Bonding between New and Substrate Concrete in Composite Beams subjected to the Effect of Repeated Loads

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ABSTRACT

This study uses experimental methods to assess the bonding strength of aged concrete compared with several types of new concrete under the effect of repeated loads. The major goal of this study is to evaluate several methods for creating bonding behavior. Additionally, it evaluates the influence of altering stiffness and shrinkage rates at the interface between concrete layers poured at different dates. The experimental tests examined the impact of numerous parameters, including surface preparation, bonding agent type, age difference, and the kind of concrete utilized in the new concrete. The flexural test results show that the percent of Pu (repeated) / Pu (static) was about 85%, 95%, 98%, 95%, 97%, 92%, and 95% for the composite beam with the shear connector, SCC, steel fibers, rough surface, SBR, SIKA, and HSC, respectively. The ultimate load increased by 126% for the composite beams with stirrups as shear connectors with respect to the reference beam. So, using stirrups as shear connectors between new and old concrete significantly increased the load-carrying capacity of the beam subjected to repeated loads.

***Keywords** beams; old concrete; repeated load; new concrete; self compacted concrete*

I. INTRODUCTION

An essential part of the repair process is the bonding of newly poured concrete with the older concrete. The usage of traditional vibrated concrete in original and overlay concrete settings was the focus of this inquiry. There is a lack of information about the behavioral characteristics of several newly produced varieties of concrete, particularly regarding overlay concrete [1-4]. The substrate, overlay, and zone of bonding are the three distinct stages that make up the maintenance system, which might be thought of as a complicated system. The term "zone of bonding" refers to the region that includes and incorporates the bond plane in this context. For the bond region to sustain the various external stresses exerted on the system, enough structural integrity must be possessed. A link's resilience and endurance are influenced by several variables. Employing testing procedures that can accurately measure bond strength and pinpoint the specific failure mechanism is crucial for ensuring the quality assurance of bond strength. Many studies have been conducted, which have resulted in the creation of various testing procedures. Tests are often carried out in both lab and on-site environments [5]. The bond strength pertains to the level of adhesion between the overlay and substrate, and it has the capacity of being the most susceptible feature of the system. A robust connection is an essential factor in the formation of a cohesive system [6-9]. The curing conditions, water-to-cement ratio, surface roughness, age difference between concrete layers, additional cementitious materials, and the kind of bonding agent are the main factors affecting the strength of interfacial bonds. The three main methods for joining old and new concrete layers include using bonding chemicals, employing nails, and roughening up the substrate surface [10-12].

Authors in [13] examined how interface treatment affects the seismic performance of columns enhanced with Reinforced Concrete (RC) jacketing to improve the bending moment at the ultimate stage. A numerical study was conducted to gain a deeper understanding of the subject. For undamaged samples with a bending moment per shear force ratio bigger than 1.0, casting an RC jacket with a thickness less than 17.5% of the column width is sufficient to achieve the monolithic behavior of the composite element.

Authors in [14] developed and built three reinforced concrete models with anchoring reinforcement to study the shear behavior of new and old concrete interfaces. A semi-cyclic loading test was carried out. RC's shear bearing capacity depended on its shear resistance and dowel pin shear, with a maximum value of approximately 1.186 × 104 kN/m^2. The shear-bearing capacity of stirrup-reinforced concrete had been raised by 28.5%. According to the obvious interface slip, the operating state of the interface between rebar bolt and concrete is classified into two stages, the interface bonding and friction. The bottom half of the tendons was predominantly sliced, whereas the upper part was shear-based.

Authors in [10] looked at the bonding behavior at the interface between Plain Concrete (PC) and Kenaf Fiber Concrete Composite (KFCC). For PC to PC, PC to KFCC, and KFCC to KFCC interfaces, shear, tensile, and compressive tests were used to determine the bond strength in shear, direct tension, and compression, respectively. One kind of concrete grade (35 MPa) was manufactured for the substrate PC, and three types (25 MPa, 35 MPa, and 45 MPa) for the KFCC. The test result demonstrated that KFCC exhibited superior interlock from the PC substrate's surface, providing a binding strength that surpassed that from PC. High compressive, tensile, and shear bond strengths were achieved by utilizing new concrete that had the maximum concrete grade, 45 MPa.

