COMPARISON (... IG BOND STRENGTH BETWEEN C(... PAIR MATERIALS

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ABSTRACT

Placing freshly mixed concrete against old existing concrete is a point of interest in repair applications, and can be sometimes a vital issue. Unless good bond is ensured at the interface, the concrete section may become improper and sometimes unsafe. An experimental study was performed to investigate the effect of testing methods on bond strength between concrete substrate and repair material. 27 numbers of sample with different dimension were prepared according to different type of testing. Sample with dimension of 150x150x150 mm cubes were required for spliting test. The cubes is constructed into two parts as old substrate concrete and repair material with a size of base size 75x150 mm and a height of 150mm. In the Bi-Surface shear method, the repair material constitutes one third of the samples which means the prisms with a base size of 100x150 mm and a height of 150 mm are cast as old or substrate concrete. Then the repair materials are cast in prisms with a base of 150x50 mm and a height of 150 mm and are bonded to the concrete substrate. Slant Shear Test samples were 100x100x400 mm and it is cut at angle 60° to their cross sectional axis whereas the old substrate designed with a base size of 100x100mm and height 113.5mm as well as the repaired material samples. Steel wire brush were rub to bonding surface in order to produce different surface roughness. The estimated amplitude of low roughness was 3–4 mm and using a similar approach, the high-roughness was roughened to amplitude of 7–8 mm. After two weeks, the new concrete was added to the substrate concrete. Splitting prism test, Bi-Surface direct shear test and Slant shear tests were performed to evaluate the bond strength at age 7 days, 14 days and 28 days The results shows sample with high roughness surface were produce more conpressive strength in all type of testing. Hence, direct shear test was develop greater comprasive strength compare to spliting prism test and slant sheat test.

ABSTRAK

Kaedah meletakkan campuran konkrit segar terhadap konkrit lama sedia ada merupakan perkara utama dalam proses membaiki dan penambahbaikan, juga boleh menjadi satu isu penting dalam bidang pembinaan. Hal ini kerana struktur konkrit boleh menjadi tidak sekata dan kadang-kadang tidak selamat walaupun cantuman antara konkrit telah diyakini sepenuhnya. Satu ekperimen telah dijalankan untuk mengenalpasti keberkesanan kaedah kajian terhadap kekuatan ikatan antara konkrit sedia ada dan lapisan konkrit baru.. 27 bilangan sampel dengan dimensi yang berbeza telah disediakan mengikut berlainan jenis ujian. Kiub dengan dimensi 150x150x150 mm diperlukan bagi "Splitting prism test" dibina kepada dua bahagian sebagai konkrit substrat lama dan bahan baru dengan saiz asas 75x150 mm dan ketinggian 150mm. Dimensi ruang konkrit baru bagi kaedah Bi-Surface shear ialah satu pertiga daripada sampel yang bermaksud prisma dengan saiz asas 100x150 mm dan ketinggian 150 mm dinyatakan sebagai konkrit lama atau substrat. Kemudian konkrit baru digabungkan dalam prisma dengan asas mm 150x50 dan ketinggian 150 mm dan terikat kepada substrat konkrit. Dimensi Slant Shear Test pula adalah 100x100x400 mm dan ia dipotong pada sudut 60 ° dengan paksi keratan rentas mereka manakala substrat lama direka dengan saiz asas 100x100mm dan ketinggian 113.5mm termasuklah ruang konkrit baru. Berus kawat telah digunakan untuk menyapu ke permukaan ikatan untuk menghasilkan kekasaran permukaan yang berbeza. Kekasaran rendah dianggarkan antara 3-4 mm dan menggunakan pendekatan yang sama, kekasaran tinggi telah dianggarkan antara 7-8 mm di permukaan sampel. Proses penggabungan konkrit baru ke atas konkrit lama dilakukan dalam tempoh dua minggu kemudian. Ujian "Splitting prism", "Bi-Surface direct shear" dan "Slant shear" telah dijalankan untuk menilai kekuatan ikatan pada tempoh 7 hari, 14 hari dan 28 hari. Keputusan menunjukkan sampel dengan kekasaran permukaan tinggi telah menghasilkan kekuatan lebih lebih dalam semua jenis ujian. Oleh itu, ujian "direct shear" lebih kuat berbanding ujian "spliting prism test" dan "slant shear test".

