EFFECT OF ALUMINUM ALLOY SHEETS ON STRUCTURAL BEHAVIOR OF RC BEAMS

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ABSTRACT. The most current used technology for strengthening reinforced concrete (RC) beams is aluminum plate (AP). The use of AP to strengthen RC beams was investigated in this study. The experimental program included twenty-five RC beams (1/5 scale), with 14 and 11 beams strengthened in shear and flexure, respectively. All beams were the same size. All beams were subjected to four-point bending flexural tests. Various AP-based strengthening approaches were used. To improve shear strength, APs were glued vertically, inclined by 45^0 degrees, diagonally, and horizontally on the beams' sides (SS). The effect of AP pitch, height, and amount was investigated. APs of varying length, number, and pitch were agglutinated at the beam soffits to improve flexure strength (FS). All APs improved shear and flexure capabilities, while some of them modified the failure mode.

KEYWORDS: *Experimental study; Reinforced concrete beam; Shear strengthening; flexure strengthening; Aluminum plates; Cracks pattern; Ultimate capacity*.

1. INTRODUCTION

The research of structural element strengthening has been more relevant in recent decades. Existing reinforced beams (RC) were strengthened using various approaches to increase their flexure and shear capabilities [1, 2]. Externally bonded strengthening (EBS) is a popular approach for retrofitting RC beams [2, 3]. Externally strengthening materials (ESM) such as steel reinforcement, steel plates, and fibre reinforced polymer (FRP) have been employed in recent years [1, 3]. Steel reinforcing technology was examined to improve shear strength of RC beams due to its high tensile strength and ductility.

The use of steel bars at the soffit of RC beams enhanced their flexure capacity [1]. One of the disadvantages of steel bars is that corrosion reduces the connection between the bar surface and the concrete. Steel plates were used by researchers to improve the shear and flexure capabilities of RC beams [1, 4, 5, 6]. This approach is insufficient due to its heavy weight, difficult penalization, and corrosion. Over the last thirty years, researchers have conducted several investigations on the strengthening of RC beams utilising FRP as ESM, either for shear or flexure augmentation [2, 3, 7, 8].

FRP is distinguished by its high tensile strength to weight ratio and resistance to corrosion, however its failure mode is rapid rupture. At high temperatures,

its tensile strength also dropped. As a result, researchers began searching for novel materials utilised as ESM in the previous 10 years. Aluminum plate (AP) fabrications are capable of being used as ESM because AP overcomes the scarcity of steel plates, steel bars, and FRP. These plates are cost-effective, lightweight, fire-resistant, non-corrosive, quick to fabricate, and simple to install. In comparison to its weight, AP has a high tensile strength [9].

Some studies [6, 10, 11] evaluated the behaviour of beams retrofitted with steel plates. The use of CFRP, either hybrid or glass, in the strengthening of RC beams has been demonstrated [2, 3, 12]. ACI committee 440 studied a guide for the design and installation of externally bonded FRP systems for reinforcing concrete structures [13]. Researchers suggested an experimental study on shear strengthening of RC beams employing externally bonded aluminium plates of varied thicknesses and methods [14].

Aluminum plates (AP) were explored as an external strengthening material (ESM) to improve flexural capability [15]. A numerical research was provided to investigate the creation of five 3D nonlinear finite element (FE) models for predicting the capacity of RC beams retrofitted under shear using AP [16]. The shear strength of the adhesive substance between AP and concrete was experimentally investigated [17]. Using the data sheet and standard specification, the chemical, physical, and mechanical characteristics of

commercial kinds of aluminium alloy plates were investigated [9, 18]. Sikadur 30 is a popular epoxy glue for connecting exterior plates to concrete [19]. The behaviour of structural components was examined in studies [20-37].

