Effect of Fatigue Loading on Bonding Shear Strength at the Interface between Two Layers Concrete

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In Japan one of the methods to repair and strengthen concrete bridge decks is the Thickness Increasing Method where a thin new concrete layer is cast on top or bottom of the existing concrete slab. In this type of repair system the bond at the interface plays an important role in achieving composite action between the new layer and the existing slab. After the repair work has been completed the bridge is open to traffic and the bonded interface is subjected to normal and shear stresses from the traffic. Torque tests were carried out on beam specimens to evaluate the bonding shear strength at the interface between new and old concrete after they were subjected to fatigue loading. From the experiments a clear relationship between stress level at various specimens' positions and the bonding shear strengths after the application of fatigue loading could not obtained. However a trend of the bonding shear strength after the application of fatigue loading could be obtained. The higher the magnitude of the load and cycles of fatigue loading the more the reduction in bonding shear strength occurs.

Key Words: Bonding shear strength, new and old concrete, interface, torque test

1. Introduction

In the last few decades, several serious deterioration of reinforced concrete slabs of highway bridges have been reported in Japan. In a study carried out by Maeda and Matsui[1], they described the mechanism of cracking in concrete slabs which started with one-way cracking in the perpendicular direction to the traffic, then cracks perpendicular to the first cracks will appear which later resulted a grid-like cracks pattern. New cracks will start from top surface, which will later join with the bottom cracks. The abrassion of cracked surfaces progress and the cracks surfaces become smooth. This followed by the partial falling out of concrete cover and finally, the falling off of a part of the slab. The fatigue failure in the reinforcing bars seldom occurs. They consider these phenomena of deterioration of concrete slabs as a kind of fatigue failures which are due to sequential repeated loading of vehicles. Fatigue failure of concrete slabs resulted the needs for expensive remedial actions, even though there is no immediate danger to human life.

Nowadays, among the many methods of repairing and strengthening bridge slabs, three methods are commonly used in Japan[2]. Those are, to add stringers between original girders, to attach a steel plate on the bottom surface of a slab and to increase the slab thickness by putting a new concrete layer on the top or bottom of the existing slab. Each method has its merits and demerits. For thickness increasing method, it is advantageous in reinforcing both shear and bending and in workability and cost of the work. However an increase in the dead load and a rise in road surface are inevitable. Also, it causes a lot of inconveniences to the public as the bridge or part of the bridge has to be close to the traffic during the repair work.

In the thickness increasing method of repair systems, the bond at the interface plays an important role in achieving composite action between the new layer and the existing slab. To realise sufficient bonding between the two layers it is important to prepare the substrate properly, to choose compatible repair and to ensure the new layer is cast and cured properly. As soon as the repair work is completed the bridge is open again to the traffic. The bonded interface between the new layer and the existing slab is again subjected to repeated normal and shear stresses from the traffic. When the stresses exceed the bonding strength capacity of the interface debonding will occur. Thus the knowledge on the bond strength between the new layer and the existing deck under fatigue loading is very important.

The objective of this study is to find out the effect of fatigue loading on bonding shear strength at the interface between the new cast concrete and the substrate and between two precast beam elements. In this study experiments were carried out on beam specimens. Firstly, the specimens were applied with predetermined fatigue loading. Then torque test which was developed by the authors[3] were carried out by making partial cores on the beams until beneath the interface. In the beam tests various bonding materials and bonding agent are tested to investigate their bonding strengths after the application of fatigue loading.

2. Fatigue Loading and Procedure to Obtain Bonding Shear Strength after Fatigue Loading

2.1 Fixed Pulsate Loading on Beam Specimen

Fatigue loading applied on the specimens was by fixed pulsating method where a pulsating load was applied by a servopulser at two points on the simply supported beam specimens as shown in Fig. 1. The loads applied was 24.5kN (max.) with the frequency of 7 Hz or and 44.1kN (max.) with 5Hz.

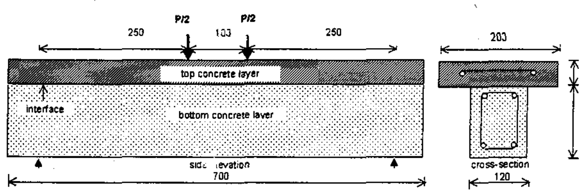

Fig.1 Fixed Pulsate Loading Position

2.2 Procedure to Obtain Bonding Shear Strength after Fatigue Loading

After fatigue loading has been carried out on each test beam, partial cores were made on the shear span of the beam as shown in Fig.2. The diameter of the core was 68mm and the depth is 60mm which is 10 mm below from the interface. Steel disks were glued to the surface of the partial cores by epoxy binder. Then torque tests were carried out on the partial cores.