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the field of repair and strengthening of concrete structures, the need often arises to place new concrete next to old, existing concrete. Examples of these applications include highway structures where concrete overlays are used and repair of corrosion-damaged concrete structures, where the deteriorated concrete must be replaced with new concrete. Good bond strength between overlay and substrate is a key factor in performance of concrete repairs. The bond strength mainly depends on adhesion in interface, friction, aggregate interlock, and time-dependent factors. Each of these main factors, in turn, depends on other variables. Adhesion to interface depends on bonding agent, material compaction, cleanness and moisture content of repair surface, samples age, and roughness of interface surface.

Concrete repairing mainly includes removing unsound concrete and replacing it with repair or overlay materials. One of the key requirements for any kind of repair system is to have adequate bond strength between the existing concrete substrate and overlay throughout the service life. When a repair is performed, the differences in the properties of two materials will affect bond strength and stress distribution. Of particular relevance are differences in shrinkage, elastic modulus and thermal movement. The repair system can be considered as three phase composite system which is substrate, overlay and bond zone. Bond zone here refers to the interface and vicinity of bond plane. The bond zone must capable of withstanding the stresses imposed on the system. Different factors have effects on the bond strength and its integrity.

Roughness is usually assessed only qualitatively, by observing the substrate surface and by classifying it from very smooth to very rough. It is usual to increase the roughness of its surface with the purpose of improving the bond between both materials. Surface treatments like wire-brushing, sandblasting, water jetting, and chipping are usually adopted. Euro code 2 indicates that, for shear at the interface between concrete cast at different times, ''surfaces may be classified as very smooth, smooth, rough or indented''.

The quality assurance of bond strength requires test methods that can quantify the bond strength as well as identify the failure mode. There have been numerous investigations led to development of different test methods. The forces which are applied in each test and the failure mode are important in order to choose the proper test. Tests are defined both in laboratory and field. An interpretive study on test methods is presented which classifies and compares the tests based on the applied force, failure mode and practical importance of each test.

1.2 PROBLEM STATEMENTS

Repair and strengthening applications are routine tasks in building construction. The transfer of internal stresses across the bond plane between new fresh concrete and old concrete is a critical aspect in the design of such composite concrete elements. In these applications, the bond between the old and new concrete usually presents a weak link in the repaired structure. Poor bond may lead to improper and sometimes unsafe section even if high strength concrete is utilized.

Concrete may be damaged due to many different reasons of which some of the more important causes. Excessive water is basically one of the most common problems that cause damages in concrete. It highly decreases the strength and the abrasion and increases the shrinkage and creep. Placing the bars too close to the surfaces or corners, lack of adequate contraction joints, slabs with insufficient expansion joints, dimensional errors, finishing defects, improper compaction or curing and many other factors in design and during construction, cause damages of concrete. Besides, corrosion of the reinforcement can be dangerous for whole the structure as they have been designed to carry forces. Corrosion can destroy the bonding between bars and concrete material so the material cannot able to transfer the loads to the bars in case of corrosion. Lastly, abrasion-erosion damage factor structure that transports water with silt, sand and rock are faced with this problem especially in case that the water velocity is high or the structure is on the slope.

1.3 OBJECTIVES OF THE STUDY.

The aim for this project is to study the effect of test methods on bond strength between concrete substrate and repair material. Three test methods with cementitious methods used were Slant Shear test, Splitting Prism test and a new direct shear named Bi-Surface shear test and three types of surface roughness were studied. In order to do so, the objectives of this study are:

i. To identify the effect of testing to concrete bonding strength.

ii. To determine the effect of surface roughness to the concrete bonding strength.

iii. To observe the failure mode of samples.

1.4 SCOPE OF STUDY

This study focuses on evaluation of bond strength between repair material and substrate at the interface. There is a need to compare different tests for measuring bond strength and to establish a relationship among the values obtained from each test. There are 27 samples were constructed and grouped into three types of roughness which are no roughness, low roughness and high roughness to be tested into three types of experiment.