2. EXPERIMENTAL PROGRAM

2.1. MATERIALS PROPERTIES

The tested specimens were cast in conventional concrete. Fine aggregate (630 kg/m³) with a density of 1600 kg/m³, well-graded crushed dolomite (1290 kg/m³) with a density of 1290 kg/m³, ordinary Portland cement (300 kg/m³), and water (175 kg/m³) comprised the concrete mix. Superplasticizer (Sikament-163M) was applied at a ratio of 1 ltr/100kg cement weight to provide an acceptable degree of workability in fresh concrete. Three 15x15x15cm cubes were casted from each beam to evaluate the concrete compressive strength. After 28 days, the average compressive strength of beams was determined to be 27.6 MPa. The steel bars utilised in this experiment are standard mild steel (NMS). The surface of steel bars is smooth. These reinforcing bars were softer. Uniaxial tensile tests were performed to assess the mechanical characteristics of used steel bars. NMS has a yield strength of 250 MPa and an ultimate strength of 344 MPa. Rebar elongation is 39.5 %. To assess mechanical qualities, three specimens of aluminium alloy plates were subjected to a uniaxial tensile test. The average yield strength achieved was 113.33 MPa, whereas the average ultimate strength obtained was 229.84 MPa. Elongation is 9.14 percent on average. AP thickness of the current work is 1.12 mm for all tested specimens. The epoxy material utilised in this investigation was X-wrap plate. This is a high strength epoxy resin that is used to bind the exterior plates to the concrete. Non-slump, high strength, ease of usage, no requirement for priming material, and chemical resistance are all advantages of X-wrap. Bonding external plates or rods into concrete is one application for X-wrap. It is also used to adhere carbon fibre strips to concrete.

2.2. TESTED BEAMS AND SET-UP

Twenty-five RC beams were used in the experiment. All specimens were sorted into two categories: I and II. Group I included fourteen RC beams, whereas Group II included eleven RC beams. Both groups of specimens had the same measurements, but not the same reinforcement. RC beams have a total length of 800 mm, with depth and breadth of 100 mm and 80 mm, respectively. The tested beams had an effective span of 700 mm. Fig. 1 depicts the specimen setup. All specimens were subjected to a four-point bending flexural test. Group I specimens lacked stirrups, but group II specimens had stirrups Ø 6@175mm, as
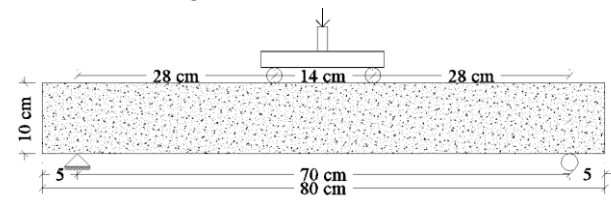
illustrated in Fig. 2.

Fig. 1. Set up of specimens of group I and group II.
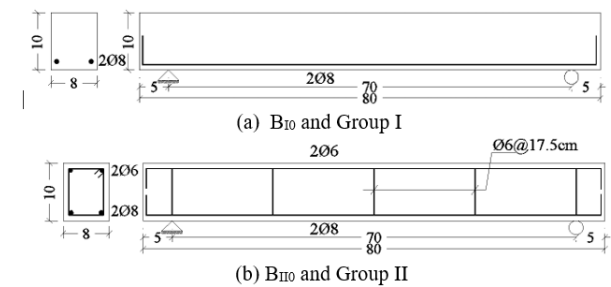

