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AHMAD FAHMY KAMARUDIN
SINGH A/L GURDIP SINGH
AHMAD ZURISMAN MOHD ALI
KOH HENG BOON

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Bonding Strength of Near Surface Mounted Glass Fibre Reinforced Polymer

*Ahmad Fahmy Kamarudin[1], Aruan Efendy Mohd Ghazali[2], Hanizah Abdul Hamid[3], Paldip Singh A/L Gurdip Singh[4], Ahmad Zurisman Mohd. Ali[5] and Koh Heng Boon[6]
[1,4,5,6] Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) 86400 Pt. Raja, Bt. Pahat, Johor, MALAYSIA
[2,3] Faculty of Civil Engineering, UniversitiTeknologi MARA (UiTM), 40450 Shah Alam, Selangor, MALAYSIA
Tel: 07-453 7431 Fax: 07-453 6070
*Email: fahmy@uthm.edu.my

Abstract

Fibre Reinforced Polymer (FRP) offers a great potential in reinforced concrete construction due to its corrosion and chemical attack resistance, high strength to weight ratio, ease of handling etc., and makes it suitable as an alternative material to potentially replace steel reinforcement used in conventional concrete construction. The performance of plain glass fibre reinforced polymer (GFRP) mounted at the outer tension surface of beams or known as near surface mounted (NSM) technique, with some bonded lengths and groove sizes was investigated for bonding strength, ultimate load and the influence of bonded lengths and groove sizes, by using pull-out bending test. Six specimens were reinforced with 12.5 mm diameter (d_b) of plain GFRP, and four bonded lengths which equal to $6d_b$, $12d_b$, $18d_b$ and $24d_b$ with three groove sizes of 16 mm, 19 mm and 25 mm were tested in this study. From the findings it shows the average bonding strength decreases when the bonded lengths is increased and vice versa for the ultimate load, while the ultimate load tends to decrease when the groove size is increased.

Keywords: Glass fibre reinforced polymer, near surface mounted, bonding strength, ultimate load

1.0 Introduction

Near Surface Mounted (NSM) FRP rods is a strengthening technique by embedding the rods into a groove surface along the direction of the member that need to be strengthened and filled by bonding or filling agents. According to Mahmoud (2009), many studies have shown, by using pull-out tests the efficiency of NSM techniques is mostly depending on the groove shape and filling material. Besides, from Gurdip (2008), the influence of surface configuration of bar also plays vital role on bonding strength and slip rate. Although it was difficult to obtain local product of plain GFRP bar, hopefully the provided data may contribute as useful references to the researchers.

2.0 Materials and Method

To study the bonding strength of NSM GFRP bars with some embedment length, a series of beam-pull-out test based on technique developed by Lorenzis and Nanni (2000) was prepared and tested in the Heavy Structures Laboratory in Universiti Teknologi MARA, Shah Alam.

Ready mix concrete of grade 50 was used for the preparation of twelve concrete blocks. A specimen was made by two concrete blocks inter-connected by a steel hinge. Only one side of the block was classified as the test region. Meanwhile in the other side of concrete blocks, the bar was fully bonded with epoxy paste. A total of six unreinforced concrete block specimens with an inverted T-shaped cross section and four groove sizes located at the center of tension surface were prepared and tested. Besides, the NSM GFRP specimens had four bonded lengths to cause bond failure in the test region. The dimensions of specimen are given in Figure 1.

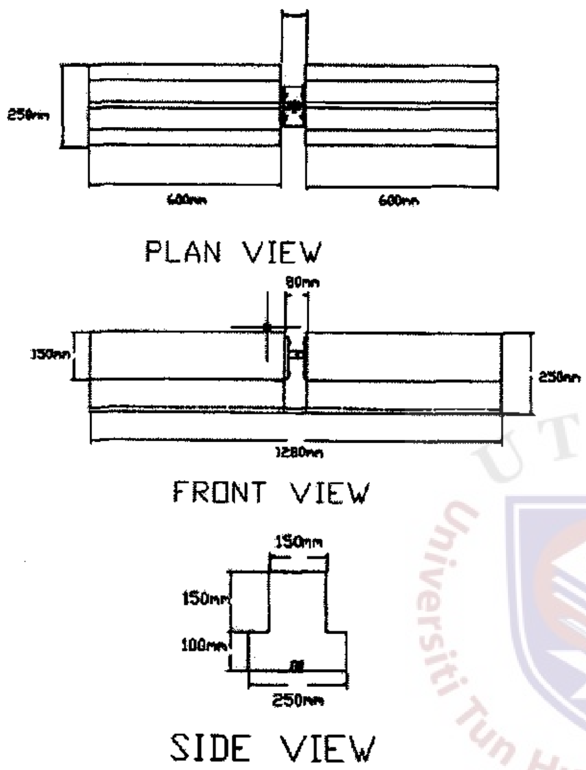

Figure 1: Block Dimensions

A plain glass fibre reinforced polymer bar was customized by a local manufacturer with a nominal bar diameter of 12.5 mm (refer to Figure 2). From the tensile test conducted by SIRIM in Shah Alam, the average tensile strength of the bars showed 407 MPa.