Authors in [15] demonstrated the Mode-I fracture development resistance at the substrate and repair concrete contact. Tests using countered double cantilever beams were conducted, so, failure plane and interfacial roughness analyses were included in the crack development resistance curve calculations (modified linear elastic fracture mechanics). Steel fibers (13 mm) and polyvinyl alcohol (8 mm and 12 mm length) were added to the repairs at 0.5% and 1% volume fractions, respectively. The findings showed that fibers enhanced the substrate-repair interface's and the repair material's fracture behavior, while associations with interfacial roughness, crack deviation, and fracture parameters were explored.

Authors in [16] employed a splitting tensile test to examine the binding strength of old concrete and reinforced concrete with nano inclusions. Utilizing an energy dispersive spectrometer and scanning electron microscope, the strengthening processes of the link resulting from Nano inclusion were also investigated. According to the experimental findings, the bond strength between old concrete and reinforced concrete with nano inclusions may reach 2.85 MPa, which is 0.8 MPa, meaning 39.0% greater than the bond strength between new concrete without nano inclusions and old concrete.

Authors in [17] investigated the effects of concrete strength and bar reinforcing on the shear characteristics of new-to-old interfaces. In the test, two failure types were noted, the plastic failure (RC) and the brittle failure (PC). The shear resistance of the implanted steel bar and the bonding force of the new-to-old concrete were the primary sources of interface shear strength. On the other hand, the interface shear strength is the least affected by the vertical friction force caused by the implanted steel bar's tensile tension. This study proposed a damage prediction model of the new-to-old concrete interface based on the micro-damage mechanism under conditions of planting reinforcement. The degree of damage to the new-to-old concrete interface when it is exposed to various planting areas may be predicted by deploying the particular model.

II. RESEARCH AND SIGNIFICANCE

The main purpose of this study is to evaluate the bonding between fresh and aged concrete in composite beams under repeated loads. This study aims to examine numerous ways to promote consistent behavior and strong connections. It determines the influence of variable stiffness and shrinkage at the interface of concrete layers cast at different ages. The bonding strength experiment was carried out in an attempt to investigate the impacts of several variables, such as surface preparation, bonding agent type, age difference, and new concrete type.

III. EXPERIMENTAL PROGRAM AND MATERIAL PROPERTIES

The experimental work for structural behavior consists of casting and testing 7 composite beams under the effect of static loads and other 7 similar beams under the effect of repeated loads. The 14 beams were divided into many groups according to the surface preparation, bonding agent, strength of the new concrete, amount of steel reinforcement crossing the interface, age of the old normal concrete, and type of new concrete, as shown in Table I. All composite beams had the same length, width, height, and reinforcement, as depicted in Figure 1. Using plastic spacers, a 25 mm transparent cover was added to each side of the produced reinforcing steel cages. The surfaces of the RC beams were wire-brushed to provide a rough surface for rough groupings before fresh concrete was poured over the old concrete surfaces. On the following day, the bases received an 1 mm - 2 mm layer of adhesive. Then, the overlay was cast. Figures 1 - 7 illustrate the steps of production of the composite beams. The reference beam was in the same dimensions but with homogeneous normal concrete and at an age of 1 year.

TABLE I. DATA OF THE COMPOSITE BEAMS' SPECIMENS

Group	Beam ID	Bonding agent	Age of old concrete	Type of surface	Type of layout concrete
Shear connectors	BR-SH	-	> 1 year	smooth	Same old layer
Surface preparation	BR-RO	-	> 1 year	rough	Same old layer
Type of bonding agent	BR-SBR	SBR	> 1 year	smooth	Same old layer
Type of new concrete	BR-SCC	-	> 1 year	smooth	SCC
	BR-SF	-	> 1 year	smooth	Steel fibers
	BR-SIKA	-	> 1 year	smooth	SIKA
	BR-HSC	-	> 1 year	smooth	HSC