The dimension of the Splitting prism forms were 150x150x150 mm cubes. The cubes is constructed into two parts as old substrate concrete and repair material with a base size 75x150 mm and a height of 150mm. In the Bi-Surface shear method, the repair material constitutes one third of the samples. Using 150 mm cube forms, prisms with a base size of 100x150 mm and a height of 150 mm are cast as old or substrate concrete then the repair materials are cast in prisms with a base of 150x50 mm and a height of 150 mm and are bonded to the concrete substrate. Slant Shear Test samples were 100x100x400 mm and it is cut at angle 60° to their cross sectional axis whereas the old substrate designed with a base size of 100x100mm and height 113.5mm as well as the repaired material sampels. Figure 1.1 and Figure 1.2 show the cube dimension and prism dimension respectively.

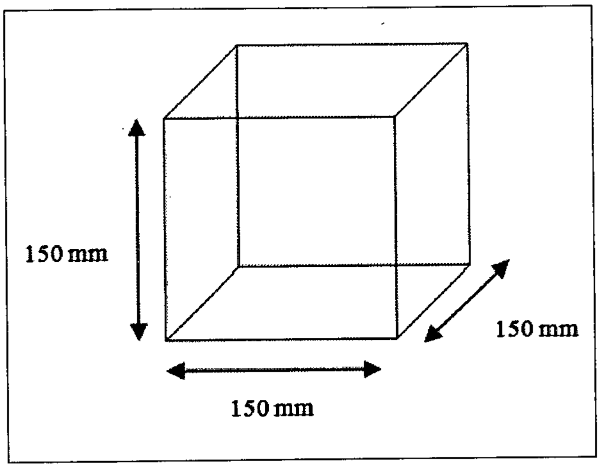


Figure 1.1: Cube dimension

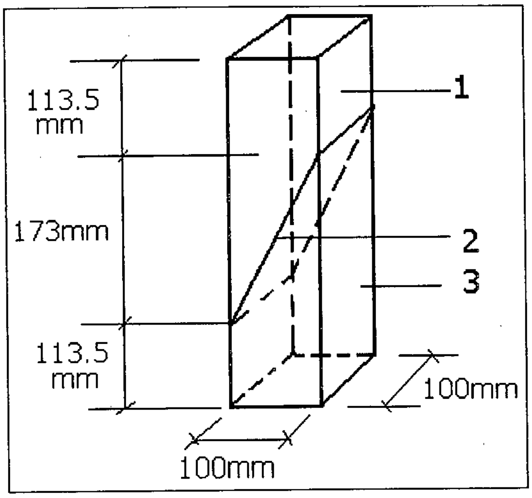


Figure 1.2: Prism dimension

The Splitting Test measures the bond under tension stress. The method was later adopted as a standard test ASTM C496 and the tensile strength of concrete is regarded as an indication of its tensile strength. The Slant Shear Test measures the bond strength under a state of stress that combines shear and compression. It was standardized in ASTM C882-99. Lastly, the Direct Shear tests measure the bond under shear stresses, and are called direct shear methods. In most cases, the bond surface for a direct shear test is actually subjected to shear stress and a small bending stress.

1.5 IMPORTANCE OF STUDY

The measured bond strength is greatly dependent on the test method. With the proliferation of chemical bonding agents, the design engineers often faced with selecting the bond strength of a particular product based on the data reported by the manufacturer. Depending on the test method used, the reported bond strength may significantly overestimate the true strength of the product for the desired applications. Therefore, there is a need to compare different tests for measuring bond strength and to establish a relationship among the values obtained from each test.

