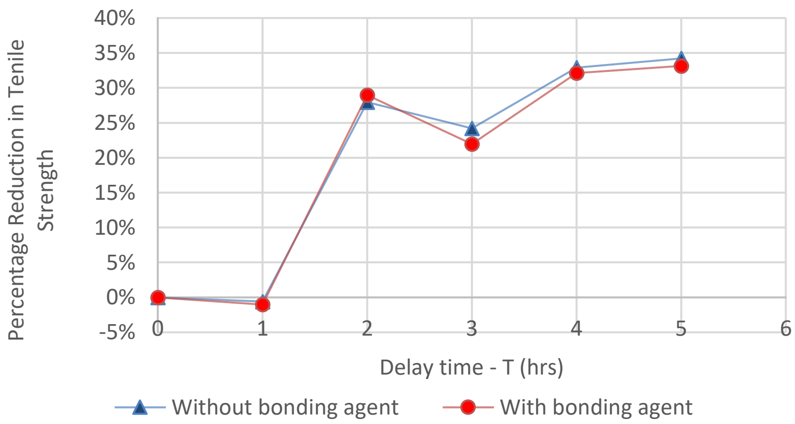

Figure 4-7 Percentage reduction in tensile strength with respect to delay time

Table 4-8 Influence of bonding agent on tensile strength

Delay Time (T) (Hrs.)	Influence of Bonding Agent on Tensile Strength (%)
0	-0.2
1	0.2
2	-1.6
3	2.7
4	0.9
5	1.4

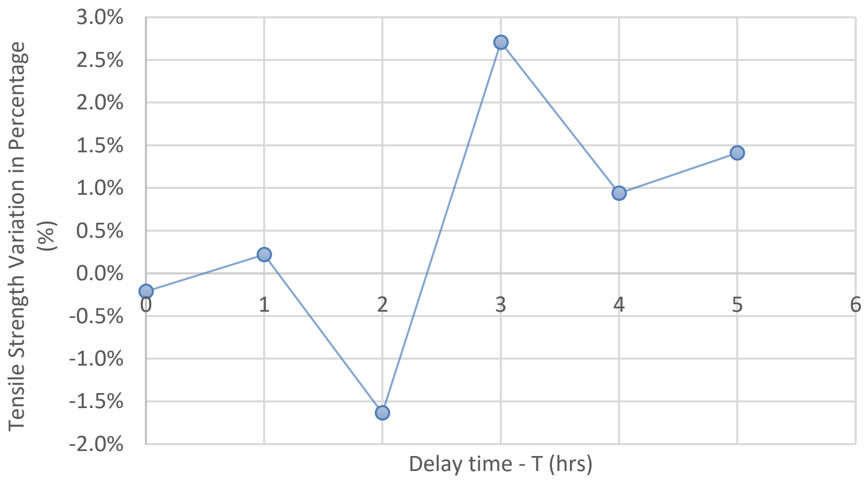

Figure 4-8 Effect of bonding agent on tensile strength

From Figure 4-7 and Figure 4-8, It was observed that, the reduction of tensile strength after 5 hours delays and compare with initial (T=0) tensile strength 33.14% and 34.21% with the presence of bonding agent or not, respectively. Further, no considerable improvement of the tensile strength observed when bonding agent presence at interface up to 5 hours delay time with respect to same cube cast without bonding agent. The detail discussion on reduction of tensile strength due to cold joint is presented in clause 4.5 below.

4.4 Failure Plane of Specimens Under Splitting Tensile Test

All the specimens were examined visually to identify the strength reduction respect to the aggregate interlocking between two layers. Figure 4-9 shows the failure surface of specimens with different delay time.

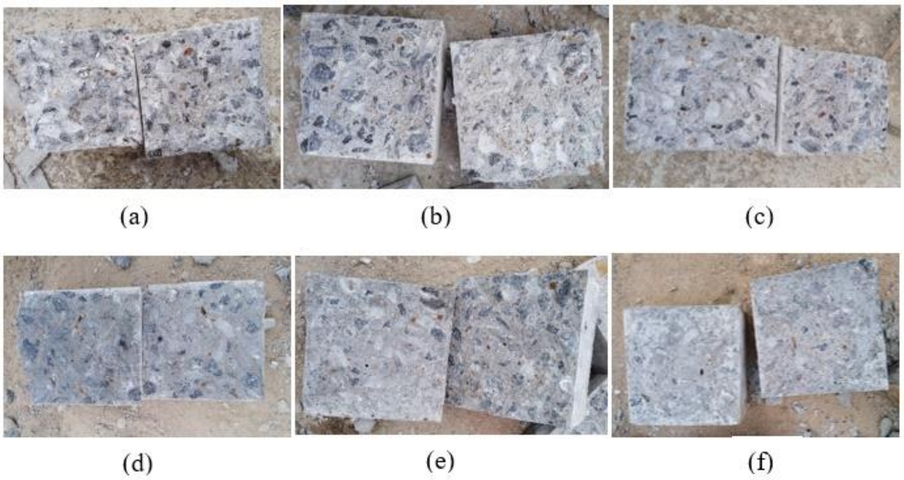

Figure 4-9 Failure surface under splitting tensile strength test; (a) delay time T=0 hrs.; (b) delay time T= 1 hrs.; (c) delay time T=2 hrs.; (d) delay time T= 3hrs.; (e) delay time T=4 hrs.; (f) delay time T= 5 hrs.

4.5 Discussions

The test results of tensile strength and compressive strength with several delay time of this research as well as previous research investigation results were analyzed and the behaviour of cold joint properties with delay time and influence of bonding agent are presented below.

4.5.1 Compressive strength

The experimental results of previous research are obtained from research paper "*Effect of cold joint on strength of concrete, Rathi and Kolase (2013*)" [47] and compressive strength with different cold joint orientation with delay time are tabulated in the Table 4-9.