Figure 2: Tensile Test of Customized GFRP Bar

Meanwhile, for the epoxy paste the Sikadur 30 with compressive strength of 65 MPa, 32.5 MPa of flexural strength and 19 MPa of tensile strength was used to embed NSM FRP reinforcement. The mixture (resin and hardener) proportion of epoxy paste used was 3:1 by its volume.

In general, Table 1 summarizes the specifications of specimens used in terms of FRP type and its surface configuration, diameter size, epoxy type, bonded lengths and groove sizes.

Table 1: Description of Specimens

Type of FRP		Glass	
Surface Configuration		Plain	
Diameter of the bar, (d_b) (mm)		12.5	
Epoxy Type		Sikadur 30	
Specimen Designation	**Bonded Length (*bl*) Coefficient**	**Unbonded Length (*ul*) (mm)**	**Groove Size (mm)**
FB1Ga(B)	6	200	16
FB2Ga(A)	12	150	16
FB2Gb(D)			19
FB2Gc(H)			25
FB3Ga(E)	18	100	16
FB4Gc(G)	24	50	25

Note:
The following variables were taken from Lorenzis and Nanni (2000), and they are;

i. Four bonded length variables equally to 6, 12, 18, 24 multiplied by d_b (in mm)
ii. The *bl* coefficients and *ul variables*
iii.

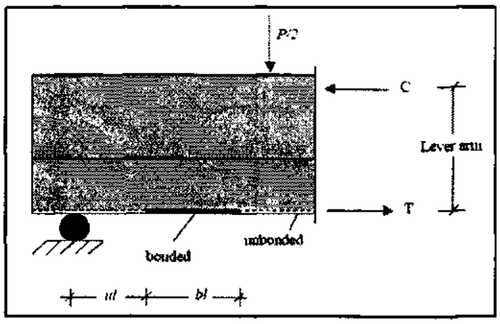

Figure 3: Bonded and Unbonded Lengths (Lorenzis and Nanni, 2000)

The fresh concrete was poured in the formwork with plastic strips which installed at tension surface to form groove (Figure 4a). After 28 days, a designed steel hinge was fitted to connect two concrete blocks at the centre by eight wall plugs (Figure 4b). All possible loose particles were air blasted. The groove was filled haft-way with epoxy paste, and the bar was then placed in the groove and lightly pressed. Full paste was applied according to bonded length as in Table 2, and finally the surface was leveled (Figure 4c). The epoxy paste was allowed to cure for at least 15 days at room temperature, prior to testing of the blocks.

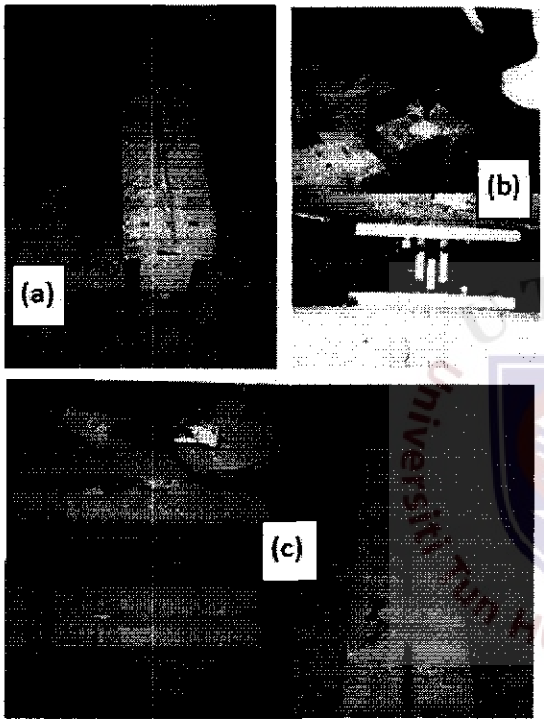

Figure 4: Specimen Preparation

Testing was performed by using Universal Testing Machine with 100 tonne of capacity. The concrete blocks were loaded under four-points bending. Each specimen was instrumented with three LVDTs. LVDT 1 and 2 were placed at the edge of concrete block and GFRP bar (Figure 5a) which located in the test region, whereas LVDT 3 was placed at mid-span (Figure 5b) of the beam. Both LVDTs installed at the edge were used to measure the slip of the bar, whereas the deflection of the beam was measured by LVDT 3.

