CFRP STRAND SHEETS STRENGTHENING ON RC BEAMS WITH VARIOUS TYPES OF ADHESIVE

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1. INTRODUCTION

The use of a carbon fiber reinforced polymer (CFRP) strand sheet for external strengthening has become a solution for strengthening/retrofitting reinforced concrete (RC) members. The aim of this study is to find out flexural strengthening effect of CFRP strand sheet with various types of adhesive. This study used three types of adhesive namely epoxy, methyl methacrylate (MMA), and polymer cement mortar (PCM).

2. EXPERIMENTAL PROGRAM

2.1 Material properties

Table 1 summarizes the mechanical properties of the CFRP strand sheet. This experiment used high tensile strength CFRP strand sheet. Table 2 shows the properties of adhesives. The properties of CFRP strand sheet and the adhesives were obtained from the manufacturer.
Table 3 presents mechanical properties of rebar. Deformed bars of 19mm in diameter were used as tension reinforcement, 10mm in diameter were used as compression reinforcement, and stirrups as shear reinforcement have a diameter of 13mm. Furthermore, the quality of concrete was used in this study can be seen in Table 4.

2.2 Test set up

Seven RC beams comprising one non retrofitted beam (specimen N) as control beam and six retrofitted beams with one layer and two layers of CFRP strand sheet for each of adhesive have been tested in this study.

Table 1 CFRP strand sheet mechanical properties

Tensile modulus (MPa)	245,000
Tensile strength (MPa)	3,400
Unit weight (g/m^2)	600
Design thickness (mm)	0.333

Table 2 Mechanical properties of adhesive (MPa)

Material Properties	Epoxy	MMA	PCM
Compressive modulus	3,970	2,500	4,800
Compressive strength	78.3	79.0	11.3
Tensile strength	35.8	43.0	2.40
Flexural strength	58.8	71.0	6.50
Lap-share strength	25.8	22.0	-

Table 3 Mechanical properties of rebar (MPa)

Material Properties	Rebar		
	Dia.10 mm	Dia.13 mm	Dia.19 mm
Tensile modulus		200,000	
Tensile strength	548	551	559
Yield strength	376	395	407

Table 4 Mechanical properties of concrete (MPa)

Material Properties	Concrete
Compressive modulus	33,800
Compressive strength	49.8
Tensile strength	4.23

Detail of the experimental program can be seen in Fig.1. Detail A in Fig.1 explains the position of the CFRP strand sheet for the two-layer specimen. To avoid stress concentration at the end, the CFRP strand sheet was shortened by 25mm for the next layer.
Fig. 2a and Fig. 2b are the cross-section of strengthened RC beams with CFRP strand sheet using epoxy resin and MMA as a bonding agent for one and two layers. Moreover, Fig. 2c and Fig. 2d show the use of PCM as an adhesive in strengthening methods with CFRP strand sheet for one and two layer.
All the beams are four-point loading beams that have a span of 2.2m with two small rollers as supports that have a span of 1.6m. The load was applied by a hydraulic jack and measured by a load cell. Deflection control was used in all the tests and deflection measurements were taken at the mid span of the beam. The strain gauges were located 100mm on each CFRP strand sheet, four on the steel reinforcement (two for tension rebar and two for compression rebar), and one on the top of the concrete in the mid span.

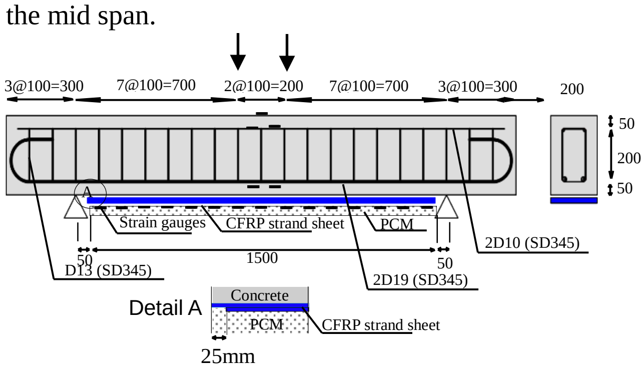

Fig.1 RC Beams specimen detail

Keywords: CFRP strand sheet, epoxy, MMA, PCM, RC beam
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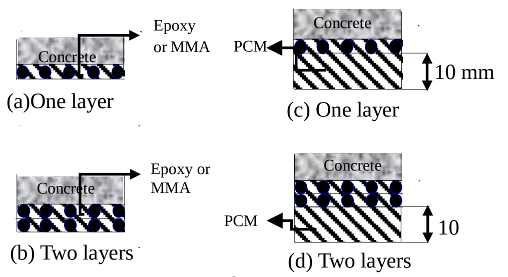