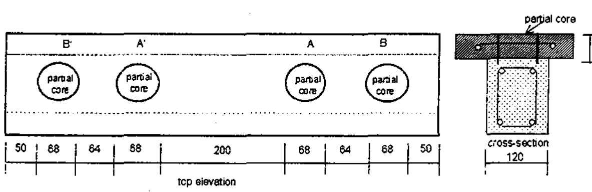

Fig. 2 Position of the Partial Cores on the Test Beam

2.2.1 Torque Test Instrument and Equilibrium Equation

The main instruments for the torque test are a set of torque wrench, a frame to give a smooth rotation of the wrench and a recorder for data recording. The torque meter is fitted on the steel disk followed by the attachment. The attachment part is fitted to the ball bearing in the frame. Power up instrument is connected to the attachment part followed by a torque wrench. The torque meter and the wrench are set up in a frame to reduce the effect of bending when applying torque. Torque is applied manually at the wrench until the failure of the specimens occurred. The data recorder records the torque moment history and its maximum is noted Since application of torque is done manually power up instrument is used to make the application of torque easier. When applying torque the vertical uplift of the specimen is free to occur during failure. This results a failure of the specimen to occur at the weakest part. The weight of the instrument has very little effect in prevent the vertical uplift. The schematic diagram of the instrument is shown in Fig. 3.

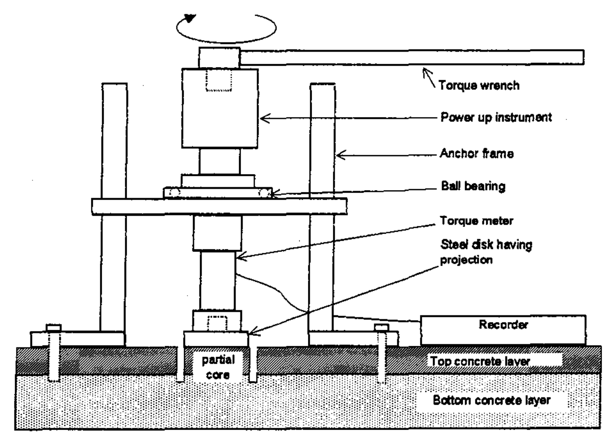

Fig. 3 Torque Test Instrument

The torsional shear stresses distributed over the cross-section of the specimen are statically equivalent to a couple and opposite to the torque moment. The maximum shear is given by the following equation[4]:

$$\tau_{\max} = \frac{16M_t}{\pi d^3} \qquad (1)$$

where, d is the diameter of the core and M_t is the maximum torque moment.

2.3.3 Failure Modes

One of the special features of torque test method is that the mode of failure can be determined by simple visual inspection of the failed surfaces of the partial cores. Failure of specimen occurs at the weakest part, which could be at the interface, new concrete, substrate or combination of these. For a material which is weaker in tension than in shear such as concrete, a diagonal torsional failure often occurs because the principle stress in tension reaches its tensile strength with the inclination angle is 45°[4].

An estimate is made in term of percentage of cross-section area of the partial core where failure had occurred i.e. percentage at interface, new concrete and substrate. The total of the three values is always 100%. The failure mode is an important factor in the interpretations of the torque test results since failures in the new concrete and/or the substrate indicate that the bonding strength is stronger than the shearing strength of the new concrete or the substrate. Those data indicate the minimum bound estimation of the bonding shear strength.

The failure modes also often provide valuable insight into specific problems such as poor substrate or repair/bonding materials, improper surface preparation and other surface defects. The typical failure modes of torque specimens are shown in Fig. 4 and are discussed together with the test results.

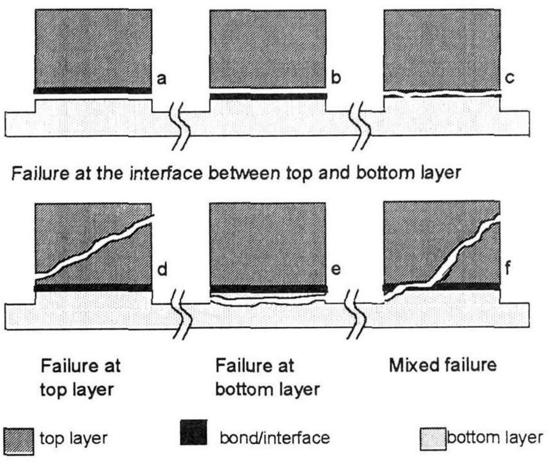

Fig. 4 Failure Modes of Specimens

3. Experimental Program

3.1 Test Specimens

The test specimens were composite beams made of a precast concrete beam (bottom layer) and a precast slab or in-situ concrete slab (top layer). Their dimensions are shown in Fig.5.