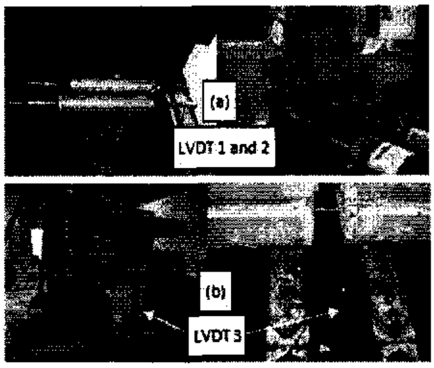

Figure 5: LVDTs Placement

The average bond strength, τ_{bu} was calculated based on the expression developed by Lorenzis and Nanni (2000) as below:

$$\tau_{bu} = \frac{T_u}{\pi \; d_b \; l_b} \qquad \text{... Eq. 1}$$

where:

T_u : the ultimate pull out load
d_b : the nominal diameter of the rod
l_b : the bonded length

3.0 Results and Discussions

The pull-out bending test results for plain GFRP bars are summarized in Table 3.1.

Table 2: T_u and τ_{bu} Testing Results

Specimen Designation	Average Concrete Strength (MPa)	Ultimate Pull-Out Load, Tu (kN)	Average Bond Strength, τ_{bu} (MPa)
FB1Ga(B)	46	19.3	6.5
FB2Ga(A)		19.5	3.3
FB2Gb(D)		18.6	3.2
FB2Gc(H)		14.9	2.5
FB3Ga(E)		27.2	3.1
FB4Gc(G)		18.6	1.6

3.1 Results of Groove Sizes 16 mm and 25 mm with Some Bonded Lengths

From Table 3, the ultimate pull-out load, T_u increased significantly up to 27.2 kN when the bonded length reached 225 mm. However, when it comes to Lorenzis and Nanni (2000) expression, the average bond strength shows t peak of 6.5 MPa at the smallest bonded length of 75 mm.

Table 3: T_u and τ_{bu} for 16 mm Groove Size

Specimen Designation	Bonded Length, (mm)	Ultimate Pull-Out Load, Tu (kN)	Average Bond Strength, τ_{bu} (MPa)
FB1Ga(B)	75	19.3	6.5
FB2Ga(A)	150	19.5	3.3
FB3Ga(E)	225	27.2	3.1

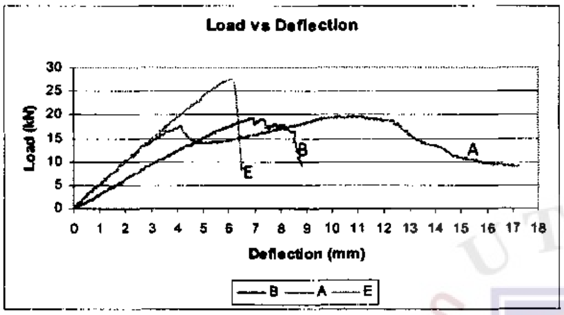

Figure 6: Load vs Deflection for Specimens B, A and E

In contrast to specimen with bonded length of 150 mm but bigger groove size (Table 4), T_u decreasing to 14.9 kN while τ_{bu} shows 2.5 MPa, if compared to the results of specimen FB2Ga(A) in Table 5. From these results, it shows that an increased in bonded length and groove size simultaneously, will not contribute to higher pull-out load or bonding strength.