CHAPTER 2

LITERATURE REVIEW

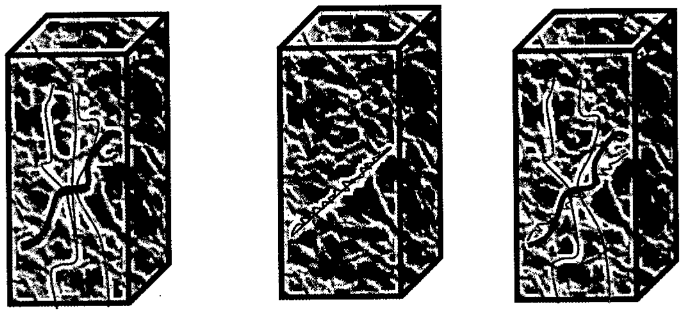
2.1 INTRODUCTION

Concreting bonding is an important area particularly in construction using prefabrication method namely precast and semi precast units. Precast and semi precast concrete units are used widely in the construction industry because of advantages of labor reduction, short construction duration and cost effectiveness. Many constructions have failed due to the debonding that occurs in semi precast concrete slab. Abu-Tair et al. (2000) and Bonaldo et al. (2005) stated that the bond performance between the old and the new concrete plays an important role in the structural performance. Failing to bond properly will cause shrinkage and finally crack that may promote the corrosion of steel reinforcement due to the penetration of chloride ions, water and other hazardous substances.

In this chapter, the effectiveness of different types of roughness in bonding the new and the old concrete was studied. The experimental work included the method of roughness the new and old concrete and also factor affecting the bond strength.

2.2 BOND STRENGTH

Beaupre (1999) mentioned that the bond strength is the adhesion between overlay and substrate which can be the weakest link of the system. Good bond strength is a key factor to have a monolithic system. Bond can be expressed by shear resistance or tensile resistance. It is important to select the one which can better state the stresses subjected to the structure in the field. The bond strength can be easily defined as maximum force divided by the interface area, in the condition that failure occurs completely at the interface. Bonaldo et al (2005) stated that failure in the substrate indicates that the bond strength is greater than the tensile strength of substrate and a failure in the overlay indicates that the bond strength is greater than the tensile strength of the overlay as referred in Figure 2.1.



(a) **(b)** **(c)**

Figure 2.1: Modes of failure (a) Concrete failure ,(b)Bond failure ,
(c) Double failure

2.3 FACTORS AFFECTING BONDING STRENGTH

The bonding strength were affected by cleanliness and surface preparation of the concrete surface. A bond must free from dust, oil, grease and other contaminants. These have significant influence of the bond strength.

2.3.1 Surface preparation

In order to gain proper bond strength the surface must be prepared prior to performing the overlay. In the repair works when the substrate is concrete before surface preparation the deteriorated concrete must be removed since it may damage the new layer and it does not have enough strength. It is also recommended when the substrate is rock, to remove the layer of chemically or mechanically damaged rock before surface preparation as in Figure 2.2 .

