BONDING BEHAVIORS BETWEEN OLD AND NEW FOAMED CONCRETE WITH DIFFERENT SUBSTRATE SURFACE

MOHD MARWAN HAFIZ BIN MOHD ANNUAR

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Faculty of Civil Engineering
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Recent years, method of concrete strengthening has been a rising issue. In structure of concrete or concrete repairing works, the most important element is that the bonding itself. The surface preparation of concrete substrate will give differ results in term of bonding behavior. Performance of a structural system such beams and slabs are relies on behavior of the bonding between the old and new concrete. The research intended at studying the bonding strength between the old and new foamed concrete due to surface preparations. Factors such as roughness of surface, compaction, and concrete curing affect the bond. In this study, the surface of the old concrete were partially chipped using a light jackhammers and differed in terms of its numbers. The research was also to observe failure mode pattern due to different number of chippings. Samples were tested for two different methods namely Splitting Test and Slant Shear Test. The slant shear tests were conducted to investigate the bonding strength in term of shear. For slant shear test, 12 blocks sizing 100 mm x 100 mm x 400 mm were prepared. Meanwhile, the slant shear test was conducted to measure the axial tensile strength of a concrete submitted to compression along its length. For this test, 12 cube specimens of size 150 mm x 150 mm x 150 mm were prepared. These tests were conducted on 28 days after standard air curing because at day 28 the concrete had fully achieved its true strength. Foamed concrete was used to reduce the self-weight of the structural element compared to the conventional concrete. For each testing method, three samples were prepared and differed in term of surface roughness of 0, 10, 20 and 30 number of drill holes. From the results, S30 for Splitting test and SR30 Slant shear test showed the highest in terms of bonding strength compared to lower surface roughness with values of 2.17 N/mm2 and 21.73 N/mm2 respectively. However, all types of surface roughness are failed in term of bonding.

ABSTRAK

Sejak beberapa tahun ini, kaedah memperkuat konkrit telah menjadi isu utama. Dalam struktur konkrit dan kerja pembaikannya, elemen paling utama adalah kekuatan cantuman itu sendiri. Penyediaan permukaan konkrit akan memberi hasil yang berbeza. Prestasi sesebuah sistem struktur seperti rasuk dan lantai bergantung pada sikap ikatan di antara konkrit lama dan yang baru. Kajian ini bertujuan menyelidik kekuatan ikatan di antara konkrit berliang lama dan baru melalui penyediaan permukaan. Faktor seperti kekasaran permukaan, pemadatan dan pengawetan konkrit menjejaskan ikatan. Dalam kajian ini, permukaan lama konkrit di tebuk sedikit terlebih dahulu dengan menggunakan gerudi kecil dan dibezakan oleh bilangan tebukan. Kajian ini juga diadakan untuk melihat corak mod kegagalan konkrit disebabkan oleh perbezaan jumlah tebukan. Sampel-sampel diuji melalui dua ujikaji yang berbeza iaitu Ujian Belahan dan Ujian Geseran Condong. Ujian geseran condong dijalankan untuk mengkaji kekuatan ikatan dalam bentuk geseran. Untuk ujian ini, sebanyak 12 blok sampel berukuran 100 mm x 100 mm x 400 mm disediakan. Sementara itu, ujian belahan pula bertujuan untuk menilai kekuatan tarikan paksi konkrit yang mengalami tekanan sepanjang jaraknya. Untuk ujian ini, 12 kiub berukuran 150 mm x 150 mm x 150 mm disediakan. Ujian-ujian ini dijalankan pada hari ke-28 selepas pengawetan udara kerana waktu itu konkrit telah mencapai kekuatan sebenarnya. Penggunaan konkrit berliang adalah untuk mengurangkan berat sendiri berbanding konkrit biasa. Untuk kedua-dua ujian, tiga sampel disediakan dan dibezakan oleh jumlah tebukan iaitu 0, 10, 20 dan 30. Keputusan kedua-dua ujian menunjukkan S30 untuk ujian Belahan dan SR30 untuk Ujian Geseran Condong mencapai kekuatan ikatan yang tertinggi berbanding sampel-sampel yang mempunyai bilangan kekasaran permukaan yang rendah dengan jumlah masing-masing adalah 2.17 N/mm^2 dan 21.73 N/mm^2. Namun begitu, kesemua sampel mengalami kegagalan jenis ikatan.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Concrete is the most common material that been used in construction globally. Apart of water, the second most make use of substance in the earth is concrete (Guan, 2010). Basic proportions in concrete are cement, water and aggregate. However, admixtures are sometimes added into the mixture depending on the usage and its necessity. The mixture is called concrete. Hardened concrete will achieve its ultimate state when the setting and curing process are well taken care of. During the hardening state, a chemical process in between cement and water cause the concrete to gain increase in strength. Thus, concrete quality need to be controlled in order to achieve its maximum strength and endurance.