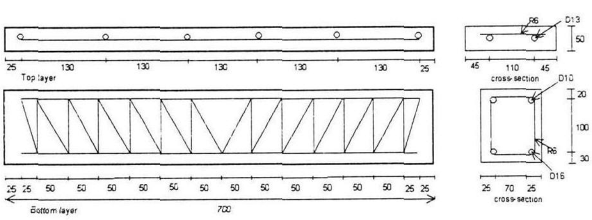

Fig.5 Test Specimen's Dimensions (unit :mm)

3.1.1 Beams - bottom layer

Precast beams of size 700x120x150mm with 2D16 bottom reinforcements, 2D10 top reinforcements and 2D6 truss shear reinforcements on both sides of the beam were prepared. The specified strength of concrete was 49 N/mm^2. The concrete of high compressive strength was chosen to reduce failure at the precast beam elements and to generate interface failure.

3.1.2 Slab- top layer

Precast slabs of size 700x200x50 with 2D13 top reinforcements were prepared. The specified strength of concrete was the same as for the beams and they were cast at the same time.

3.2 Experiment Parameters

The following factors are selected as the parameters of the experiment in order to examine the effect of fatigue loading and factors governing bonding strength.

3.2.1 Mechanical Surface Treatment of the Substrate

The top surfaces of the beams are mechanically treated with grinding, shot blasting, chipping and no mechanical treatment.

3.2.2 Bonding Materials / Agents

The bonding materials / agents used are polymer modified cement mortar (Styrene Butadiene), cement mortar, epoxy resin and no bonding agent.

The parameters combinations between bonding materials and surface treatments are given in Table1

Table 1 Parameters Combinations between Bonding Materials and Surface Treatments

Specimen Catagories	Bonding Material	Surface Treatment
NG	No bond agent	grinding
NB	No bond agent	shot blast
NC	No bond agent	chipping
EN	Epoxy	no treatment
EG	Epoxy	grinding
EB	Epoxy	shot blast
PB	Polymer m. c.	shot blast
CB	Cement mortar	shot blast

3.2.3 Predetermined Fatigue Loading

The fatigues loading given to each test beam are predetermined as shown in Table 2.

Table 2 Combinations between Fatigue Loading and Specimen Categories

Specimens Catagories / Fatigue Loading	NG	NB	NC	EN	EG	EB	PB	CB
24.5kN 5,000 cycles	○	○	○	○	○	○		
24.5kN 50,000cycles	○	○	○	○	○	○		
24.5kN 500,000 cycles	○	○	○	○	○	○		
31.36kN 50,000cycles								○
37.24kN 50,000cycles								○
44.1kN 5,000cycles	○	○	○	○	○	○	○	
44.1kN 50,000cycles	○	○	○	○	○	○	○	○
44.1kN 500,000cycles	○	○	○	○	○	○	○	
44.1kN 5,000,000cycles				○	○	○	○	
44.1kN 10,000,000cycles						○	○	

3.3 Test Procedure

After curing for one month at a room temperature, mechanical surface treatments were carried out on the top surfaces of the beams. Shot blast was carried out on the slabs. Surface roughness measurement were carried out by using a laser displacement which was consist of a sensor head Keyence LK 030 and a laser sensor Keyence LK 2000. The sensor head generates a laser ray continuously and the height variations of a surface profile are processed by moving the laser sensor. The height variations at every 0.3mm horizontal distance were recorded by a computer using wave shot program. After surface roughness measurement the precast slab and beam were glued to become a T beam by using bonding materials shown in Fig. 2.

For no bonding agent specimens, after mechanical surface treatments were carried out on the top surface of the beams, fresh concrete of specified strength of 23.5N/mm^2 was cast on the bottom beam. This specified strength is commonly used as in-situ concrete. The final shape and the size of these beams were the same as the precast beams.

After curing of the bonding materials or the in-situ concrete, the test beams were subjected to the predetermined fatigue loading. Then partial coring were carried out on the beams as shown in Fig 2. Torque tests were carried out on the cores. To obtain the initial data without fatigue loading one set of each type of the beams were tested by the torque test only.

