# Bonding Behavior between Reinforcement and PCM

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## I. Introduction

Recently, the single reinforcement (steel or CFRP-grid) pull-out to evaluate the interfacial properties has attracted great interest. The control of adhesion between the reinforce-matrix (concrete or PCM/Polymer Cement Mortar) interfaces in concrete/PCM with steel/CFRP-grid composites is of paramount importance in determining the usefulness of these materials. PCM replaces the cement hydrate binder of the conventional material with polymeric resins. Polymeric concretes harden rapidly and have high strength than normal concrete, lower permeability, and better resistance to chemical attack than portland cement concretes. This study discusses bond behavior the use of flexible PCM as a matrix in the block type under pull-out test.

## II. Specimens and Material Properties

The pull-out test specimens classified into 7 types according to the concrete, PCM (high strength and low elasticity) as in **Table 1**, material properties in **Table 2**, steel reinforcement in **Table 3** and CFRP-grid in **Table 4** respectively. Thus, there were 3 specimens on each types as shown in **Fig.1**. In **Fig.1(a)** shows Type 1 until Type 3 of specimens and other types is shown in **Fig.1(b)**.

Based on JIS A 1132[1)], the adhesive strength examination of reinforcement to the concrete and PCM was made. The adhesive length ($l_1$) and non-adhesive length ($l_2$) were design according to diameter of steel reinforcement (D22:SD345), which for $l_1$ was designed four times of D22 or 88mm, and lateral strip ($l_3$) for grid types was designed. The grid was made one lattice at lateral strip intervals, and totally, there were two lattices in the block types. The spiral reinforcement D6 to improve confinement for both block types was installed. Then, shape of block type had free edge side 10mm and fix edge side 1200mm. Especially for grid block types, to placing the expansive mortar was installed steel sleeve 200mm with position at 50mm from the fix edge side by aims to evaluating effect of bond both CF-grid and expansive mortar.

**Table 1** Details of specimens

| Types | Reinforce | Matrix | $l_1$ (mm) | $l_2$ (mm) | $l_3$ (mm) |
|---|---|---|---|---|---|
| 1 | D22 | Concrete | 88 | 62 | - |
| 2 | D22 | PCM high strgh. | 88 | 62 | - |
| 3 | D22 | PCM low elast. | 88 | 62 | - |
| 4 | CF-grid | PCM high strgh. | 100 | 50 | 25 |
| 5 | CF-grid | PCM high strgh. | 100 | 50 | 50 |
| 6 | CF-grid | PCM low elast. | 100 | 50 | 25 |
| 7 | CF-grid | PCM low elast. | 100 | 50 | 50 |

**Table 2** Details of material properties

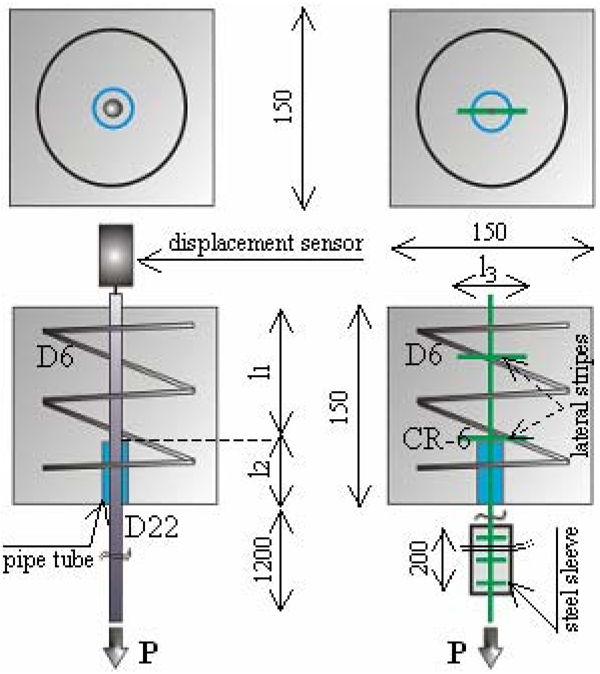
| Material | $f'_c$ (MPa) | $f_t$ (MPa) | Poisson's ratio | $E_c$ (MPa) |
|---|---|---|---|---|
| Concrete | 35.0 | 2.99 | 0.19 | $3.06 \times 10^4$ |
| PCM high strength | 59.8 | 2.91 | 0.20 | $2.48 \times 10^4$ |
| PCM low elasticity | 25.0 | 2.16 | 0.20 | $1.33 \times 10^4$ |

**Table 3** Details of steel reinforcement

| Diameter | Spec. | $f_y$ (MPa) | $f_t$ (MPa) | $E_s$ (MPa) |
|---|---|---|---|---|
| D22 | SD345 | 395 | 582 | $2.0 \times 10^5$ |

**Table 4** Details of CFRP-grid

| Spec. | $A_{cf}$ ($mm^2$) | $f_{tcf}$ (MPa) | $E_{cf}$ (MPa) |
|---|---|---|---|
| CR-5 | 13.2 | 1400 | $1.0 \times 10^5$ |




a) Type 1-3 (Steel reinforcement)    b) Type 4-7 (CF-grid)

**Fig.1** Details of specimens

Key word Bonding behavior, CFRP-grid, PCM (Polymer cement mortar), Pull-out test

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## III. Experimental Results

**Fig.2** shows the load-displacement graph. Based on load-displacement behavior, it is clear that the reinforcement pull-out curve is linear until initial debonding. Upon initial debonding, catastrophic debonding occurs along the entire embedded reinforcement length, and the stress drops suddenly in the reinforcement pull-out curve and complete debonding was occurs (Type 1 – Type 3). Then the load continuously decreases to zero until the steel is fully pulled-out from the material block. However, in initial debonding condition for CFRP-grid types was broken and complete debonding not occurs.