There are two types of concrete, namely conventional concrete and lightweight concrete. These types of concrete are differ from each other in term of mechanical properties and its necessity of usage. The most significance of those two types is they possess different density. As for conventional concrete, the density is about 2300 kg/m3 while the density for lightweight concrete ranging from 300 kg/m^3 to 1800 kg/m^3 (Abdullah et al., 2012).

Concrete improvement has always been a pivotal issue for researchers. The purpose is that to create and develop the strongest concrete while greatly reduce its self weight and load. One of interesting research example on concrete engineering is lightweight foamed concrete. For this type of concrete, a liquid substance called foam agent is added into concrete mixture in order to reduce the concrete density (Zuhairi, 2010).

1.2 PROBLEM STATEMENT

Detoriation is the common issue in concrete structure. In order to do the material repairing or coating application, the surface of the old concrete need to be prepared. But, the surface preparation of concrete structures is not a simple task. The bonding between old and new concrete are be the major problem as the bonding strength is weak. The performance of the new concrete may vary depending on method used on the surface of old concrete.

1.3 OBJECTIVES OF THE RESEARCH

The main objectives of this study are:

(i) To determine the bonding strength of sample under slant shear and splitting test.

(ii) To observe the failure mode pattern of old and new foamed concrete substrate under different number of drill holes.

1.4 SCOPE OF RESEARCH

This paper of study analyses experimental research which pointing at inquiring the bonding strength of concrete substrate when new concrete is applied on the old concrete. Basically two types of samples with different dimension were casted. First type of sample was needed for splitting test, dimensioning 150 mm x 150 mm x 75 mm (half sample) and the second type was used for slant shear test dimensioning 100 mm x 100 mm x 400 mm. These two types of samples were prepared and differed in term of surface preparation, which first sample is solid surface as a control sample, second is 10 drill holes, third is 20 drill holes and fourth is 30 drill holes.

The density design of lightweight foamed concrete was about 1600 kg/m^3 with water-cement proportion ratio 2:1:1 constitutes of cement to sand to water ratio of 0.5. Total of 12 cubes and 12 prisms were casted and prepared. For each sample type were tested for splitting test and slant shear test on 28 days after the day sample has been casted. All of the samples were bared to air curing at day 28. The splitting test and slant shear test were conducted in the FKASA Laboratory right after the samples reach maturity at the followed curing days. For all the conducted works in this research study were fully presented in chapter 3.

1.5 RESEARCH SIGNIFICANCE

This study plays a major role in determining the bonding strength of old and new foamed concrete. The bonding strength of concrete substrate can be determined after the slant shear test and splitting test is conducted. The massive demand of concrete repairing and strengthening works pushed researchers and engineers to overcome the decaying structural problem in bond between old concrete substrate and new overlaying concrete. The vital part in these works are by preparing the surface of old concrete where surface roughness is most influencing parameters in good bonding strength. Thus, the importance of repairing and strengthening is greatly important in cost reduction for most construction.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Lightweight foamed concrete consist only cements, fine aggregates, water and foam. Foamed concrete is light in weight because majority of the concrete contain no coarse aggregates (Puttappa, 2008). It is one type of concrete that extensively used in construction nowadays. Lightweight foamed concrete possess same strength as conventional concrete, however the density is not the same. LFC having dry density of 300 kg/m^3 up to 1800 kg/m^3 while 2400 kg/m^3 for conventional concrete. Minimum quantity of aggregate ensures the high flow ability of LFC. Ramamurthy et al. (2009) mentioned several key factors in preparing stable foamed concrete such as, foam preparations, foaming agent selection, uniform air-voids distribution, grade of materials and mixture ration design. Behfarnia (2010) in his study also stated that strength of bond depends on not only physical and chemical properties, but also the remaining factors such as initial curing periods, preparation of substrate surface and environmental conditions. Therefore, this literature review explains the ongoing knowledge on foamed concrete which consist of characteristics and bonding behavior of old and new concrete substrate.

2.2 BASIC MATERIALS

Basic materials that were used in order to produce lightweight foamed concrete are cement, water, fine aggregate and foam.