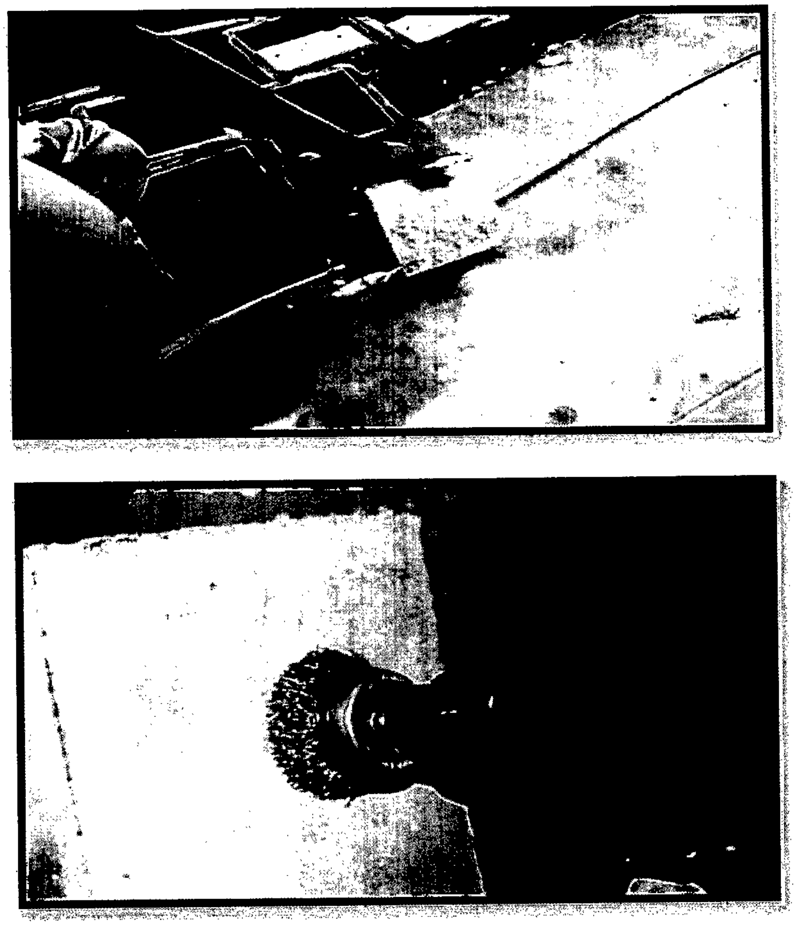


Figure 2.2: Cleanliness surface of the sample

There are several methods to prepare the surface and it is quiet important to choose the best way since it has a decisive influence on bond in the interface. Some methods can only remove a thin layer of concrete, while others have the ability to remove material to a significant depth as in Table 2.1. Silfwerbrand (1990) and Talbot et al (1994) stated that it is important to take into consideration that if the surface produced by a vigorous method, i.e. hammering, the surface will be very rough but micro cracks will be induced just beneath the prepared surface, making it weak.

Micro cracks reduce bond strength substantially and they have a detrimental effect on the uppermost layer of the substrate. Micro cracks cause reduction in the effective bond area. Also micro cracks develop due to the stress concentrated at their tips. Knutson (1990) founded that distress like faulting, pumping and loss of support, shattered slabs, transverse cracks, longitudinal cracks and joint deterioration needed to be repaired by proper remedy before overlay placement.

Although mechanical methods i.e. hammers are likely to introduce micro cracking, field tests however have shown that the bond strength can reach satisfactory values if mechanical removal is followed by high pressure water cleaning. Based on tests that have been done by Silfwerbrand (1990), water-jetting is one of the best solutions both having the high roughness and not having micro cracks.

Table 2.1: Methods of concrete removal

Removal method	Principle behaviour	Advantages	Disadvantages
Sand-blasting	Blasting with sands	No micro cracking	Not selective, leaves considerable sand.
Scrabbling	Pneumatically driven bits impaction	No micro cracking, no dust.	Not selective
Shot blasting	Blasting with steel balls.	No micro cracking, no dust	Not selective
Grinding (planning)	Grinding with rotating lamella.	Removes uneven parts.	Dust development, not selective.
Pneumatic (jack) hammers (chipping)	Compressed-air-operated chipping	Simple and flexible use, large ones are effective.	Micro cracking, damages reinforcement, poor working environment, slow production rate, not selective.
Explosive blasting	Controlled blasting using small, densely spaced blasting charges.	Effective for large removal volumes.	Difficult to limit to solely damaged concrete and safety, not selective.
Water-jetting/ hydro demolition	High pressure water jet from a unit with a movable nozzle	Effective, selective, does not damage reinforcement	Water handling, removal in frost degrees, costs for establishment

2.3.2 Surface roughness

The surface roughness is important to provide friction and aggregate interlock but Silfwerbrand proved that roughness in its own does not have significant influent but the method of surface preparation and the absence of micro cracks is more important as in Silfwerbrand (1990). Within the first two days of casting, repairing surfaces were roughened in one of three categories: no, low or high roughness. The low-roughness category was obtained using a steel wire brush to remove slurry cement from external surface of both fine and coarse aggregates. The estimated amplitude of roughness was 3–4 mm; using a similar approach, the high-roughness category was roughened to an amplitude of 7–8 mm.

No roughness	**Low roughness**	**High roughness**
	(3-4 mm)	(7-8 mm)