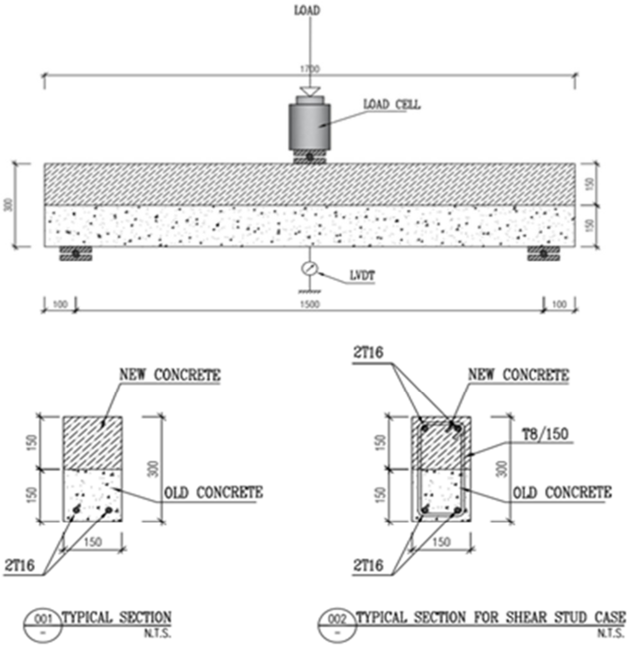

Fig. 1. Details of composite beams.

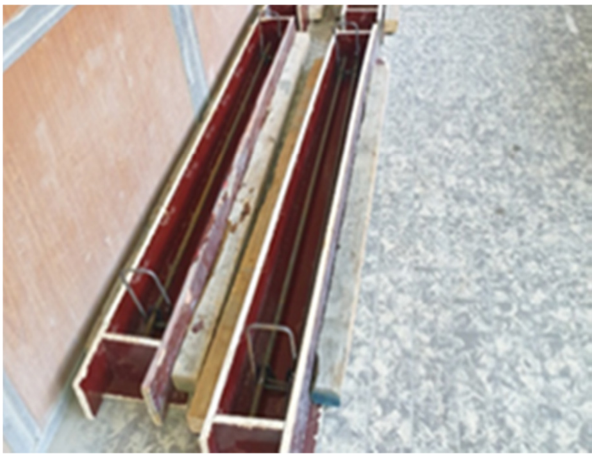

Fig. 2. The wooden mold and reinforcing steel cage for composite beams.

Fig. 3. Pouring old concrete layer.

Fig. 4. Applying the adhesive to the old concrete.

Fig. 5. Pouring the new concrete layer.

Fig. 6. Composite beams test setup.

Fig. 7. Steel fiber concrete mix.

Table II portrays the chemical properties of sikalatex material, and Table III shows the chemical properties of sikacrete-114-PK. Table IV displays the tensile properties of the used steel bars, and Table V presents the detail of the mix proportion of substrate (NSC) mix. All the experimental work was carried out in the Civil Engineering Department Laboratory- Engineering college - Basrah University.

TABLE II. CHEMICAL PROPERTIES OF SIKALATEX

Composition	Styrene butadiene emulsion
Shelf life	12 months
Appearance and color	White liquid
Density	~1.0 kg/l
Total Chloride Ion Content	≤ 0.1 %

TABLE III. CHEMICAL PROPERTIES OF SIKACRETE-114 PK

Chemical base	Portland cement, selected fillers, and aggregates, special additives
Shelf life	6 months minimum from date of production.
Appearance and color	Grey powder
Maximum grain size	Max. 10 mm
Compressive strength	1 Day
	≥ 35 N/mm^2
Modulus of elasticity in compression	33 000 N/mm^2 (ASTM C 469-94)
Tensile strength	~5 N/mm^2 (ASTM C307)

TABLE IV. TENSILE PROPERTIES OF THE USED STEEL BARS

Nominal diameter (mm)	Area (mm^2)	Average yield tensile stress (MPa)	Average ultimate tensile strength (MPa)	Elongation at ultimate stress (%)
8	50.3	523	662	12.4
16	201	508.70	647.43	15.90

TABLE V. DETAIL OF MIX PROPORTION OF SUBSTRATE (NSC) MIX

Mix proportions (kg/m^3)				
w/c	Cement	Sand	Gravel	SIKA ViscoCrete 1681 (SP)
0.4	400	672	1113	3.5

IV. TEST RESULTS

The results of 7 composite beams loaded by repeated loads using several techniques to study the bonding between old and new concrete in beams are presented in this section.