2.2.1 Concrete

Concrete can be best defined as a blend of ordinary Portland cement or other cementations of hydraulic, water, coarse aggregate, fine aggregate with or without admixture. Historically, concrete already proven as the most used constituent in any structural construction since the rise of Roman Empire (Benjamin, 2002). He also stated that numerous concrete structures such as Pantheon and Coliseums are to prove that during that concrete is one of the finest examples of Roman architecture. Nowadays, it is impossible to imagine life without concrete as most of construction use concrete as the main constituent. Modern day concrete is called Portland cement.

To form concrete mixture, the important thing to know is that cement powder will reacts with water in order to form a cement paste. Thus, this reaction will form a hard and solid material (Parveen & Ankit, 2013). The combination of cement paste and fine aggregates that are sieved to designated size of as low of few millimeters will be called concrete mortar. Meanwhile, the addition of small rocks or coarse aggregates of up to few centimeters will be called concrete. They also mentioned that the importance of aggregates is to fill in the void or pore in between cement paste. This is because, concrete is a porous substance and it is vital to take up the space by adding aggregates.

2.2.2 Cement

Acting as a folder, cement is a material that mixes, solidify and stick other substance together. According to Benjamin (2002), cement is invented by the Romans back in the middle Ages. The success in developing cement by the Romans was found to the mixing of crumble limes together with pozzolan, an ash gathered from volcano. He also added that since those days, the reinvention and production of cement are massively done until the scientific inquiry of hydraulic cement which solidifies under water is found out. Nowadays, Portland cement takes place and be the most used type of cement. The production of Portland cement is through heating of calcium carbonate or limestone. Later, the material is put in a kiln to undergo calcinations process, where carbon dioxide is extracted to form calcium oxide or quicklime. Later, gypsum is added into the powder to make Ordinary Portland Cement.

Sean (2009) identified two classifications of concrete, namely hydraulic and non-hydraulic cement. Any of chemical reaction between cement powder and water is called hydration process. Therefore, hydraulic cement can solidify when react to water or even disclosed in wet weather condition. Non-hydraulic cement, in other hand, did not solidify in any underwater condition. In his major study, he also mentioned that this type of cement only solidifies only by under reaction with carbon dioxide. However, cement plays the most important role in concrete as it is the main ingredient in mortar and concrete production.

2.2.3 Water

One of the fundamental elements in hydration process of cement is water. Water is directly consumed in production of concrete (Sean, 2009). However, the consumption of water in concrete may differ due to weather conditions and location of construction site from the concrete source. Alexa et al. (2012) draws our attention by stating that water can be obtained from various sources, namely batch water, ice and aggregate moisture content.

2.2.4 Fine Aggregate

Any natural sand taken from river sand or any inert materials that possess the same characteristic as sand which having hard, strong and durable particles is called fine aggregate. According to Alexa (2012), compare to coarse aggregates, fine aggregate sizes ranging from 150 μm to 9.5 mm. Fine aggregate purposely added into concrete mix to add strength to the mixture. Plus, fine aggregate can fill the void left by cement during hydration process thus create stronger bonding.

2.2.5 Foam

There are two ways to prepare foamed concrete, either by pre-foaming or mixed foaming method. Method of pre-foaming includes the production of base mix separately and alter were thoroughly blended with foam into the base mix. Mixed foaming, on the other hand, needs the foam to be added during the process of mixing producing cellular structure in concrete (Byun et al., 1998). Foam must be added as a base material and should possess stability and not collapsing during pumping, placement and curing (Puttappa et al., 2008).

Foam is most vital element in producing foamed concrete. Foaming agent will be produced in the laboratory by using pre-formed method. The method of pre-formed is advantageous because it gives lower foaming agent requirement and close relationship between amounts of foaming agent used and air content of mix (Ramamurthy et al., 2009).

He also classified pre-formed foam by wet and dry. Dry foam is adversely stable and smaller in size compared to wet foam. Foam is prepared in the mixing chamber where dry foam is produced by forcing the foaming agent solution through a series of high density restrictions and forcing compressed air simultaneously.

2.3 PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE

Like other concrete, lightweight foamed concrete does posses important mechanical properties such as fresh state properties and hard state properties. Fresh state properties such as stability and hardening rate while as hard state properties are compressive strength and bonding strength.

2.3.1 Fresh State Properties

LFC cannot be compacted or vibrated as this concrete possesses high flowability and self-compactibility. These parameters are assessed by the term of stability and consistency of foam concrete which affected by the water compound in the mixture and quantity of foam added (Ramamurthy et al., 2009).