Table 4-9 Experimental result of the experiment done by Rathi and Kolase, 2013

Delay Time (Hrs.)	Compressive Strength (N/mm^2)		
	Diagonal Plane	Vertical Plane	Horizontal Plane
0	34.84	34.84	34.84
0.75	33.67	34.01	34.30
1.25	31.79	32.23	32.57
2	30.46	30.20	31.84
3	28.71	30.80	30.91

Above previous research experiment was carried out for grade 25 concrete and the calculated percentage of reduction of concrete strength with delay time as well as orientation are tabulated in the Table 4-10.

Table 4-10 Percentage reduction in compressive strength (Calculated from Table 4-9)

Delay Time (Hrs.)	% Reduction of Compressive Strength (N/mm^2)		
	Diagonal Plane	Vertical Plane	Horizontal Plane
0	0.00%	0.00%	0.00%
0.75	3.36%	2.38%	1.55%
1.25	8.75%	7.49%	6.52%
2	12.57%	13.32%	8.61%
3	17.59%	11.60%	11.28%

Experimental percentage compressive strength reduction results from Table 4-3 and previous results from Table 4-10 are plotted in a single graph as shown in Figure 4-10.

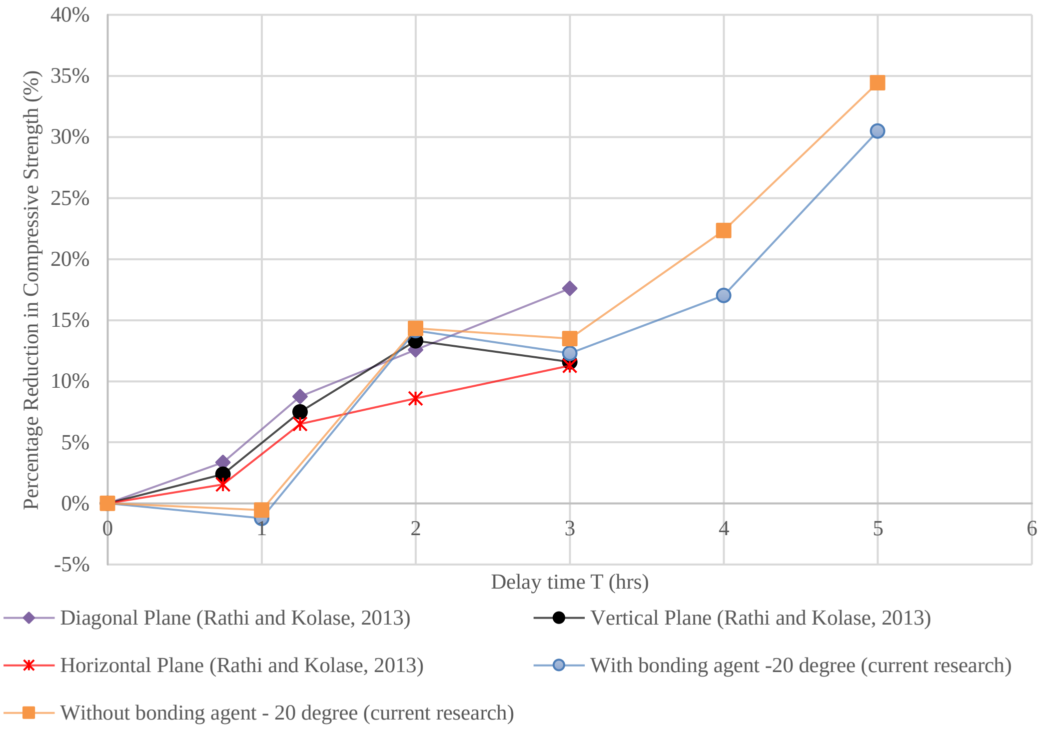

Figure 4-10 Percentage reduction of compressive strength of experimental results with previous research results

Figure 4-1 represents the relationship between compressive strength with respect to delay time and with or without applying the bonding agent. It was noticed that the initial (T=0) compressive strength of concrete achieved the required 28 days strength and at delay time of one hour (T =1) it was a slight increment of compressive strength due to effect of re-vibration. However, it also noticed that a considerable reduction in the compressive strength at delay time of two hours (T=2) due to disturbing of concrete which passed the initial setting time while compacting of 2nd layer. After that, the compressive strength was decreased with delay time for both with and without applying bonding agent at the interface.

Figure 4-10 represent the relationship between reduction of compressive strength with respect to delay time and with or without bonding agent of current research results with results from previous research (Rathi & Kolase, 2013). From above graph (Figure 4-10), it was observed that the reduction of compressive strength after 5 hours lag time was 30.18% and 34.44% with or without applying the bonding agent, respectively. Further, this current experimental result also almost follows the same trend as the previous research (Rathi & Kolase, 2013) result considered here.

4.5.2 Tensile Strength

The experimental test results of previous research are obtained from research paper *"Investigation of the Factors Affecting the Formation of Cold Joints in Concrete, Jatheesan et. al, (2010)"* [15]. The tensile strength with different delay time is tabulated in the Table 4-11.

Table 4-11 Test results of the experiment done by Jatheesan et. al, 2010

Delay Time T (Hrs.)	Average Tensile Strength N/mm^2	Percentage Reduction of Tensile Strength (%)
0	1.7	0.0
1	1.6	2.5
2	1.2	13.3
3	1.1	14.7
4	0.8	25.6
5	0.6	30.8

Current experimental percentage tensile strength reduction results from Table 4-7 and result from previous research (Jatheesan, et al., 2010) Table 4-11 are plotted in a single graph as shown in Figure 4-11.