A. *Results of the Tested Beams under the Applied Repeated Load*

Line loading was applied as an equal pressure to the top surface of the load plate over a 2.50 mm contact width in the concrete. The ultimate load value was taken from the static load test and the load was divided every 25% of the ultimate load (0.25 Pu, 0.5 Pu, 0.75 Pu, and Pu). For each of these four loads, ten load and unload cycles were performed. The results were discussed with two main divisions to have a better understanding for the behavior of composite beams under the effect of repeated loads. These are:

1. Load-deflection behavior.
2. Load capacity and mode of failure.

1) Load-Deflection Behavior

At every load step of the repeated load test program, the vertical deflection at the beam's midspan was observed. At the ultimate load, the specimens' deflection was addressed. The deflections at the Middle-Span of the samples at the ultimate repeated load are displayed in Table VI.

TABLE VI. DEFLECTIONS AT THE MIDDLE-SPAN OF SAMPLES AT ULTIMATE REPEATED LOAD

Specimen	Ultimate load (kN)	Deflection at ultimate load (mm)	% Increase in deflection at ultimate load
BR-SCC	62.9	3.5	Ref.
BR-SH	152	9.62	175
BR-SF	66.9	4.01	14.6
BR-RO	73.6	4.15	18.6
BR-SBR	68	4.63	32.3
BR-SIKA	77.6	4.23	20.9
BR-HSC	81.7	4.34	24

According to the data evidenced in Table II, the middle span deflection at the ultimate load increased by 175%, 14.6%, 18.6%, 32.3%, 20.9%, and 24% for the composite beam with the shear connector, steel fibres, rough surface, SBR, SIKA, and HSC with respect to the reference beam with SCC. The load-deflection behavior at the mid-span and the comparison between repeated and monotonic test is illustrated in Figures 8-14.

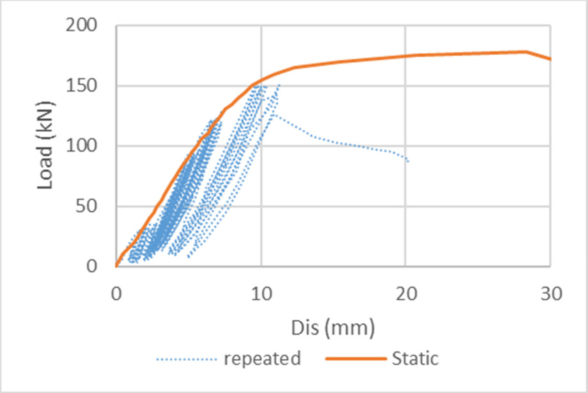

Fig. 8. Load-deflection curves for static and repeated load (BR-SH).

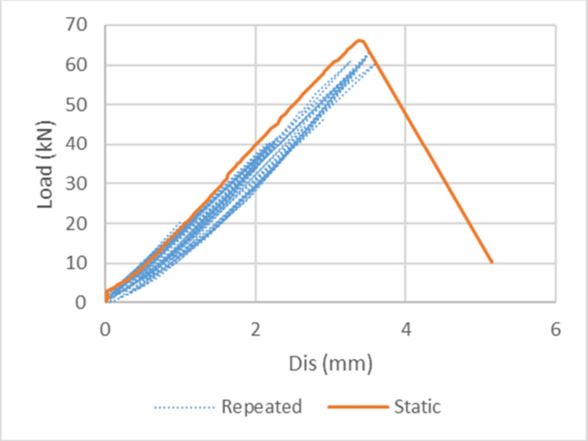

Fig. 9. Load-deflection curves for static and repeated load (BR-SCC).