4 Results and Discussions

4.1 Material Tests Results

Table 3 and 4 show the material test results of the concrete and the bonding materials used in this experiment. Epoxy has the highest compressive and tensile strength compared to other bonding materials. Polymer modified cement mortar has a lower compressive strength but higher tensile strength compared to the precst concrete.

Table 3. Material Test Results of Concrete

Concrete	Ave. Comp. Strength (N/mm^2)	Ave. Tensile Strength (N/mm^2)
Top layer (Fresh conc.)	25.50	2.27
Top layer (Precast conc.)	62.27	4.35
Bottom layer	62.27	4.35

Table 4. Material Test Result of Bonding Materials

Repair Materials	Sand/ Cement Ratio	Water/ Cement Ratio	Polymer/ Cement Ratio	Base Agent :Hardener	Ave.Comp. Strength (N/mm^2)	Ave Tensile Strength (N/mm^2)
Cement mortar	2.5	0.6	-	-	30.10	2.29
Polymer m.c.mortar	2.5	0.45	0.15	-	52.17	4.91
Epoxy (winter)	-	-	-	7:3	80.80*	264.76*

Note : manufacture's data at 20°C,*

4.2 Surface Roughness

Table 5 shows the result of surface roughness on the top surface of the bottom beam and Fig.6 shows the relative comparison of their surface profile. R_a is the average of the absolute values of surface height variations measured from the mean surface level. R_z is the average height difference between five highest peaks and five deepest valleys within a sampling length measured from a line parallel to the mean surface level. From Table 5 and Fig.6 it is observed that the chipping treated beams have the highest degree of surface roughness followed by shot blast, grinding and no surface treatment specimens.

Table 5 Surface Roughness of the Top Surface of the Bottom Beams

Mechanical Surface Treatment	R_a (mm)	R_z (mm)
No Treatment	0.09	0.325
Grinding	0.10	0.464
Shot Blasting	0.11	1.340
Chipping	0.32	2.050

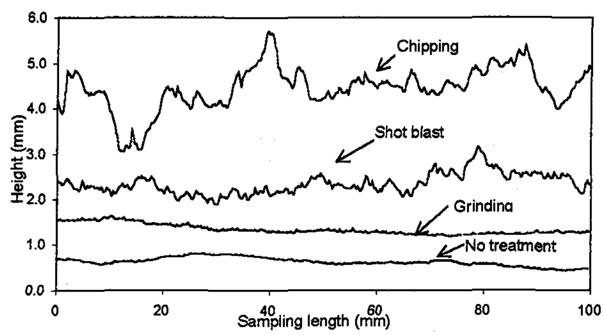

Fig. 6 Relative Comparison of Surface Profile of the Top Surface of Bottom Beams

4.2 Beam Analysis

Fig.7 shows the analytical shearing stress distribution at the interface of the T beams under two concentrated loads. When a load of 44.1kN is applied to the beam the maximum shear stress at the coring position A is about 1.18N/mm^2 and at position B the maximum shear stress is about 0.69N/mm^2. For 24.5kN loading, the shear stress at positions A and B are about the same that is about 0.49N/mm^2.

4.3 Result of Torque Tests on Specimens Without Fatigue Loading

Table 6 shows the results of torque test carried out on the beams, which were not subjected to fatigue loading. If no bonding agent was used, it is observed that surface roughness has great influence on the

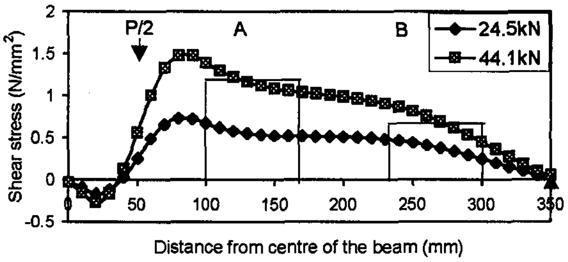

Fig.7 Shear Stresses at the interface versed Distance from the centre of the beam

bonding shear strength. The measured bonding shear strength varies from 0.68N/mm^2 in the case of NG specimens (grinding treated surface) to 3.06N/mm^2 for NB specimens (shot blast treated surface). The higher the degree of surface roughness is the higher the bonding shear strengths are. This is due to the increases in contact area and shear connecting effects of the rougher surface. However the chipping treated surface (NC) specimens have lower bonding shear strength compared to shot blast treated (NB)specimens although the degree of roughness by chipping is higher than shot blasting. This may be due to the micro-cracks remaining in the bottom layer by chipping[5)]. The failure modes of no bonding agent specimens were mainly at the interface.