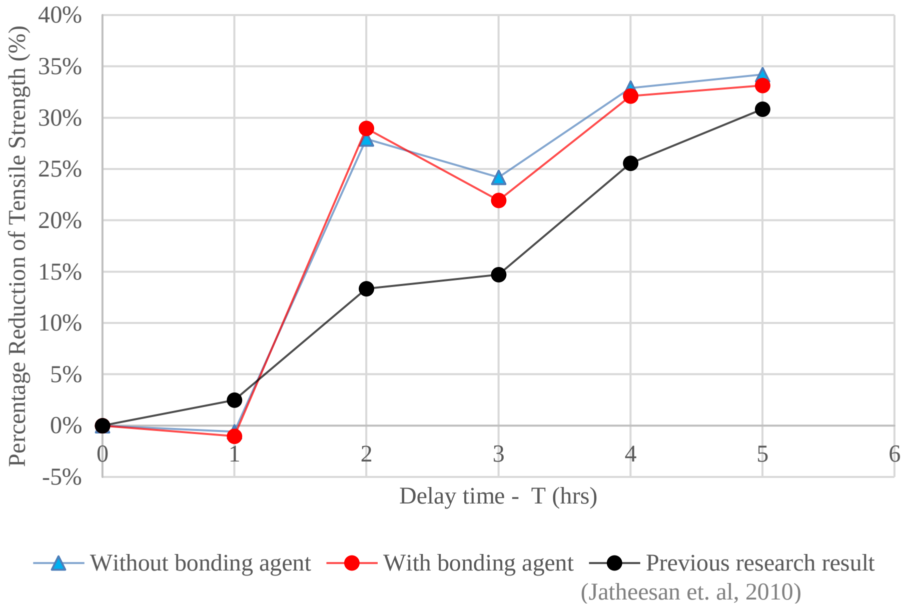

Figure 4-11 Percentage reduction of tensile strength of experimental results with previous research results

Figure 4-5 represent the relationship between tensile strength with respect to delay time and with or without applying the bonding agent. The initial (T=0) of tensile strength was considered as reference result. At delay time of one hour (T =1) it was a slight increment of tensile strength due to effect of re-vibration. However, it also noticed that considerable reduction in the tensile strength at delay time of two hours (T=2) due to disturbing of concrete which passed the initial setting time while compacting of 2nd layer and the same behavior was observed in the compressive strength as well. After that, the tensile strength was decreased with delay time with or without applying the bonding agent.

Figure 4-11 represents the relationship between reduction of tensile strength with respect to delay time and with or without bonding agent of current research result with result from previous research (Jatheesan, et al., 2010). It was observed that the reduction of tensile strength was 33.14% and 34.21% with or without applying the bonding agent, respectively. Further, this current experimental result also almost follows the same trend as the previous research result (Jatheesan, et al., 2010) considered here.

In addition to that, from Figure 4-10, clearly indicates the failure surfaces of concrete layers, there is no aggregate interlocking observed when cast 2nd layer after the five hours of delay. Therefore, reduction of strength is obvious according to failure surface.

4.5.1 Comparison of Bond Strengths

The board experimental investigation has been carried out by Rashid, et al., (2020) on influence of different adhesive layers on bond strength which is explained in clause 2.8 of chapter 2.

From above previous research experimental test results, spilt tensile strength of specimens with different adhesive layer applied on old to fresh concrete are tabulated in Table 4-12.

Table 4-12 Comparison of bond strength results

Description		Tensile Strength (N/mm^2)	Percentage of Bond Strength
Previous Research	Bulk Specimens		
	Substate Concrete	4.41	
	Repair Concrete	4.86	
	Adhesive at Interface of Composite Specimens		
	Cement Paste	0.38	8.62%
	Epoxy Bonding Agent	0.46	10.43%
	Styrene Butadiene rubber (SBR) - Latex	0.5	11.34%
	Carbon Fiber Reinforced Polymer (CFRP)	0.6	13.61%
Current Research	No Additives	1.82	65.79%
	Styrene Butadiene Copolymer - Latex (Emaco 157D)	1.84	66.86%