(a) B_{I0} and Group I

(b) B_{II0} and Group II

Fig. 2. Details of reference beams of two groups

To avoid flexural collapse, the primary tension steel in Group I was 2 Ø 8 and all beams lacked stirrups. As hanger stirrups, the primary tension steel was 2 Ø 8 and the top longitudinal steel was 2 Ø 6 for group II examples. Table 1 shows six AP-based strengthening approaches offered for two groups. For all strengthening techniques, AP was pasted on the vertical beam sides or beam soffit but the difference was inclination angle, AP number and AP length. The techniques were labeled (1), (2), (3), (4), (5) and (6). The technique (1) is fixing a vertical AP on the vertical beam sides with inclination angle 90º. In this technique, the AP number was 8, 6, 4 and 3 plates per each beam side. The beams; B_{I90-8}, B_{I90-6}, B_{I90-4}, and B_{I90-3} were strengthened to enhance the shear capacity using the technique (1) as shown in Fig. 3. AP height is 80% of the beam section height. Width and height of AP are 3 cm and 8 cm, respectively. Strengthening technique (2) was similar to strengthening technique (1) except the inclination angle of AP was 45⁰ instead of 90⁰. Each AP rotated about its center by 45⁰. The beams; B_{I45-8} , B_{I45-6}, B_{I45-4} , B_{I45-6c} , $B_{I45-6c*}$ were strengthened by the technique (2) as shown in Fig. 4. The APs were distributed on the expected crack pass for both beams B_{I45-6c}, $B_{I45-6c*}$. Strengthening technique (3) consisted of two diagonal AP pasted on each beam side. Center of each plate is middle of the line that reached from the support to the loading point. Dimension of each plate is 30x3cm. AP inclined by 14º respect to horizontal beam center. Strengthening technique (3) was used in the beams; B_{ID-2} as shown in Fig. 5. Strengthening technique (4) is pasting one, two or three horizontal AP on the vertical sides of the beams; B_{IH-1}, B_{IH-2}, and B_{IH-3}. Fig. 6 shows organization of plates and its details.

Strengthening technique (5) is fixing one, two or three horizontal AP at the beam soffit. The beams; $B_{II-1-3-70}$,

$B_{II-1-3-70*}$, $B_{II-2-3-70}$, $B_{II-2-1.5-70}$, $B_{II-2-1.5-70*}$, $B_{II-3-1-70}$ and $B_{II-3-1-70*}$ were strengthen by Strengthening technique (5). The AP length was 70 cm. Fig. 7 shows organization of plates and its details. Strengthening technique (6) is putting one or two horizontal AP at the soffit side of the beams; $B_{II-1-3-26}$, $B_{II-1-3-26*}$, and $B_{II-2-3-26}$. The AP length was 26 cm. Fig. 8 shows configuration of strengthening technique (6).

Table 1. Details of strengthening techniques used for the tested specimens and results of group I and II.