Fig. 2 Cross-section of material CFRP strand sheet

3. RESULTS AND DISCUSSION

The experimental result for each loading stage are given in Table 5. The results show an increase for almost all stages of loading. When in the crack state, there is an increase in almost the crack load. For epoxy adhesive, an increase in crack load is 38% and 27% for specimen Epoxy1 and Epoxy2, respectively, compare with control beam (specimen N). For MMA adhesive, the results are 26% and 39% for specimen MMA1 and MMA2, respectively, higher than specimen N. Meanwhile, for specimen PCM1, there is almost same result. Moreover, for specimen PCM2, a decrease in capacity of load crack compared with specimen N occur. It is possible that initial crack has happened prior to loading on the specimen PCM2.

From Table 5 can be seen that all strengthened beams with CFRP strand sheet have an increase in capacity of yield load compared to the normal beam at the yield loading stage. These show an increase of 46% and 80% in the yield load capacity for specimen Epoxy1 and Epoxy2, respectively, over the specimen N. For MMA adhesive, there is an increase of 56% and 65% than control beam. An increase of 31% and 46% compared with specimen N occurs in the specimen PCM1 and PCM2 respectively. It means that the CFRP strand sheet and the adhesives could delay the reinforcing steel to experience yield.

From Table 5 can be seen the results of maximum load for each beam. An increase in capacity is observed to be 46% and 80% of normal beam for Epoxy1 and Epoxy2, respectively. An increase in maximum load for specimen MMA1 and MMA2 can be observed in Table 5. The values are 55% and 65% higher than specimen N. For PCM adhesive, there is an increase of 35% and 22% for PCM1 and PCM2, respectively.

It could be noted that although there is an increase in maximum load but the use of one layer of CFRP strand sheet is more effective than two layers for PCM adhesive. This is different from assumption that increasing the number of layers will increase the capacity of beam. This is because in the two-layer specimen (specimen PCM2), the interface layer between CFRP strand sheets is not too effective to resist shear stress and so reduces the capability of existing composite mechanisms.

Fig.3 shows the relationship between total load and mid-span deflection of the specimen. In general, it may be noted that after the maximum load is achieved, load will be closer to the yield load on the specimen N. It means that the specimens show ductile behavior up to failure, so it may be able to absorb the energy well and can avoid the collapse that occurs suddenly.

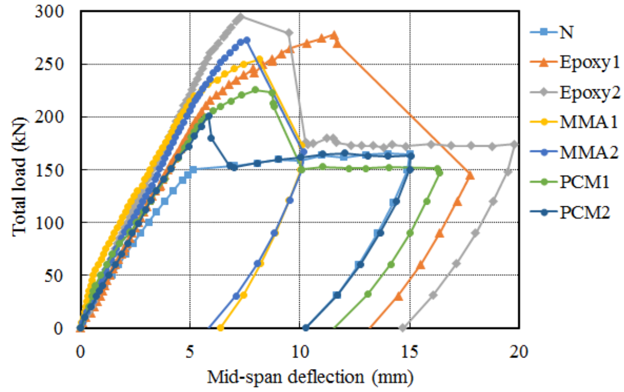

Fig.3 Total load versus mid-span deflection

Table 5 Experimental results

Spec.	Layers Numb.	P_{Crack} (kN)	P_{Yield} (kN)	$P_{Ultimite}$ (kN)
N	-	39.8	131	165
Epoxy1	1	50.4	191	278
Epoxy2	2	55.0	236	295
MMA1	1	50.1	205	255
MMA2	2	55.3	216	272
PCM1	1	40.1	171	223
PCM2	2	35.1	191	201

4. CONCLUSION

The conclusion of this study are as follows:

(1) CFRP strand sheet strengthening with Epoxy, MMA, and PCM as adhesive can improve the capacity of RC beam.

(2) The maximum load of specimen PCM2 (two layers) lower than specimen PCM1 (one layer). This is because, the interface layer between CFRP strand sheets of specimen PCM2 is not too effective to resist shear stress and so reduces the capability of existing composite mechanisms.

(3) After maximum load is achieved, the load of strengthened RC beams will be closer to yield point on the beam normal.

REFERENCES

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