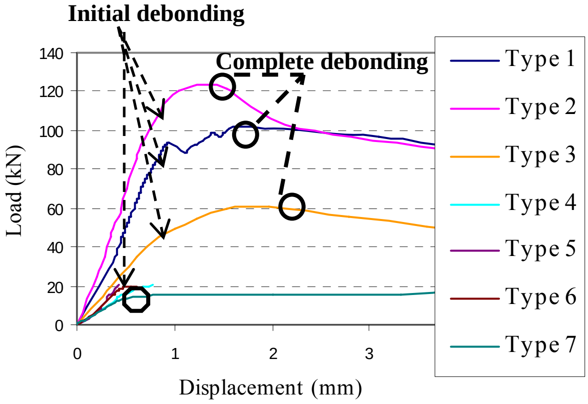


**Fig.2** Load-displacement relationships

**Fig.3** shows pull-out results of CF-grid block types. During applied load, tensile stress was increasing on interfacial debonding between CF-grid and PCM in the material block. On the other hand, tensile stress concentration on the rod of CF-grid was occurs. Upon maximum load was applied to the specimens, on the rod of CF-grid was broken and complete debonding not occurs.

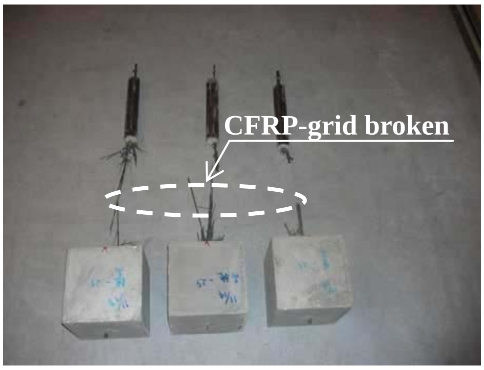


**Fig.3** Results of pull-out test (CF-grid)

Interfacial friction requires contact between the reinforcement and the matrix during the pull-out process. When composites have sufficiently strong interfacial bonding or sufficiently weak residual clamping stress, the reinforcement can separate from the matrix upon interfacial debonding. **Fig.4** shows specimens of PCM high strength has adhesive strength more than concrete and PCM low elasticity by pull-out test. Based on pull-out test at Type 1, Type 2, and Type 3 were obtained adhesive strength between the steel reinforcement (D22) with interfaces of PCM high strength was giving strongly interfacial bonding. On JSCE-G-503-1999[2)], adhesive strength was depending on compressive strength of the matrix and as the results obtained that all of matrix lower than experiment results except at PCM low elasticity.

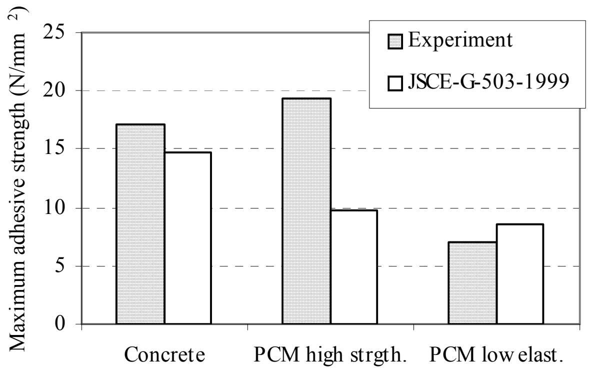


**Fig.4** Maximum adhesive strength

**Fig.5** shows maximum load on each specimen's grid types, interfacial debonding between PCM with stripes lattices of CF-grid almost same value after receiving tensile forces in axial direction. The red line shows design value about 18.5kN and almost all of grid specimen's experimental results over the design value.

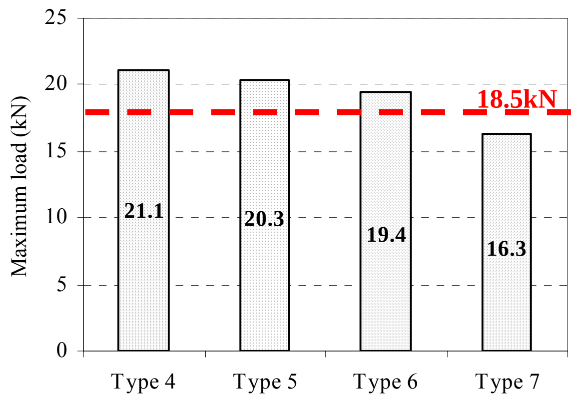


**Fig.5** Maximum load

## IV. Conclusions

1) On Type 2 and Type 3, the result shows adhesive strength was almost same value for JSCE-G-503-1999.

2) On Type 4 until Type 6, the load of examination results shows over the design value except Type 7 where slip was occurs.

3) The adhesive strength in this experimental is useful for design pier specimens.

## References

1) Standards specifications for concrete structures, Test method and specifications, 2005.

2) Standards specifications for concrete structures, JSCE standards, 2005.