Group I specification	Specimen	Aluminum plate number	Aluminum plate dimensions (cm)	Inclination angle of AP	Strengthening technique	P_u (kN)	Increase of P_u %	Failure Type
	B_{I0}	-	-	-	-	19	-	Shear
	B_{I90-4}	4	3x8	90°		19.31	1.63	Shear
	B_{I90-6}	6	3x8	90°	(1)	19.4	2.1	Shear
	B_{I90-8}	8	3x8	90°		21.94	15.5	Shear
	B_{I90-3}	3	3x8	90°		28.58	50.4	Shear
	B_{I45-4}	4	3x8	45°		19.92	4.8	Shear
Group I; with main tension steel of 2∅8	B_{I45-6}	6	3x8	45°		31.24	64.4	Shear
	B_{I45-8}	8	3x8	45°	(2)	22.95	20.8	Shear
	B_{I45-6c}	6	3x8	45°		30.21	59	Flexure
	$B_{I45-6c*}$	6	3x8	45°		25.79	35.7	Flexure
	B_{ID-2}	2	3x30	14°	(3)	22.73	19.6	Shear
	B_{IH-1}	1	3x70	0		25.71	35.3	Shear
	B_{IH-3}	3	1x70	0	(4)	25.35	33.4	Shear
	B_{IH-2}	2	1.5x70	0		25.23	32.8	Shear
	B_{II0}	-	-	-	-	20.56	-	Flexure-tension
	$B_{II1-3-70}$	1	3x70	-		27.86	35.5	Flexure-compression
	$B_{II1-3-70*}$	1	3x70	-		27.51	33.8	Flexure-compression
	$B_{II2-3-70}$	2	3x70	-		27.97	36	Shear
Group II; with tension steel (2∅8), compression steel (2∅6) and stirrups	$B_{II2-1.5-70}$	2	1.5x70	-	(5)	31.35	52.48	Flexure-tension
	$B_{II2-1.5-70*}$	2	1.5x70	-		33.39	62.4	Flexure-compression
	$B_{II3-1-70}$	3	1x70	-		23.98	16.63	Shear
	$B_{II3-1-70*}$	3	1x70	-		32.73	59.19	Flexure-tension
	$B_{II1-3-26}$	1	3x26	-		23.96	16.53	Flexure-tension
	$B_{II1-3-26*}$	1	3x26	-	(6)	29.54	43.68	Shear
	$B_{II2-3-26}$	2	3x26	-		29.49	43.43	Flexure-compression
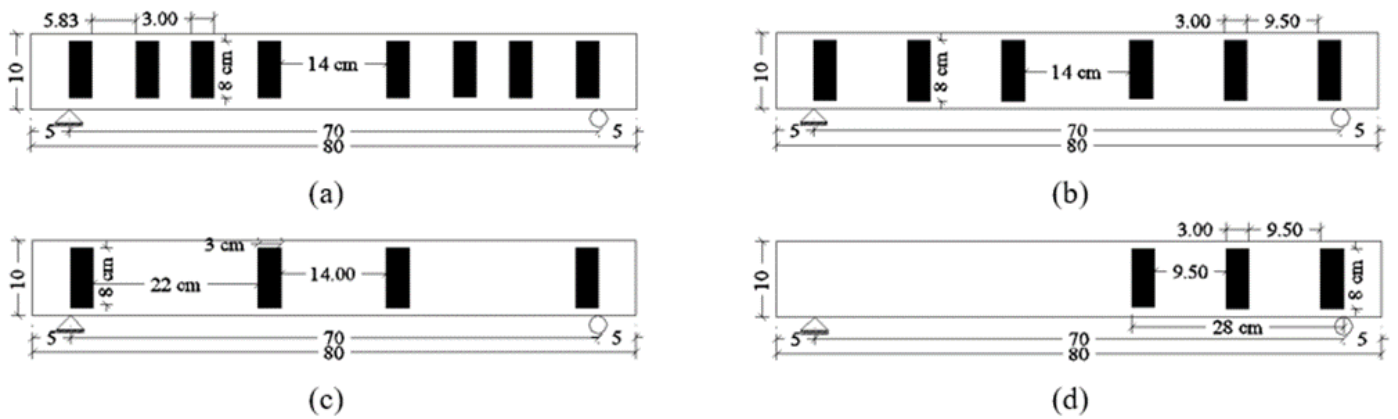
Fig. 3. Details of RC beams strengthened using technique (1); (a) B_{I90-8} (b) B_{I90-6} (c) B_{I90-4} (d) B_{I90-3}
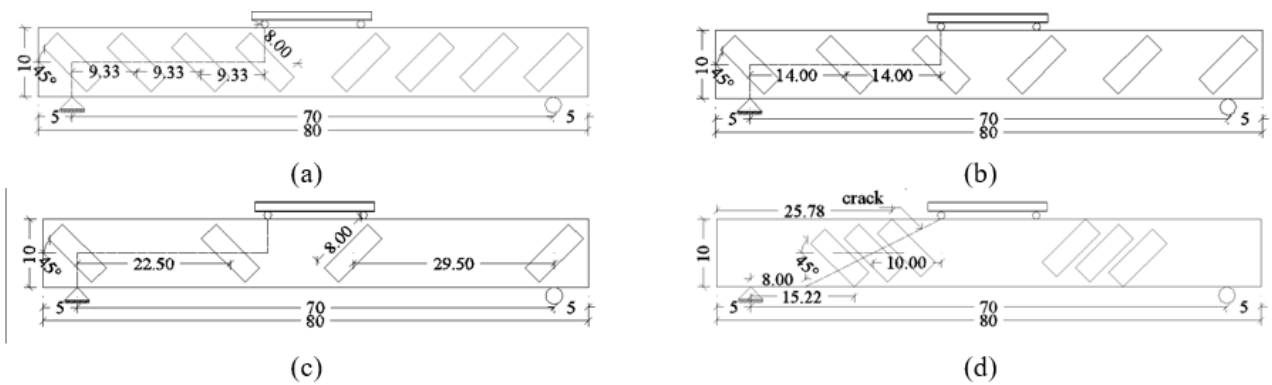
Fig. 4. Details of RC beams strengthened using technique (2); (a) B_{I45-8} (b) B_{I45-6}, (c) B_{I45-4} and (d) B_{I45-6c} and $B_{I45-6c*}$
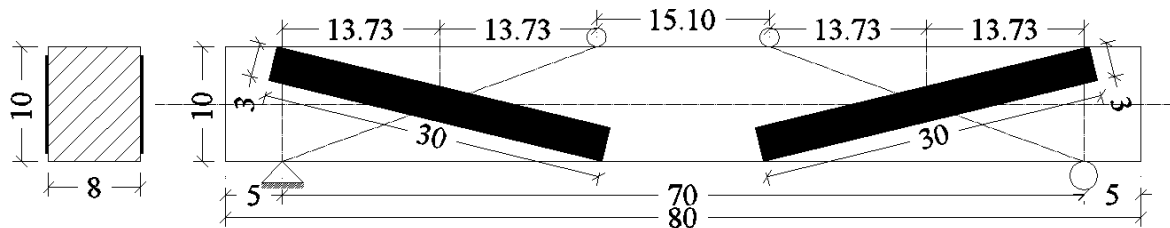