Table 6 Results of Torque Test Without Fatigue Loading

Specimens Categories	Bonding Material	Surface Treatment	Ave. τ_{max} (N/mm^2)	Failure at interface / Total torque specimens
NG	No bond material	grinding	0.68	8/8
NB	No bond material	shot blast	3.06	4/7
NC	No bond material	chipping	2.84	5/6
EN	Epoxy	no treatment	5.16	0/3
EG	Epoxy	grinding	5.21	0/5
EB	Epoxy	shot blast	5.14	0/5
PB	Polymer m. c.	shot blast	5.34	0/4
CB	Cement mortar	shot blast	1.56	4/4

For specimens using epoxy and polymer modified cement mortar as bonding material, the bonding shear strength are quite stable that are between 5.14-5.21N/mm^2. The influence of surface roughness could not be seen because failure modes were not at the interface. These values can be treated as the lower bound of the bonding shear strength measured.

For CB specimens, the bonding shear strength is lower compared with NB although the surface treatment carried out is the same. This maybe due to the absorption of part of mixing water to the top and bottom beams when they are bonded together. This causes incomplete hydration of the cement mortar and inability of the reactive component to enter to the capillaries of the top and bottom beams thus the cement mortar does not adhere firmly. The failure modes for both cases are interface failures.

4.4 Torque Results of Specimens After Fatigue Loading

4.4.1 Specimens Without Bonding Agent

Table 7 shows the summary of the torque test results without bonding agent after fatigue loading. The tend in the data could be seen clearly in the graph of bonding shear strength of specimen without bonding agent verses loading cycles as shown in Fig.8. "0 kN" line on the graph indicates the initial data of bonding shear strength without fatigue loading.

Table 7 Result of torque Test after Application of Fatigue Loading.- Without Bonding Agent

Specimens Categories	Loading (kN)	Cycles	Ave. τ_{max} (N/mm^2)	Failure at interface / Total torque specimens
NG-1	24.52	5,000	0.51	4/4
NG-2	24.52	50,000	0.23	4/4
NG-3	24.52	500,000	0.42	4/4
NG-4	44.13	5,000	0.31	4/4
NG-5	44.13	50,000	0.10	4/4
NG-6	44.13	500,000	0.13	4/4
NB-1	24.52	5,000	3.81	1/2
NB-2	24.52	50,000	3.73	0/2
NB-3	24.52	500,000	2.58	2/2
NB-4	44.13	5,000	1.54	2/2
NB-5	44.13	50,000	3.58	2/2
NB-6	44.13	500,000	1.73	6/6
NC-1	24.52	5,000	3.19	1/2
NC-2	24.52	50,000	3.93	0/2
NC-3	24.52	500,000	2.08	2/2
NC-4	44.13	5,000	2.03	2/2
NC-5	44.13	50,000	1.02	2/2
NC-6	44.13	500,000	0.78	2/2

For NG specimens, the effect of fatigue load could be seen in both results of 24.5 and 44.1kN fatigue loading. From the average bonding shear strength of 0.68N/mm^2 for specimens without fatigue loading, the bonding shear strength is reduced to 0.31N/mm^2 after 5,000 cycles of 44.1kN fatigue loading is applied and further reduced to 0.13N/mm^2 for 500,000 cycles. Reduction in bonding strength is also seen for 24.5kN fatigue loading. By the fatigue load of 24.5kN and 500,000 cycles the bonding shear strength is reduced to 0.42kN/mm^2. Failure modes of all NG specimens are pure shear failure at the interface.

For NC specimens, the effect of fatigue loading could be seen with the loading of 44.1kN. Without the application of fatigue loading the bonding shear strength is 2.84N/mm^2. When 5,000 cycles of 44.1kN fatigue loading are applied the bonding shear strength is reduced to 2.03N/mm^2, for 50,000 cycles it reduced to 1.02N/mm^2 and for 500,000 cycles it is reduced to 0.78N/mm^2. For 24.5kN fatigue loading the effect could be seen at 500,000 cycles when the bonding shear strength reduces to 2.08N/mm^2. Except for the results after 5,000 and 50,00 cycles of the load 24.5kN all NC specimens failed at the interface.

For NB specimens, the reduction in bonding shear strength could only be seen at 500,000 cycles of 24.5 and 44.1kN. The bonding shear strengths reduce from 3.06N/mm^2 of no fatigue loading to 2.58N/mm^2 for 500,000 cycles of 24.5kN and to 1.73N/mm^2 for 500,000 cycles of 44.1kN. Except for the specimens of 5,000 cycles of 24.5kN all NB specimens failed at the interface.