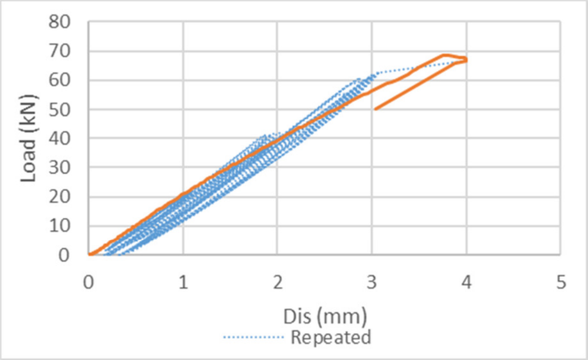

Fig. 10. Load-deflection curves for static and repeated load (BR-SF).

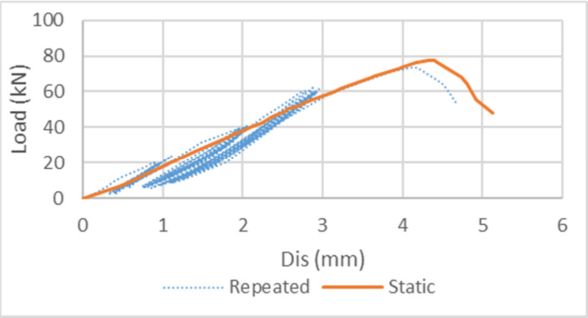

Fig. 11. Load-deflection curves for static and repeated load (BR-RO).

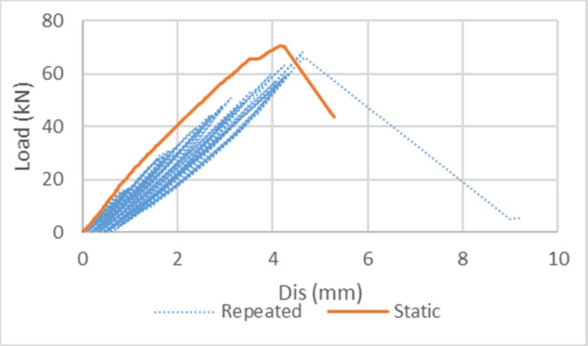

Fig. 12. Load-deflection curves for static and repeated load (BR-SBR).

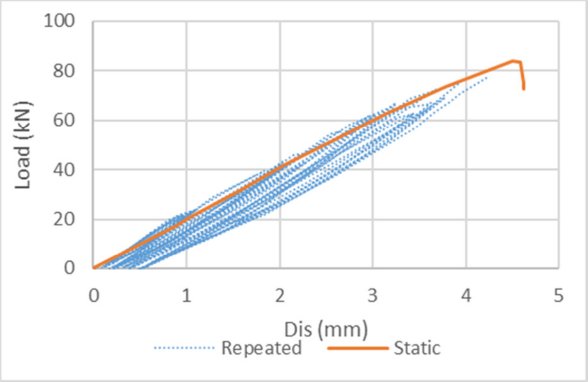

Fig. 13. Load-deflection curves for static and repeated load (BR-SIKA).

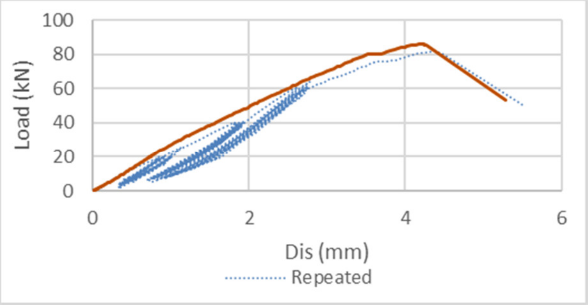

Fig. 14. Load-deflection curves for static and repeated load (BR-HSC).

2) Load Capacity and Mode of Failure

Figure 15 demonstrates that diagonal tensile fracture caused shear failure in all tested beams. The shear failure modes seen in specimens under repeated loading are like those found in specimens under monotonic stress. Repeated loads result in crashing at the top fiber of the beam because they erode the rigidity of the concrete and increase the amount of concrete that crashes.

Table VII compares the ultimate loads from static and repetitive load tests., where the ratio of Pu (R) / Pu (M) was about 85%, 95%, 98%, 95%, 97%, 92%, and 95% for the composite beam with the shear connector, SCC, steel fibers, rough surface, SBR, SIKA, and HSC, respectively. The composite beam with shear connectors has the highest value of ultimate load, whether in/being under static or repeated load test, while the beam with SCC has the lowest value as it is the new layer. Four types have been used for the new concrete of the beams (SIKA, SCC, concrete with steel fibers, and HSC) in repeated load tests. The composite beam with HSC as a new layer has the highest value of ultimate load, whether in/under static or repeated load tests, while the beam with SCC as a new layer has the lowest value.