Fig. 5.   Details of RC beam strengthened using technique (3); B_{ID-2}
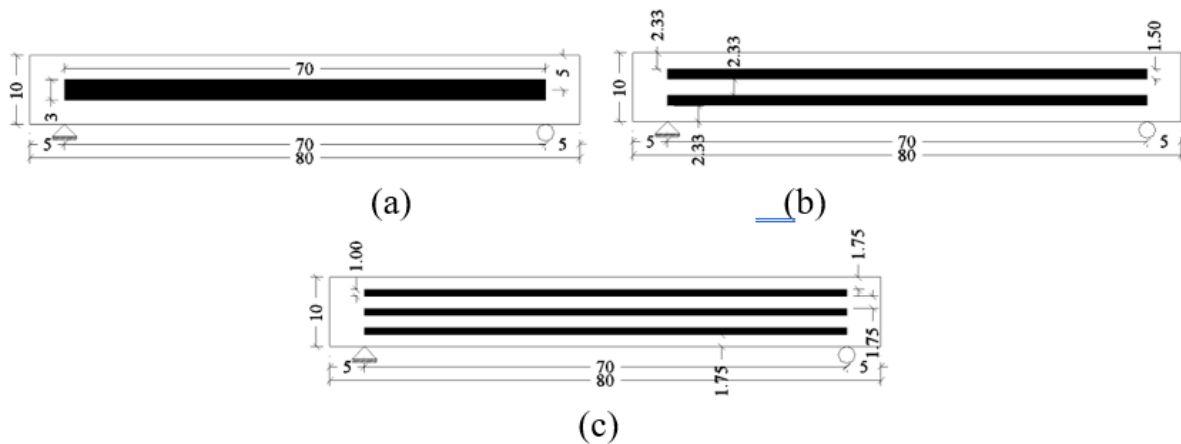