2.3.1.1 Stability

Stability is among the variables of workability and consistency in concrete. It is the ability to resist segregation. Segregation plays in measuring instability. LFC is highly flowable and having low cementitious material contents, it plays a major role to ensure an adequate air void system. Thus, void system need to remain stable during process of agitation, placement and setting (Maziah, 2011).

In previous research made by Ramamurthy et al. (2009), awareness on instability of foamed concrete always been expressed. Water to cement (w/c) ratio should be high in avoiding water extraction from the foam that leading to collapse.

2.3.1.2 Hardening Rate

The normal setting time for foamed concrete is usually between 12 to 24 hours. It varies because hardening time depends on amount of foam added into the mixture. However, the average setting time of LFC can be raised by using rapid hardening cement types, insulation formwork, increment of temperature or using accelerators (Maziah, 2011).

2.3.2 Hardened State Properties

Two most important properties of hardened state are compressive strength and bonding strength of hardened concrete.

2.3.2.1 Compressive Strength

Like conventional concrete, LFC also having increase in strength when cement content is raised. So, foamed concrete is potentially used as a structural material although the strength increase was found to be minimal above cement content of 500 kg/m^3 (Jones, 2000). Therefore, adhering to an acceptable minimum cement content are economical and practicable (Kearsley and Mostert, 2005). Some factors affecting compressive strength of LFC are cement-sand ratio, water-cement ration curing regime, particle size distribution and foaming agent itself (Ramamurthy et al., 2009). A summary of foamed concrete properties indicating compressive strength is shown in Table 2.1.

Table 2.1: Summary of properties of hardened foamed concrete

Dry density (kg/m³)	7-day compressive strength (N/mm²)	Thermal conductivity (W/mK)	Modulus of Elasticity (kN/mm²)	Drying Shrinkage (%)
400	0.5 – 1.0	0.1	0.8 – 1.0	0.30 – 0.35
600	1.0 – 1.5	0.11	1.0 – 1.5	0.22 – 0.25
800	1.5 – 2.0	0.17 – 0.23	2.0 – 2.5	0.20 – 0.22
1000	2.5 – 3.0	0.23 – 0.30	2.5 – 3.0	0.18 -0.15
1200	4.5 – 5.5	0.38 – 0.42	3.5 – 4.0	0.11 – 0.19
1400	6.0 – 8.0	0.50 – 0.55	5.0 – 6.0	0.09 – 0.07
1600	7.5 – 10.0	10.0 – 12.0	10.0 – 12.0	0.07 – 0.06

Source: BCA (1994)

2.3.2.2 Bonding Strength

Adding a new layer of fresh concrete against old hardened concrete demands a good and strong bond to fulfill its purpose. Increasing of member thickness is common when structural members such as slabs require strengthening. In order to improve bonding strength between substrate surfaces of foamed concrete, roughness of the substrate surface need to be increased (Dinis et al., 2012). They also mentioned several factors influencing the bond strength of concrete-to-concrete. They might be affected by the substrate surface preparation, usage of bonding agent at interface, mechanical properties of both concrete layers, stress state at interface, cracking presence at substrate and amount of reinforcement bars across the interface.

Bond between the overlay and the substrate concrete is a key factor that determines the service life of a repaired structure (Mustafa et al., 2013). The bond strength of the concrete-to-concrete interface increased with the increase of the surface roughness (Pedro & Eduardo, 2011). Bond between substrate concrete and repair concrete is greatly influence the compatibility of concrete repairing systems, and therefore determine its successful use (Maan et al., 2010). In recent studies by Bassam et al. (2013), they found that the lowest shear bond strength was recorded in the case of the as casted surface due to no surface preparation of the substrate. Meanwhile, the bonding test results show that both surface roughness and moisture conditions of substrate has a significant influence on the bond strength (Amjad & Abdenour, 2011).

There are two different equations on determining bonding strengths for both splitting and slant shear testing (Momayez et al., 2005). For splitting test, the formula for bonding strength calculation is shown as in Eq. (2.1):

$$\sigma = 2P / \pi A \tag{2.1}$$

where σ is tensile splitting strength (in MPa); P is the maximum applied load (in kN); and A is the area of bonding surface (in mm^2). Bonding strength of slant shear strength however, was calculated by using the equation expressed in Eq. (2.2):

$$S = P / A_L \tag{2.2}$$

where P is bonding strength (in MPa); P is the maximum applied force (in kN); and A_L is slant surface area (in mm^2). In this study, the slant surface area is taken as 100 mm x 100 mm / sin 30° = 20, 000 mm^2.