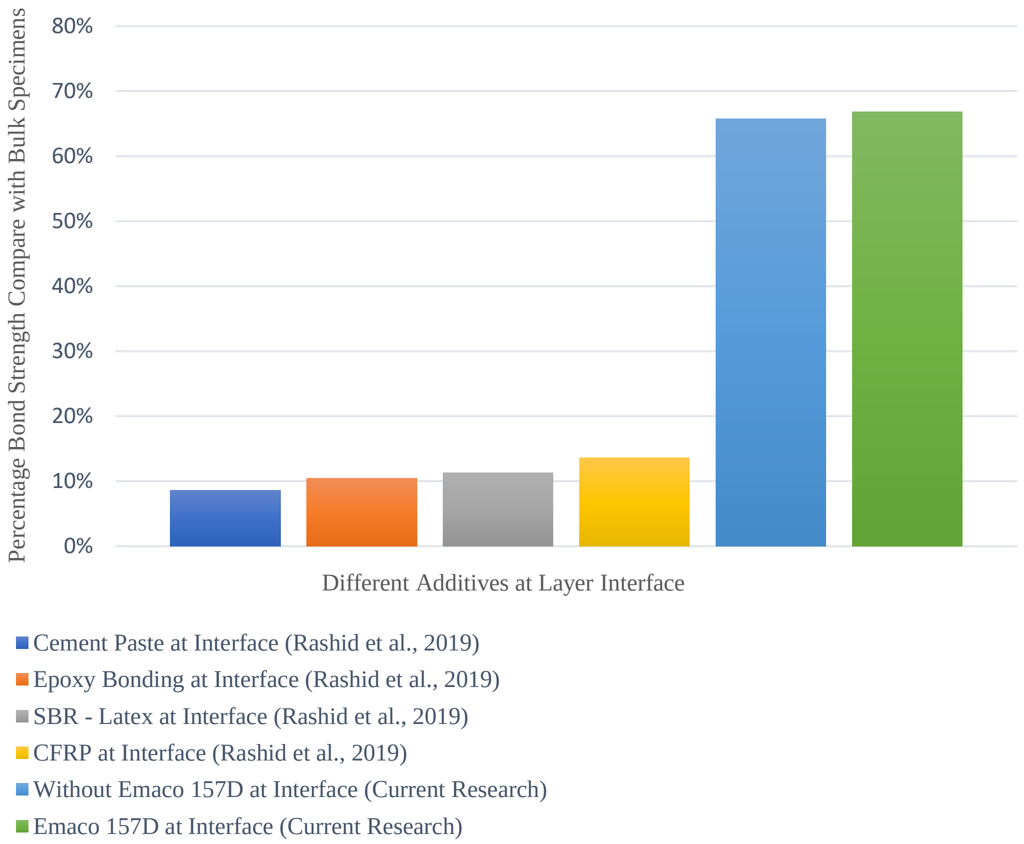

Figure 4-12 Comparison of bond strength

Figure 4-12 represents Comparison between concrete tensile strength with different adhesive at layer interface with their bulk specimens. According to that, large tensile strength reductions were noticed even applied different adhesives. From the previous research results, for old to fresh connection, the tensile strength of the substate concrete was used in the range of 8.5% to 13.6% only. But, according to current research, after 5 hour time gaps between the consecutive layers, tensile strength of the bulk concrete was used in the range of 65.8% to 66.9% without any additives and use of Emaco 157D at the interface, respectively. However, reduction will be more when the time gap between the consecutive layers increases. Therefore, concrete layer interface plays critical role in the strength of layered concrete structures and must be appropriately evaluated.

CHAPTER - 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 General Introduction

The conclusions and the recommendations for future works are discussed in this chapter with the available results obtained from this study.

5.2 Conclusions

The primary aim of this research was to identify the alternative methods to eliminate the cold joint. The usage of bonding agent at the interface of the concrete layers was examined due to less understanding on this method in Sri Lanka context.

The results obtained in this experimental investigation as well as from literatures, the following conclusions can be made:

1. Compressive strength and tensile strength of concrete members with cold joint decrease with the delay time irrespective from the provision of bonding agent at the interface of the concrete layers

2. Cold joint cannot be eliminated by applying a bonding agent alone since it is purely depending on aggregate interlocking between two layers

3. Influence of bonding agent on compressive strength shows a 6% improvement while indicating a negligible impact on tensile strength. This may be non-consistency of test results rather than the improvement

4. Re-vibration within the initial setting time improve the compressive strength and tensile strength. However, after passing the initial setting time, re-vibration indicated detrimental effects on material properties of concrete members

5.3 Recommendations

- It is recommended to apply the 2^{nd} layer in concrete pouring within the initial setting time of first layer and both layers should be vibrated together to avoid interface failure behaviour of old and new layers

- In flexural members such as suspended slabs and beams, the most efficient location to have a cold joint is middle third of span of slab and beam (zero shear), but location should be verified. The vertical cold joint is best for such member. However, horizontal cold joints should be avoided

- In vertical members such as columns and wall, the most efficient location to have a cold joint is underside of floor slabs or beam and at the tops of footing or floor slabs. The horizontal cold joints are normally adopted for such members

5.4 Recommendations for Future Works

- It worth to carry out the same investigation instead of applying the bonding agent, applying the retarding agent (normally used for green cutting) on top of the 1st layer and cast 2nd layer at different delay times. Since the depth of retardation active up to 8 mm. It may help to improve the interface performance

- It is important to investigate the alternative simple mechanical anchorage system to create the behaviour similar to aggregate interlocking between two layers

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ANNEXES

ANNEX – 1

Material Test Reports

UNIVERSITY OF MORATUWA
Department of Civil Engineering
Moratuwa, Sri Lanka

Tel : Head of Department –2 645422
General –2 650567, 2650568
Fax : 2651216

Your Ref: AE/OCP/MWPP/UOM/2019/003 *My Ref:* CE/GA17/ST/2019/357

04-04-2019

Client: QA/QC Engineer,
Mannar Wind Power Project,
Access Engineering PLC,
"Access Towers", No 278, Union Place, Colombo.

Project: Construction of 100MW Semi Dispatchable Wind Farm in Mannar Island.

Service Required: (1) (i) Sieve analysis (ii) Aggregate Impact value (iii) Flakiness Index and Elongation Index and (iv) Specific Gravity and water absorption for Coarse Aggregate ACC/MWPP/AGG/20/001.

(2) (i) Sieve analysis (ii) Specific Gravity and water absorption (iii) Clay, Silt and Dust content for Fine Aggregate ACC/MWPP/QUD/0001.

Results: (1) Coarse Aggregate ACC/MWPP/AGG/20/001

(i) Sieve analysis : The test was carried out in accordance with BS 812: Part 103: 1985 - Coarse Aggregate ACC/MWPP/AGG/20/001

Sieve size (mm)	% Passing	BS 882:1992 limits Graded 20-5mm	BS 882:1992 limits Single-sized 20mm
20	99.1	90 - 100	85 - 100
14	57.4	40 - 80	0 - 70
10	27.0	30 - 60	0 - 25
5.0	2.9	0 - 10	0 - 5

The grading of Coarse aggregate Sample ACC/MWPP/AGG/20/001 is close to both Graded 20-5 mm and Single - sized 20 mm aggregates according to BS 882: 1992.