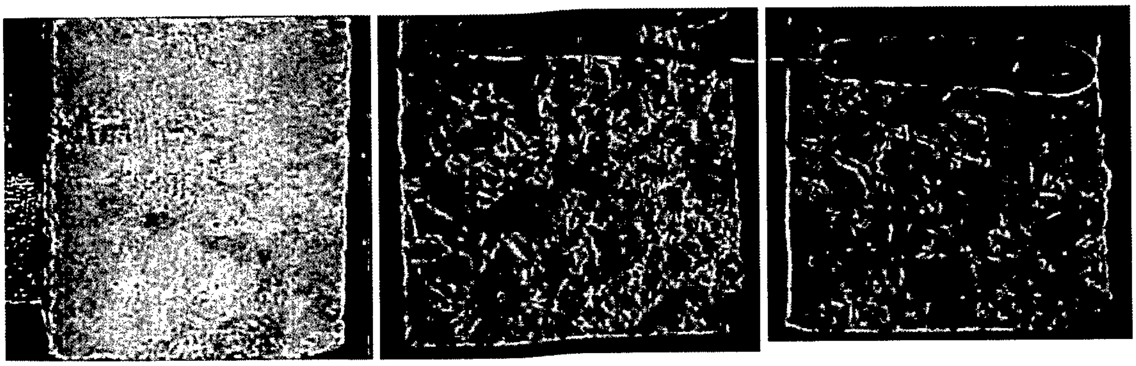


Figure 2.3: Types of surface roughness

2.3.2.1 Interfacial transition zone (ITZ)

The modified volume is called interfacial transition zone (ITZ). Because of "Wall Effect", which means inability of cement particles to pack efficiently around embedment, the ITZ has a high porosity and reduction of unreacted cement near the surface. Some other engineers have tended to objectively suggest that the ITZ is indeed not the major influence on concrete properties. With respect to mechanical effects, Van

Mier and Vervuurt ,1999 concluded that the conventional physical model to treat the ITZ as separated phase should be replaced.

2.3.2.2 Effect of surface roughness on bond strength

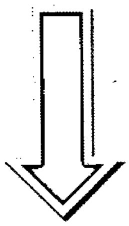
Knutson (1990) found that the bond strength between the old and new concrete is affected by the surface texture and moisture conditions of existing concrete and bonding agents. Milling and shot blasting are usually used to clean and roughen the surface of the substrate. Several controversies still exist on the effects of bonding agents and moisture condition of substrate.

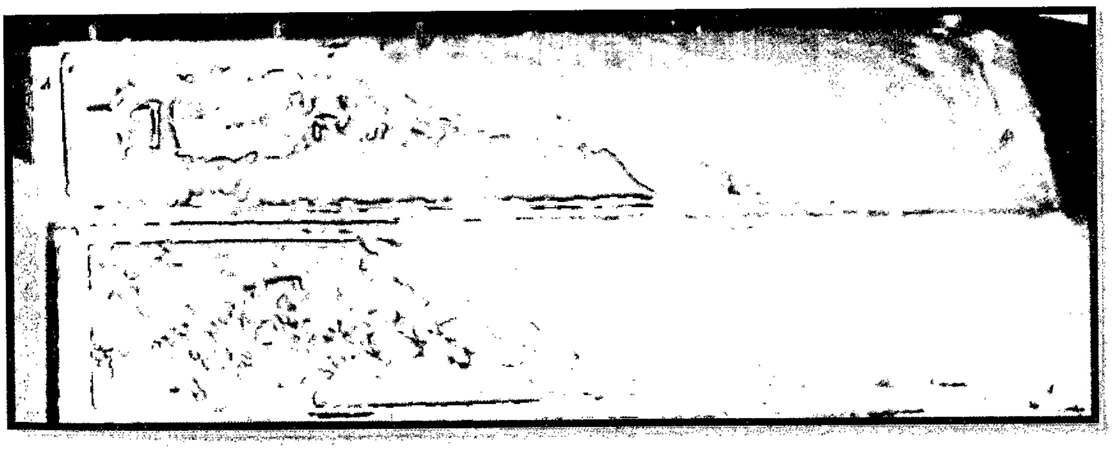
By covering laboratory bond tests, experimental field projects, and survey of projects in use, Felt (1956) found that the two main factors governing bond were: the strength and integrity of the old base concrete, and the cleanness of old surface; a good bond may be achieved without using a grout layer. However, he pointed out that the chance of increasing bond strength can be improved by using grout and best bond could be obtained with dry and grouted base concrete. By determined samples size, maximum aggregate size of repair materials, types of repair materials, interface roughness and age at loading as variables, Momayez (2004) pointed out that the bond strength was improved with surface roughness, silica fume content, and age at testing.