Sprinkel and Ozyldirim (2000), in their study divide bond quality into five main categories which are excellent, very good, good, fair and poor for material that undergoes splitting test. "Excellent" bond strength is the one that exceeds 2.1MPa. They stated that "excellent" bond quality is the most suitable to be applied as repair material. However, usage of "very good" bond quality which ranging from 1.7 MPa to 2.1 MPa are still acceptable as repair material. The bond quantification by Sprinkel and Ozyldirim (2000) are summarized in Table 2.2.

Table 2.2: Bond quantification for splitting test samples

Bond Quality	Bond (MPa)
Excellent	> 2.1
Very Good	1.7 – 2.1
Good	1.4 – 1.7
Fair	0.7 – 1.4
Poor	0 – 0.7

Chynoweth et al. (2001) in their books ACI Concrete Repair Guide stated that sample undergoes slant shear test should ranging from 6.9 MPa to 12 MPa for them to be used for repairing cause (Chynoweth et al., 2001). However, the samples should be at least cured for about 7 days. Meanwhile, acceptable bond for repair works of 28 days samples should be ranging from 13.8 MPa to 20.7 MPa.

2.4 SURFACE PREPARATION

Preparation of the surface of old concrete is important to ensure the adhesive and bonding when new concrete is added. Deterioration which often occurred at the surface of concrete gives problem to serviceability and performance of concrete. Interface of concrete-to-concrete in structural member are prepared when assertive strengthening operations of existing structures are performed or when precast concrete members with cast-in-situ parts are used (Saldanha et al., 2013).

Proper preparation will provide a clean concrete interface which free from dirt, oil and dust. Hence, Bassam et al. (2013) stated repair and rehabilitation of deteriorated concrete structure are important not only to maximize them for their proposed service-life but also to assure the safety and serviceability of the associated components.

2.4.1 Surface Removal

Prior to performing an overlay and gaining proper bond strength, Keivan (2010) justified that deteriorated concrete need to be removed since it may damage the new layer and it does not have enough strength. Table 2.3 below summarizes some of the concrete removal method in concrete repairing works:

Table 2.3: Methods of concrete removal

Removal method	Principle behaviour	Important advantages	Important disadvantages
Sand-blasting	Blasting with sands.	No microcracking.	Not selective, leaves considerable sand.
Scrabbling	Pneumatically driven bits impaction	No microcracking, no dust.	Not selective.
Shot blasting	Blasting with steel balls.	No microcracking, no dust.	Not selective.
Grinding (planning)	Grinding with rotating lamella.	Removes uneven parts.	Dust development, not selective.
Milling (scarifying)	Longitudinal tracks are introduced by rotating metal lamellas.	Suitable for large volume work, good bond if followed by water flushing.	Microcracking is likely, reinforcement may be damaged, dust development, noisy, not selective.
Pneumatic (jack) hammers (chipping), hand-held or boom-mounted	Compressed-air-operated chipping	Simple and flexible use, large ones are effective.	Microcracking, 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, safety and environmental regulations limit use, not selective.

Source: Courard (2006)

2.4.2 Surface Treatments

There are several types of treatments than can be applied onto surface of concrete. Most common used in treatment of surface is by roughing the surface of old concrete before new concrete can be applied onto it. The purpose is to increase its strength and performance for long time use. Three most common methods to prepare different surface are scarification (SCA), sandblasting (SAB) and chipping hammer (Perez et al., 2009). Before repair work can take place, however, the surface must be clean and washed with clean water to clear away any stained dust and later allow drying (Ahmed, 2010).

2.4.3 Surface Roughness

Recent work on roughness of surface was undertaken by Dinis et al., (2012). They mentioned that bond strength between substrate and the new concrete can be enhanced by increasing the substrate surface roughness. Conducted experiment by them also proved that when a fresh concrete is casted against old substrate, the improvement of the surface roughness gives a significant contribution for the achieved bond strength. As for this study, method of chipping hammer is used to roughen the substrate surface.

2.4.4 Failure Mode

Everaldo et al. (2005) mentioned failure mode of concrete can be categorized into three which are material failure, bond failure and combine material and bond failure. In concrete overlaying and repairing works, these failures rather provide important information in term of adequacy of repair system. Location of the failure occurrence will give clue about the concrete bonding performance. When failure occurs at the bonding of two concrete materials, it indicates that the weak adhesion between them. Meanwhile, if failure occurs at the other location it shows that the concrete strength is larger than the tensile strength between concrete substrate. Thus, this type failure is called material failure. Combined bond and material failure, on the other hand, are rarely occurs. This kind of