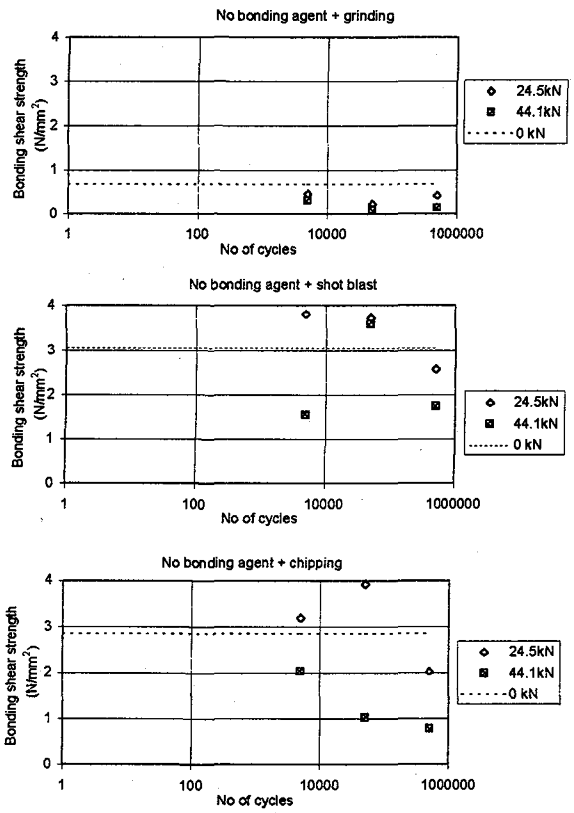

Fig. 8 Bonding shear strength after the application of Fatigue Loading – without Bonding Agents

4.4.2 Specimens with Epoxy as Bonding Agent

As seen in Table 8 and Fig.9 for EG and EB specimens there is almost no effect of the fatigue loading on the bonding strength as the results are almost the same as the result of no fatigue loading. Only for EN specimens, it is observed that the effect of fatigue loading seems to take place after 500,000 cycles of 44.1kN. There is a remarkable drop in the bonding shear strength to 2.88N/mm^2 after 5,000,000 cycles of 44.1kN. The failure modes for three of these specimens are failure at the interface as seen in Table 8. Although epoxy has very strong adhesion strength the laitance at top of the bottom beams seems to affect occasionally on the fatigue strength at the interface. When concrete s set, bleeding of concrete takes place and after the water evaporates the weak layer remains. This layer contains a large number of microcracks. Under fatigue loading these microcrcks extend easily to joint the other microcrack to form macrocracks which reduces the bonding strength and failures occur at the interface. The usage of a good bonding agent becomes ineffective unless the surface of the substrate is prepared properly first..

Table 8 Results of Torque Tests After the Application of Fatigue Loading – Epoxy as Binding agent

Specimens Categories	Loading (kN)	Cycles	Ave. τ_{max} (N/mm^2)	Failure at interface / Total torque specimens
EN-1	24.52	5,000	4.96	0/4
EN-2	24.52	50,000	5.38	0/4
EN-3	24.52	500,000	6.61	0/4
EN-4	44.13	5,000	5.05	2/4
EN-5	44.13	50,000	4.91	0/4
EN-6	44.13	500,000	4.41	1/4
EN-7	44.13	5,000,000	2.88	3/4
EG-1	24.52	5,000	4.64	0/4
EG-2	24.52	50,000	5.07	0/4
EG-3	24.52	500,000	5.30	0/4
EG-4	44.13	5,000	5.15	0/4
EG-5	44.13	50,000	5.61	0/4
EG-6	44.13	500,000	5.15	0/4
EG-7	44.13	5,000,000	5.54	0/12
EB-1	24.52	5,000	4.92	0/4
EB-2	24.52	50,000	6.00	0/4
EB-3	24.52	500,000	5.44	0/4
EB-4	44.13	5,000	5.07	0/4
EB-5	44.13	50,000	5.32	0/4
EB-6	44.13	500,000	4.99	0/4
EB-7	44.13	5,000,000	5.11	0/4
EB-8	44.13	10,000,000	5.04	0/8