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Department of Civil Engineering
University of Moratuwa
Moratuwa

K. Basl

(ii) Aggregate Impact Value of Coarse aggregates Sample ACC/MWPP/AGG/20/001 in accordance with BS 812: Part 112: 1990

Parameter	**Coarse aggregates Sample ACC/MWPP/AGG/20/001**
Aggregate Impact Value (%)	18.2

(iii) Flakiness index and elongation index of Coarse aggregates Sample ACC/MWPP/AGG/20/001 in accordance with BS 812

Parameter	**Coarse aggregates Sample ACC/MWPP/AGG/20/001**
Flakiness index (%)	18.6
Elongation index (%)	18.5

(iv) Water absorption and Specific Gravity of Coarse aggregate in accordance with BS 812: Part 2: 1985 - Coarse aggregates Sample ACC/MWPP/AGG/20/001

Parameter	**Coarse aggregates Sample ACC/MWPP/AGG/20/001**
Water absorption (%)	0.17
Bulk Specific Gravity	2.82

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Structural Engineering
Department of Civil Engineering
University of Moratuwa
Moratuwa

K. Baskaran

CONSTRUCTION of 100MW SEMI DISPATCHABLE WIND FARM IN MANNAR ISLAND

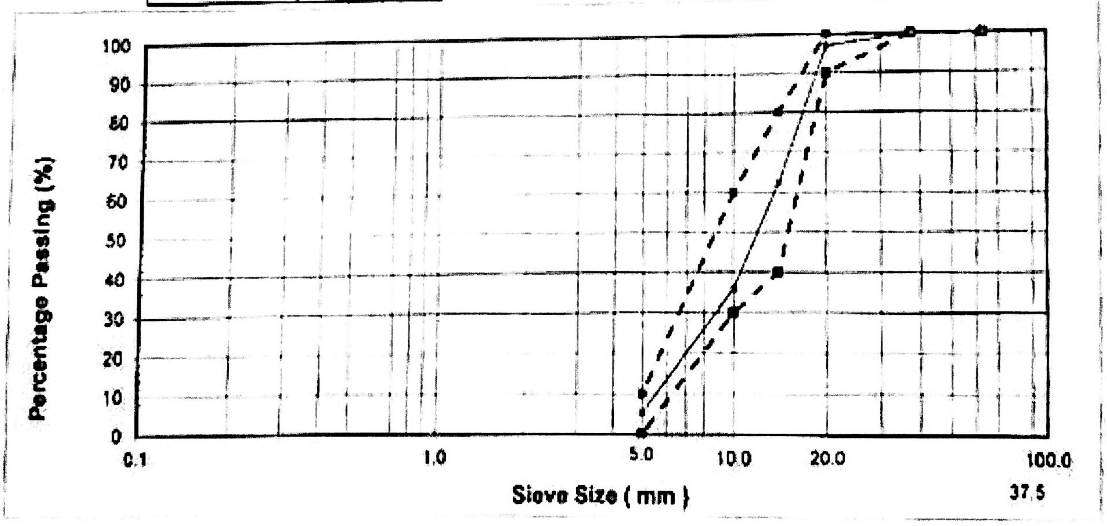
Engineer : Ceylon Electricity Board	Main Contractor : Vestas	Sub Contractor : Access Engineering PLC

SIEVE ANALYSIS OF COARSE AGGREGATE FOR CONCRETE

(TEST METHOD BS 882:1992) (Graded Aggregate)

Sample No.	ACC/MWPP/Agg/20mm/011	Source/Supplier	Vauniya
Date of Sampling	03/06/2019	Location / Stockpile	Concrete Batching Plant
Date of Testing	05/06/2019	Weight before (g)	2832.0
Type of Material	20mm	Weght of A/Washing (g)	2812.0

Sieve Size (mm)	Weight Retained (g)	% Retained	Total Passing %	Spec limits	
63.0	0.0	0.0	100.0	100	100
37.5	0.0	0.0	100.0	100	100
20.0	83.0	2.9	97.1	90	100
14.0	985.0	34.8	62.3	40	80
10.0	744.0	26.3	36.0	30	60
5.0	871.0	30.8	5.3	0	10
Pan	129.0				
Total	2812.0				



Remarks:- ....

	Tested by (Access)	Checked by (Access)	Certified by (Access)	Witness by (Vestas)	Witness by (CEB)
Signature	[signature]	[signature]	[signature]	[signature]	[signature]
Name	D Udayange	Y. Santhum	Priyan/Conq	T. Tharthee	S.Kabilnath
Designation	MCT	ME	QA/QC M	CE	C.S
Date	20/06/2019	24/06/19	24/06/2019	24/06/2019	24/06/2019

(2) Fine Aggregate ACC/MWPP/QUD/0001

(i) Sieve analysis : The test was carried out in accordance with BS 812: Part 103: 1985 -

Fine Aggregate ACC/MWPP/QUD/0001

Sieve size (mm)	% Passing	BS 882:1992 limits Grading C		BS 882:1992 limits Grading M		BS 882:1992 limits Grading F	
5	100.0						
2.36	84.9	60.0	100.0	65.0	100.0	80.0	100.0
1.18	66.9	30.0	90.0	45.0	100.0	70.0	100.0
0.6	50.9	15.0	54.0	25.0	80.0	55.0	100.0
0.3	34.9	5.0	40.0	5.0	48.0	5.0	70.0

Sieve Analysis results – Fine Aggregate ACC/MWPP/QUD/0001

The fine aggregate Sample ACC/MWPP/QUD/0001 is satisfying the limits of Grading C and M for fine aggregate according to BS 882:1992 limits.