2.3.3. Compaction and placement of the overlay

Compaction is an important factor for obtaining a dense and homogeneous overlay as well as a good and even bond. Compaction helps the overlay fill and cover cavities and voids at the surface which means to have more efficient contact area and fewer caves. The other advantage is to have better and less permeable overlay which is also helpful for durability of the bond. Silfwerbrand (1990) mentioned that on rough and uneven surface, there is a risk for air pockets in the depressions of the surface.

Before Overlay (Substrate)





After Overlay

Figure 2.4: Placement of new concrete

2.3.4 Overlay curing and temperature effect

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. Since the hydration of cement does take time, days and even weeks curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Concrete strength depends on the growth of crystals within the matrix of the concrete. These crystals grow from a reaction between Portland cement and water, a reaction known as hydration. Kosmatka et al (2002) stated effect of curing duration on compressive strength development is presented in Figure 2.5.

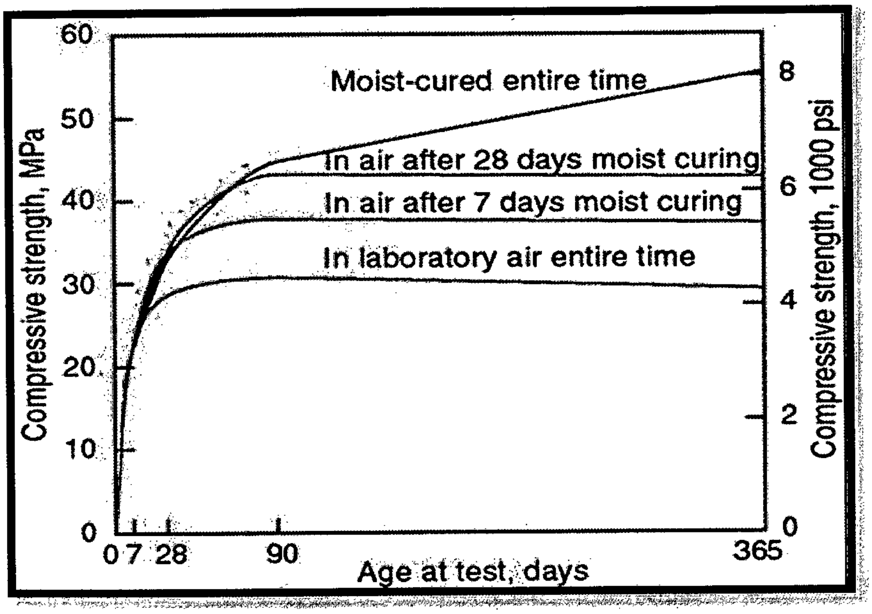


Figure 2.5: Effect of curing duration on compressive strength development

Source: (Kosmatka et al, 2002).

2.4 SECONDARY FACTORS INFLUENCING BOND

2.4.1 Pre wetting

The moisture condition has influence on bonding strength and failure mode. The moisture condition of both the surface and the substrate is important. If the surface and substrate are too dry, part of mixing water of the top layer will be absorbed by the substrate before any components in a cement paste are formed. This causes a risk for heterogeneous and porous zone close to the bond surface. Referring to Austin.et al, 1995, if the surface and substrate are too wet and saturated, the capillary pores in the substrate are filled and therefore the excess water will rise up to the surface and it make a layer with high water cement ratio.

2.4.2 Traffic vibrations

Of course the heavy vibration and traffic can be harmful for newly cast overlay. Although the vertical vibrations due to the traffic in some structures such as bridge decks or concrete pavements can be useful, but in tunnel blasting the vibrations do not play a positive role since vibrations which come from explosions in the vicinity are normally heavy and the waves are both vertical and horizontal. So that they cause shear forces in the interface make the early age bond weak as shown in Silfwerbrand (1990).

2.4.3 Environmental factors

Environmental factors such as temperature, temperature changes, thawing and freezing, humidity can influence the bond durability. Medina et al (2007) found that temperature had a significant effect on cracking and debonding behavior and tensile debonding failure is shown to be a dominant failure mode at early ages between old concrete pavement and new overlay. Both temperature and moisture gradients through the depth of pavements cause curling and warping. An aggressive environment indirectly has a negative effect on bond strength. It makes difficulties especially for curing and later during the service time.