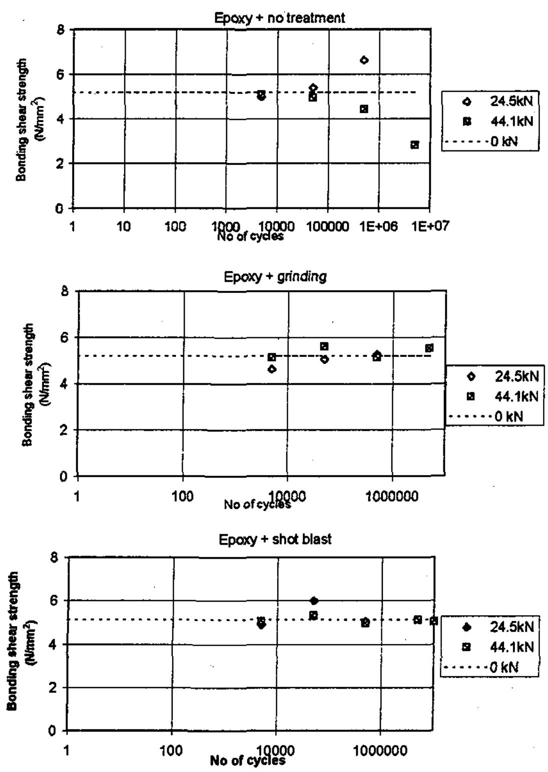

Fig.9 Bonding Shear Strength of Specimens after the Application of Fatigue Loading - Epoxy Bonding Agent

4.4.3 Specimens with Polymer Modified Cement Mortar as Bonding Material

As seen in Table 9 and Fig 10, for PB specimens the effect of fatigue loading could only been seen after 500,000 cycles where the bonding shear strength reduces from 5.34N/mm^2 of no fatigue load to 4.96N/mm^2 at 500,000 cycles and to 4.72N/mm^2 at 10 million cycles. At 500,00 cycles only one specimen failed at the interface while at 10 millions cycles three out of eight specimens failed at the interface. The reduction of strength due to fatigue loading is very slow. Since not all specimens failed at the interface the reduction of strength is not fully due to weakening of the interface. The high bonding strength of polymer modified cement mortar specimens is caused by polymer modification bridging capillary pores and microcracks at the interface zone and improve bonding.[7)]

Table 9 Results of Torque Tests After the Application of Fatigue Loading- Polymer m.c.m. as Bonding Agent

Specimens Categories	Loading (kN)	Cycles	Ave. τ_{max} (N/mm^2)	Failure at interface / Total torque specimens
PB-1	44.13	5,000	2.43	3/4
PB-2	44.13	50,000	5.08	0/4
PB-3	44.13	500,000	4.96	1/8
PB-4	44.13	5,000,000	5.51	1/4
PB-5	44.13	10,000,000	4.72	3/8

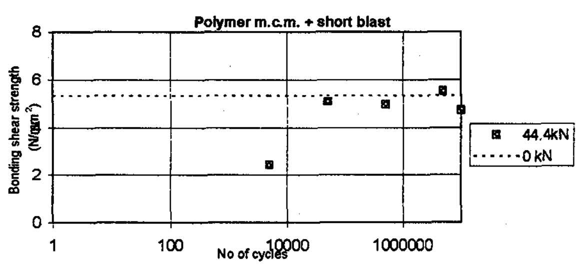

Fig.10 Bonding Shear Strength of Specimens After the Applications of Fatigue Loading –Polymer m.c.m. as Bonding Material

4.4.4 Specimens with Cement Mortar as Bonding Material

As seen in Table 10 and Fig 11 for CB specimens, the reduction of bonding shear strength could be seen at 44.1kN and 50,000 cycles where the bonding shear strength is reduced from 1.56N/mm^2 of no fatigue loading to 1.20N/mm^2. All specimens in this category failed at the interface.

In cement mortar there is a presence of microcracks in the cement matrix. Under fatigue loading, slow extension of of microcracking takes place as the result of repeated stressing. When these microcracks reach a critical dimension and they join up to form a macrocracks. These macrocracks reduce the strength of the concrete. The aggregate in the cement mortar or concrete plays an important part in providing cracks barrier, which limit the extent of crack propagation [6)]. At the interface, due to the smoothness of the surface, even fine aggregates could not enter into the pores of the substrate so the crack barrier effect could not take place effectively. Furthermore, the interface of cement mortar on the substrate is weak because of incomplete hydration of cement due to mixing waterr being suck off into the substrate when the substrate is dry. The bigger and the more cycles of fatigue loading the faster the growth of the microcracks will be and the bonding shear strength will reduce.