(ii) Water absorption and Specific Gravity of fine aggregate in accordance with BS 812: Part 2: 1985 - Fine Aggregate ACC/MWPP/QUD/0001

Parameter	Fine Aggregate ACC/MWPP/QUD/0001
Water absorption (%)	0.73
Bulk Specific Gravity	2.89

(iii) Clay, fine silt and dust content of fine aggregate in accordance with BS 812: Part 103: 1985, Fine Aggregate ACC/MWPP/QUD/0001

Parameter	Fine Aggregate ACC/MWPP/QUD/0001
Clay, fine silt and dust content (%)	13.4

Mr H.T.R.M Thanthirige
Technical Officer

Dr.K.Baskaran
Senior Lecturer

Division of Building & Structural Engineering
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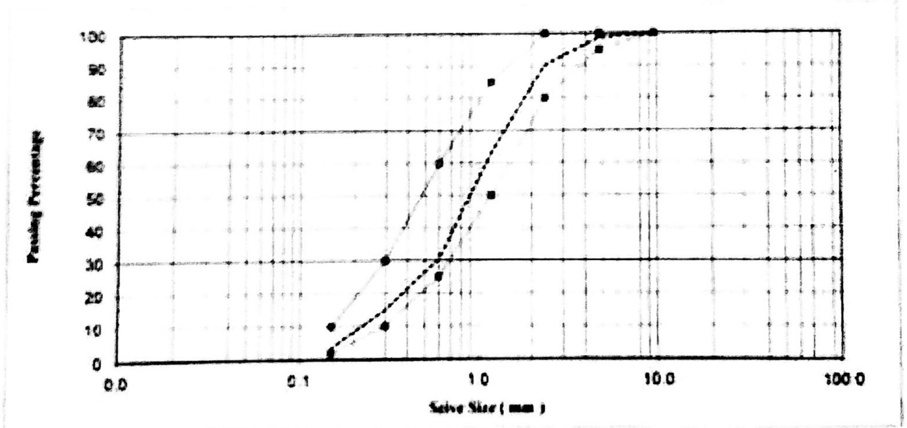
CONSTRUCTION of 100MW SEMI DISPATCHABLE WIND FARM IN MANNAR ISLAND

Engineer : Ceylon Electricity Board	Main Contractor : Vestas	Sub Contractor : Access Engineering PLC

PARTICLE-SIZE ANALYSIS OF SAND

Sample No	ACC/MWPP/SAND/01)	Source/Supplier	Koorai/Chaturanga
Date of Sampling	03/06/2019	SampaleLocation	Concrete Paching Plant
Date of Testing	05/06/2019	Type of Material	RIVER SAND
Weight of Dry Sample (Before Washed) (g)		1375.0	
Weight of Dry Sample (After Washed) (g)		1354.0	

Sieve Size (mm)	Weight of Retained (g)	Percentage Retained (%)	Total Passing Percentage (%)	Spec limit (According to Table 7.6.2 Project specifications)	
9.5	0.0	0.0	100.0	100	100
4.75	20.0	1.5	98.5	95	100
2.36	113.0	8.2	90.3	80	100
1.18	372.0	27.1	63.3	50	85
0.600	451.0	32.8	30.5	25	60
0.300	213.0	15.5	15.0	10	30
0.150	158.0	11.5	3.5	2	10
Pan	26.0				
Total	1353.0				



Weight of Dry Sample (Before Washed) (g)	1375.0
Weight of 0.075mm Passing Weight (g)	45.0
Clay Content (%) < 4%	3.3

Remarks ....

	Tested by (Access)	Checked by (Access)	Certified by (Access)	Witness by (Vestas)	Witness by (CEB)
Signature	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Name	[illegible]	Y. Santhu[illegible]	Priyankara	V. Thas[illegible]	S. Rabilnath
Designation	MCT	ME	QA/QC M	CE	C-S
Date	25-06-2019	25/06/19	25/06/2019	25/06/19.	25/06/2019

BASF
The Chemical Company

EMACO® 157D PRIMER (Barra Emulsion 57D)

SBR based bonding and polymer modifying agent for concrete and mortars

DESCRIPTION

EMACO 157D PRIMER is an aqueous emulsion of styrene-butadiene copolymer latex, specially formulated for use in cementitious mixtures to improve wear resistance, durability, waterproofing and bonding properties.

EMACO 157D PRIMER is also compatible with sulphate-resisting or high alumina cement and gypsum plaster.

FIELDS OF APPLICATION

EMACO 157D PRIMER is the ideal SBR-latex recommended for use:

- With cement as a bonding slurry
- In weather resistant exterior or interior renderings
- In floor screeds and toppings, or plasters for improved chemical resistance
- In repair of honeycombed and spalled concrete, beams and precast elements
- In tile or mosaic bedding compounds for bedding tiles or re-fixing slip bricks

FEATURES AND BENEFITS

- Water resistant
- Excellent adhesion to concrete, steel and brick
- High abrasion resistance
- Good resistance to salts, mineral oils and many other chemicals
- Reduces bleeding
- Greatly increased durability
- High flexibility
- Plasticizing effect and reduced shrinkage
- Highly increased tensile strength
- Non-toxic. Can be used in contact with potable water
- Improved corrosion protection
- Lower water/cement ratio
- Promotes high early strength in mortars

PROPERTIES

Supply form:	liquid
Colour:	milky white
Specific gravity:	1.01 kg/L
pH value:	approx 9 – 10.5
Storage temperature:	sensitive to frost
Application temperature:	not below 5°C
Toxicity:	non-toxic

APPLICATION

Substrate Preparation

The substrate must be clean, sound and free of dust and loose particles. Cement laitance, oil, grease, mould release oil or curing compounds must be removed from concrete surfaces by using gritblasting or other means. Steel surfaces should be degreased with a suitable solvent and/or treated by gritblasting or wire brushing where necessary.