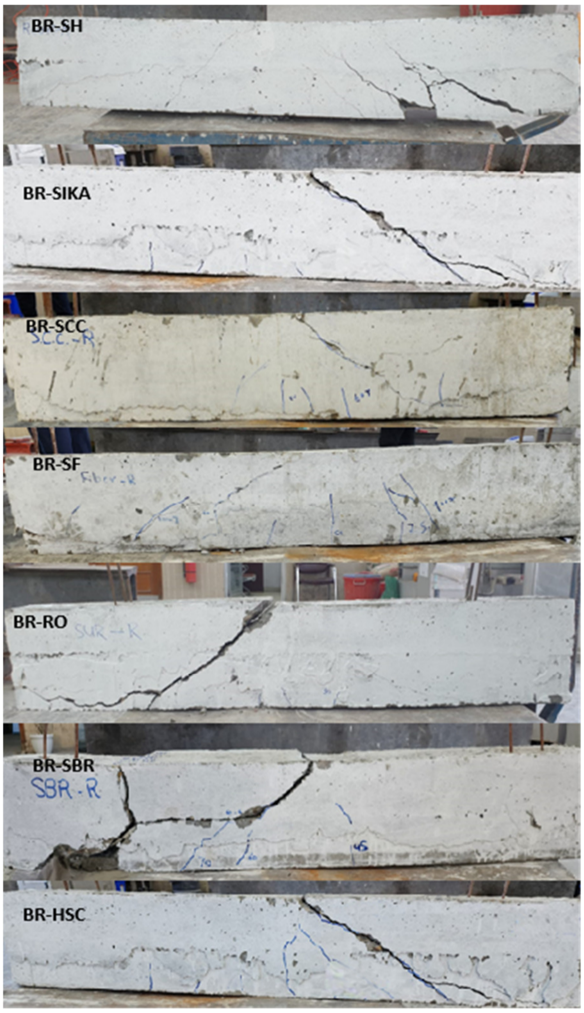

Fig. 15. Failure modes of beams under repeated loads.

TABLE VII. COMPARISON IN ULTIMATE LOADS OF STATIC AND REPETITIVE LOAD TEST

beam ID	ultimate load (Pu) (kN) under monotonic load (M)	ultimate load (Pu) (kN) under repeated load (R)	Pu(R)/Pu(M)
BR-SH	178.4	152	0.85
BR-SCC	66.1	62.9	0.95
BR-SF	68.4	66.9	0.98
BR-RO	77.5	73.6	0.95
BR-SBR	70.3	68	0.97
BR-SIKA	84	77.6	0.92
BR-HSC	86	81.7	0.95

V. CONCLUSIONS

1. For the repeated load, the middle span deflection at the ultimate load increases by 175%, 14.6%, 18.6%, 32.3%, 20.9%, and 24% for the composite beam with the shear connector, steel fibers, rough surface, SBR, SIKA, and HSC with respect to the reference beam with SCC.
2. The ultimate load increased by 126% for the composite beam with stirrups as shear connectors with respect to the reference beam. So, using stirrups as shear connectors between new and old concrete significantly increased the load carrying capacity of the beam subjected to repeated loads.
3. For the repeated load, every tested beam had a diagonal tensile fracture due to shear failure. The shear failure modes seen in specimens under repeated loading were like those found in specimens under monotonic stress. Repeated loads result in crashing at the top fiber of the beam because they eroded the rigidity of the concrete and increased the amount of concrete that crashes.
4. The percent of Pu (R) / Pu (M) was about 85%, 95%, 98%, 95%, 97%, 92%, and 95% for the composite beam with the shear connector, SCC, steel fibers, rough surface, SBR, SIKA, and HSC respectively. The composite beam with sheer connectors had the highest value of ultimate load whether in/under static or repeated load test, while the beam with SCC as new layer had the lowest value.

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