Table 10 Results of Torque Test After the Application of Fatigue Loading – Cement Mortar Bonding Material

Specimens Categories	Loading (kN)	Cycles	Ave. τ_{max} (N/mm^2)	Failure at interface / Total torque specimens
CB-1	31.34	50,000	0.40	4/4
CB-2	37.26	50,000	1.83	12/12
CB-3	44.13	50,000	1.20	4/4

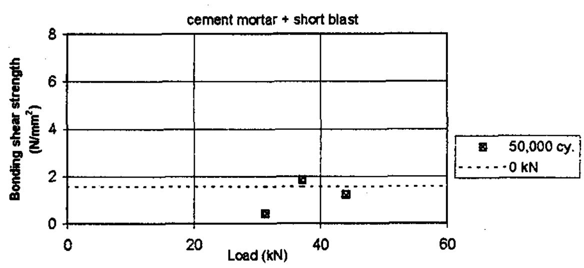

Fig 11 Bonding Shear Strength of Specimens After the Application of Fatigue Loading – Cement Mortar as Bonding Material

4.4.5 Comparison between Bonding Materials

Comparing between bonding materials used, it is found that epoxy has excellent bonding property and the bond is not weaken by the fatigue loading provided surface treatment is properly done. Polymer modified cement mortar also have a good bonding property as the data obtained is as high as epoxy specimens, however a few specimens failed at the interface. This means that polymer modified cement mortar bonding is slightly weaken by fatigue loading. Fresh concrete with no bonding agent and cement mortar as the bonding material do not have good bonding property. They depend largely on surface roughness to achieve a better bonding strength. Their bonding strengths are easily weaken by the fatigue loading so much so that some of the specimens fails even during coring.

4.4.6 Difference in Bonding Shear Strength at Position A and B after the Application of Fatigue Loading

Figure 12 shows two plots of bonding shear strength at position A and B after the application of fatigue loading. Position A is the location of the inner partial core and position B is the outer partial core of the test beam as shown in Fig.2. From FEM analysis as shown in Fig.7 because at position A the maximum shear stress is 1.18N/mm^2 under the load of 44.1kN and at position B is 0.69N/mm^2, it is expected that the bonding shear strength at position A will be lower than at position B after the application of fatigue loading. However from Fig.12 no judgement could be made on the relationship between the position of the partial core and the bonding shear strength. The relationship could not be obtained because of high variations in the data, the applied load is small and the number of specimens is small. If the applied load is bigger the difference in the maximum shear stress level at the two locations will be higher and may be the trend could be seen clearly. Only data for 44.1kN fatigue loading are plotted because the shear stress caused by 24.5kN load is quite evenly distributed throughout the shear span as seen in Fig.7.

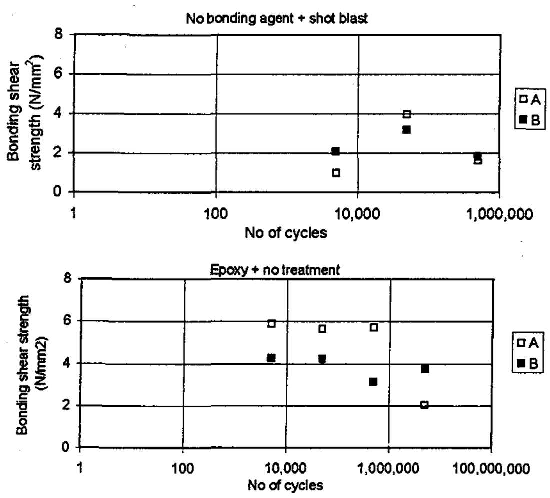

Fig.12. Bonding Shear Strength at Position A and B After the Application of Fatigue Loading

5 Conclusions

From this experiments the following could be concluded.

1) Surface roughness has a great influence on the bonding shear strength when no bonding agent is used. The higher the degree of the surface roughness is the higher is the bonding shear strength.
2) When no bonding agent is used fatigue loading has a great effect in reducing the bonding shear strength. The higher the magnitude and the cycles of fatigue loading the more the reduction in bonding shear strength occurs. When epoxy or polymer modified cement mortar is used as bonding material/agent fatigue loading has very little effect because bonding strength of these materials is very high.
3) A clear relationship between the stress level and the bonding shear strength by the difference of positions of the cores after the application of fatigue loading could not be obtained because of the high variance in the data, small level of shear stress applied and few number of specimens. More experiments with bigger stress difference need to be carried out.
4) By using torque test a trend could be obtained between the bonding shear strength and the magnitude and cycles of fatigue loading of specimens using no bonding agent.

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