Steel rebars must also be clean from grease, oil or rust and ideally treated by gritblasting. Corroded rebars should be protected using EMACO Nanocrete AP (refer separate data sheet). When repairing spalled or deteriorated concrete, ensure that the concrete has been cut back to sound material. In cases where corrosion is absent, wire brushing to a clean bright surface is sufficient.

Before applying **EMACO 157D PRIMER**, be sure to pre-wet the concrete substrate thoroughly to saturate the pores completely with water. During application of **EMACO 157D PRIMER**, the temperature of the substrate should not be below 5°C. To avoid too high a surface temperature, it is advisable to shade application areas.

Mixing

Stir well before use. Preferably, mixing should be done in an efficient pan type mixer or by means of a low speed drill with appropriate paddle. Hand mixing is not recommended.

Application Method

Bonding slurry (priming) - Apply a slurry onto the still damp substrate, consisting of 1 part **EMACO 157D PRIMER** and 2 parts by volume of cement, mixed to a lump-free creamy consistency. A stiff brush should be used to work the bonding slurry well into the damp surface. This slurry should not be applied in a thickness exceeding approximately 2mm. The mortar must be placed wet-on-wet. If the slurry does dry, a further slurry coat must be applied.

Renderings (to vertical surfaces) - After brushing the bonding slurry onto the prepared surface, apply immediately **EMACO 157D PRIMER** modified mortar, in average thicknesses of 10 mm, as thicker layers tend to sag. However, several layers can be applied in quick succession. If thicker layers are applied, suitable formwork has to be used.

To provide good mechanical bond, scratch the freshly applied coat of rendering when the next coat is to be applied the following day.

Screed and toppings (to horizontal surfaces) - Always place screed, topping or patching mortar onto the still wet bonding slurry. Use low water-cement ratio for thick layers of mortar.

BASF Construction Chemicals offices in ASEAN

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Fax :+65-6861-3186	Fax :+60-3-5628-3776	Fax :+62-21-526-2541	Fax :+66-2664-9267	Fax :+84-650-3743-200	Fax : +63-2-838-1025

BASF

The Chemical Company

EMACO® 157D PRIMER (Barra Emulsion 57D)

Repair mortars (to horizontal and vertical surfaces) - Mix **EMACO 157D PRIMER** with sand/cement in ratio of 1:3. The thinner the repair patch is, the higher the dosage rate of **EMACO 157D PRIMER**. Apply the **EMACO 157D PRIMER** modified mortar onto the still tacky bonding slurry.

Tile or mosaic bedding compound - Dampen the substrate as well as the tiles. Apply a bonding slurry to the damp substrate and to the back of the tile. Before the slurry starts to dry, plaster the tile with mortar in the required thickness and firmly press to the floor or wall to ensure full contact. Strike off surplus mortar and do not disturb until set. For thin bed applications, press the tiles straight onto the substrate using only the bonding slurry. Strut tile surfaces until set.

ESTIMATING DATA

Depending on type of application (refer to "Application Method").

CURING

Freshly applied screeds and renderings, when mixed with **EMACO 157D PRIMER**, should be kept damp and be protected from direct sunlight, rain, wind or frost, until sufficiently hardened. Excessive rapid drying may cause shrinkage, insufficient strength and other defects.

CLEANING

Tools should be cleaned with water before the material hardens.

SHELF LIFE

EMACO 157D PRIMER should be stored out of direct sunlight. If kept in a dry place in tightly closed original packing above freezing point, it has 12 month shelf life.

PACKAGING

Available in 25L pails and 200L drums.

GENERAL GUIDELINES

Materials for **EMACO 157D PRIMER** modified mixtures:

- Sand should be washed, well graded and free from excessive fines.
- Although **EMACO 157D PRIMER** is compatible with high alumina cement, hardening will be delayed. Always use fresh cement.
- Expansion joints in the substrate must be carried through the **EMACO 157D PRIMER** modified mixture.
- **EMACO 157D PRIMER** modified mixtures should be applied to damp, but never wet, surfaces. Where running water is present, this must first be sealed and plugged.
- Do not over trowel and avoid re-trowelling of setting mortar.
- **EMACO 157D PRIMER** may float to the surface and impair the adhesion of subsequently applied materials.
- Do not work at temperatures below 5°C.

PRECAUTIONS

For detailed Health, Safety and Environmental recommendations, please consult and follow all instructions in the product Material Safety Data Sheet.

AN/157DPrimer/v7/060612

ANNEX – 2

Mix Design

1	**Details**	**Reference**			
1.1	Characteristic compressive strength N/mm^2 at 28 days	Specified	fc	30	N/mm^2
1.2	Standard deviation	Fig. 2-34	s	4	N/mm^2
1.3	Margin	Specified	k=1.64	6.56	N/mm^2
			fm=fc+1.64*s		
1.4	Target mean strength	2.10 S1		36.56	N/mm^2
1.5	Cement class	Specified		42.5	
1.6.1	Type of course aggregate	Specified		crushed	
1.6.2	Type of sand (fine aggregate)	Specified		uncrushed	
1.7	Free water/cement ratio	Table 2-1, fig. 2-35		0.56	
2					
2.1	Degree of workability (slump)	Specified		100	mm
2.2	Nominal max size of aggregate	Specified		20	mm
2.3	Free-water content	Table 2-2	$2/3W_f+1/3W_c$	205	kg/m^3
3					
3.1	Cement content	2.10 S4		366	kg/m^3
4					
4.1	Relative density of aggregate (SSD)			2.7	
4.2	Concrete density	Fig. 2-36		2410	kg/m^3
4.3	Total aggregate content	2.10 S6		1839	kg/m^3
5					
5.1	Grading of fine aggregate	%passing 600μm		36.25	%
5.2	Proportion of fine aggregate	Fig. 2-37		44	%
5.3	Fine aggregate content	2.10 S7		809.16	kg/m^3
5.4	Coarse aggregate content	2.10 S8		1029.84	kg/m^3