Table 4: T_u and τ_{bu} for 25 mm Groove Size

Specimen Designation	Bonded Length, (mm)	Ultimate Pull-Out Load, Tu (kN)	Average Bond Strength, τ_{bu} (MPa)
FB2Gc(H)	150	14.9	2.5
FB4Gc(G)	300	18.6	1.6

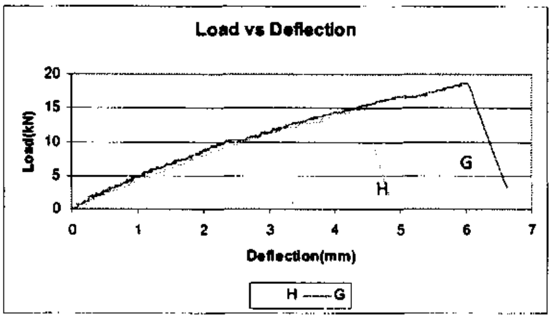

Figure 7: Load vs Deflection for Samples H and G

3.2 Results of 150 mm Bonded Length with Some Groove Sizes

Specimen with the smallest size of groove (16mm) shows the maximum ultimate pull-out load of 19.5 kN and average bond strength of 3.3 MPa compared to the other specimens with 19 mm and 25 mm of groove sizes.

Table 5: T_u and τ_{bu} for 150 mm of Bonded Length with Some Groove Sizes

Specimen Designation	Groove Size, (mm)	Ultimate Pull-Out Load, Tu (kN)	Average Bond Strength, τ_{bu} (MPa)
FB2Ga(A)	16	19.5	3.3
FB2Ga(D)	19	18.6	3.2
FB2Ga(H)	25	14.9	2.5

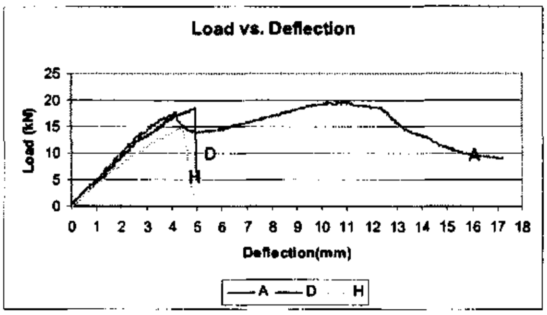

Figure 8: Load vs Deflection for Specimens A, D and H

3.3 The Influences of Bonded Lengths and Groove Sizes

The ultimate pull-out load of rod will increase for longer bonded length but vice versa for bonding strength when similar groove size is used. From this study, the bonding strength shows a reduction to more than 36% when the bonded length is two times longer.

In comparison between specimens with a bonded length but increasing of groove sizes, the ultimate pull-out load and bonding strength show a decreasing performance. Opposite finding given by Lorenzis and Nanni (2002) against this study by stating an increases of groove size will increase the thickness of the epoxy cover and offer higher resistance for deformed bar to split. Therefore, it is beneficial for deformed bar to enhance the pull-out loading and bonding strength by extra groove sizes but contradict to the plain GFRP bar. It was proven from Figure 9 that, specimen A with the smallest groove size (16 mm) slipped the least (0.042 mm), compared to 19 mm (0.186 mm) and 25 mm (0.124 mm) of groove sizes.

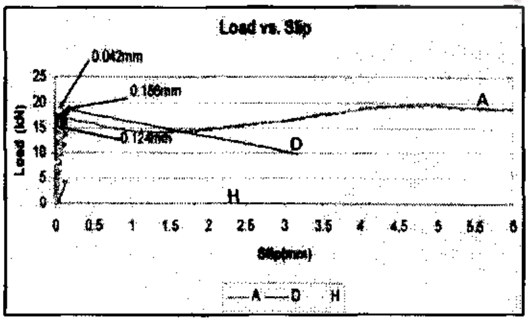

Figure 9: Load vs Slip Rates

Besides, neither cracking at the concrete blocks nor splitting of epoxy paste was observed during and after testing (Figure 10). However, slips were still occurred since the LVDT 1 and 2 had shown some reading during testing. The maximum slip values before failure is shown in Table 6.

Bonding failure may occur at the bar-epoxy interface. According to Lorenzis and Teng (2006), insufficient mechanical interlocking between bar and groove filler creates bar-epoxy interface failure or pure interfacial failure. In addition, the bonding resistance relies primarily on bar and filler adhesion.

Table 6: Maximum Slip Rates

Specimen Designation	Groove Size (mm)	Bonded Length (mm)	Maximum Slip Rate (mm)
FB1Ga(B)	16	75	Decode
FB2Ga(A)	16	150	0.042
FB2Gb(D)	19	150	0.186
FB2Gc(H)	25	150	0.124
FB3Ga(E)	16	225	0.275
FB4Gc(G)	25	300	0.108

Figure 10: Epoxy Paste after Testing

4.0 Conclusion

In conclusion, the average bond strength will reduce if the bonded length is increased. In addition, larger groove size also contributes to significant reduction of bonding strength and ultimate pull out load, even though no clear failures of bar-epoxy or epoxy-concrete was found after testing.

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