ANNEX – 3

Experimental Test Results

Compressive Strength

With Bonding agent						Without Bonding agent					
T=0	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)	T=0	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)
1	8557	24.87	910	910.31	40.46	1	8555	24.87	912	912.32	40.55
2	8518	24.76	858	858.13	38.14	2	8478	24.64	878	878.20	39.03
3	8539	24.82	803	802.96	35.69	3	8577	24.93	782	781.90	34.75
AVG		24.82			**38.09**	AVG		24.81			**38.11**
With Bonding agent						Without Bonding agent					
T=1 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)	T=1 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)
1	8600	25.00	893	893.3	39.70	1	8687	25.25	808	807.97	35.91
2	8641	25.12	748	747.8	33.24	2	8573	24.92	910	910.31	40.46
3	8616	25.04	961	961.5	42.73	3	8600	25.00	868	868.17	38.59
AVG		25.05			**38.56**	AVG		25.06			**38.32**
With Bonding agent						Without Bonding agent					
T=2 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)	T=2 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)
1	8560	24.88	758	757.83	33.68	1	8542	24.83	799	798.95	35.51
2	8597	24.99	781	780.90	34.71	2	8577	24.93	634	633.57	28.16
3	8592	24.97	669	668.63	29.72	3	8524	24.78	771	770.87	34.26
AVG		24.95			**32.70**	AVG		24.85			**32.64**
With Bonding agent						Without Bonding agent					
T=3 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)	T=3 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)
1	8463	24.60	783	782.90	34.80	1	8592	24.97	708	707.71	31.45
2	8609	25.02	678	677.65	30.12	2	8511	24.74	785	784.91	34.88
3	8557	24.87	795	794.94	35.33	3	8460	24.59	733	732.77	32.57
AVG		24.83			**33.41**	AVG		24.77			**32.97**
With Bonding agent						Without Bonding agent					
T=4 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)	T=4 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)
1	8529	24.79	694	693.68	30.83	1	8610	25.03	607	606.52	26.96
2	8576	24.93	722	721.74	32.08	2	8498	24.70	669	668.63	29.72
3	8632	25.09	718	717.73	31.90	3	8474	24.63	723	722.75	32.12
AVG		24.94			**31.60**	AVG		24.79			**29.60**
With Bonding agent						Without Bonding agent					
T=5 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)	T=5 hrs	Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Compressive Strength (N/mm^2)
1	8531	24.80	602	601.52	26.73	1	8502	24.71	590	589.50	26.20
2	8508	24.73	553	552.46	24.55	2	8624	25.07	572	571.48	25.40
3	8611	25.03	634	633.57	28.16	3	8649	25.14	526	525.44	23.35
AVG		24.85			**26.48**	AVG		24.97			**24.98**

Splitting Tensile Strength

		With Bonding agent							Without Bonding agent				
T=0		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)	T=0		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)
	1	8414	24.46	83.58	83.78	2.37		1	8511	24.74	86.5	86.68	2.45
	2	8523	24.77	92	92.16	2.61		2	8434	24.51	91	91.17	2.58
	3	8542	24.83	116.3	116.36	3.29		3	8319	24.18	115	115.07	3.26
Avg			24.69			**2.76**	Avg			24.48			**2.76**
		With Bonding agent							Without Bonding agent				
T=1 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)	T=1 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)
	1	8490	24.68	108	108.09	3.06		1	8458	24.58	103	103.11	2.92
	2	8483	24.66	86.89	87.07	2.46		2	8579	24.94	101	101.12	2.86
	3	8662	25.18	100	100.13	2.83		3	8535	24.81	90.24	90.41	2.56
Avg			24.84			**2.79**	Avg			24.78			**2.78**
		With Bonding agent							Without Bonding agent				
T=2 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)	T=2 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)
	1	8349	24.27	66.92	67.19	1.90		1	8423	24.48	67.29	67.56	1.91
	2	8380	24.36	63.44	63.73	1.80		2	8479	24.65	76.7	76.93	2.18
	3	8456	24.58	76.48	76.71	2.17		3	8407	24.44	66.32	66.60	1.88
			24.40			**1.96**	Avg			24.52			**1.99**
		With Bonding agent							Without Bonding agent				
T=3 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)	T=3 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)
	1	8516	24.75	83.45	83.65	2.37		1	8436	24.52	71.1	71.35	2.02
	2	8434	24.51	72.58	72.83	2.06		2	8443	24.54	72.43	72.68	2.06
	3	8418	24.47	71.38	71.63	2.03		3	8477	24.64	77.84	78.06	2.21
Avg			24.58			**2.15**	Avg			24.57			**2.09**
		With Bonding agent							Without Bonding agent				
T=4 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)	T=4 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)
	1	8410	24.45	70.55	70.81	2.00		1	8497	24.70	63.14	63.43	1.79
	2	8383	24.37	66.34	66.62	1.88		2	8532	24.80	66.28	66.56	1.88
	3	8412	24.45	60.7	61.00	1.73		3	8375	24.34	66.32	66.60	1.88
Avg			24.42			**1.87**	Avg			24.61			**1.85**
		With Bonding agent							Without Bonding agent				
T=5 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)	T=5 hrs		Weight (g)	Density (kN/m^3)	Machine Reading (kN)	True Reading (kN)	Tensile strength (N/mm^2)
	1	8480	24.65	63.49	63.78	1.80		1	8525	24.78	58.5	58.81	1.66
	2	8461	24.59	70.84	71.09	2.01		2	8537	24.81	62.34	62.63	1.77
	3	8311	24.16	60.25	60.55	1.71		3	8413	24.45	71.01	71.26	2.02
Avg			24.47			**1.84**	Avg			24.68			**1.82**