Fig. 6. Details of RC beams strengthened using technique (4); (a) B_{IH-1} (b) B_{IH-2} and (c) B_{IH-3}
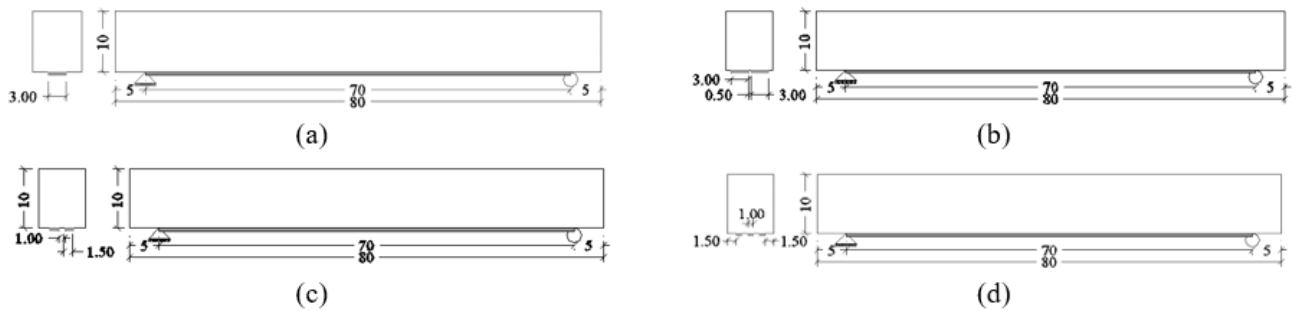
Fig. 7. *Details of RC beams strengthened using technique (5); (a) $B_{II-1-3-70}$ and $B_{II-1-3-70*}$ (b) $B_{II-2-3-70}$ (c) $B_{II-2-1.5-70}$ and $B_{II-2-1.5-70*}$ (d) $B_{II-3-1-70}$ and $B_{II-3-1-70*}$*
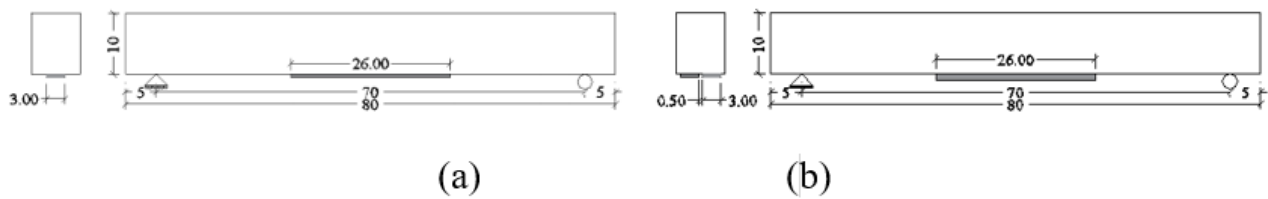

Fig. 8. *Details of RC beams strengthened using technique (6); (a) $B_{II-1-3-26}$ and $B_{II-1-3-26*}$ (b) $B_{II-2-3-26}$*

3. RESULTS AND DISCUSSION

3.1. PEAK LOAD

Table 1 listed the increase ratios in ultimate loads for all specimens. Ultimate carrying loads (P_u) of specimens of group I was increased using various AP techniques. Ratios of enhancement of inclined APs by 450 were better than the vertical APs. Average of P_u of the beams B_{90} was higher than P_u of control beam by 17.4 %. For the beams that strengthen by inclined AP the average increase ratio is 36.94 % compared to control beam. The P_u of the beam B_{ID-2} was larger than P_u of B_{I0} by 19.6%. Horizontal APs achieved an increase ratio in P_u equal 33.83%. The aim of group I is enhancement of shear capacity of the RC beams using APs and the results achieved this objective. Specimens of group II were strengthen in flexure. Using APs at the beams soffit increased the flexure capacity by 39.96 % compared to B_{II0}. The highest ratio in ultimate load is 62.4%.

3.2. FAILURE MODE

For all specimens of group I, Shear strength of the section was weak due to absence of stirrups. Shear strengthening techniques were applied to this group to enhance the shear strength. The control beam B_{I0} failed at 19 KN due to shear failure. The angle of shear crack was measured and it was found 30°. The crack path began from the loading point to the bottom side of the beam close to the support. Fig. 9 show cracks and failure mode for control beam B_{I0}.

Fig. 9. *crack pattern of control beam B_{I0}*

Fig. 10 showed crack propagation and type of failure for the beams retrofitted using strengthening technique (1). For $B_{I\ 90-4}$, the ultimate load is 19.31 KN. The crack inclination was 29° as shown in Fig. 10. The failure occurs because of stress concentration of shear in shear zone between the support and the loading point in right third of the span. The shear strength did not affected by strengthening because the crack took placed between two AP in the right third of the span. For B_{I90-6}, the failure took placed due to shear failure at the left third of the beam. The crack width of B_{I90-6} was less than crack width of control beam due to AP restriction. For $B_{I\ 90-8}$, the crack pattern was similar to the beam B_{I90-6} as shown in Fig. 10. Increase of AP from 6 plates to 8 plates on one side of the beam enhanced the capacity of the beam by 13%. For $B_{I\ 90-3}$, a three vertical AP were pasted at the right shear span from two sides of the beam. The left shear span was without AP. The ultimate load is 19.2 KN. The failure took placed due to shear failure similar to control beam. The crack took placed at unstrengthen shear span as shown in Fig. 10.
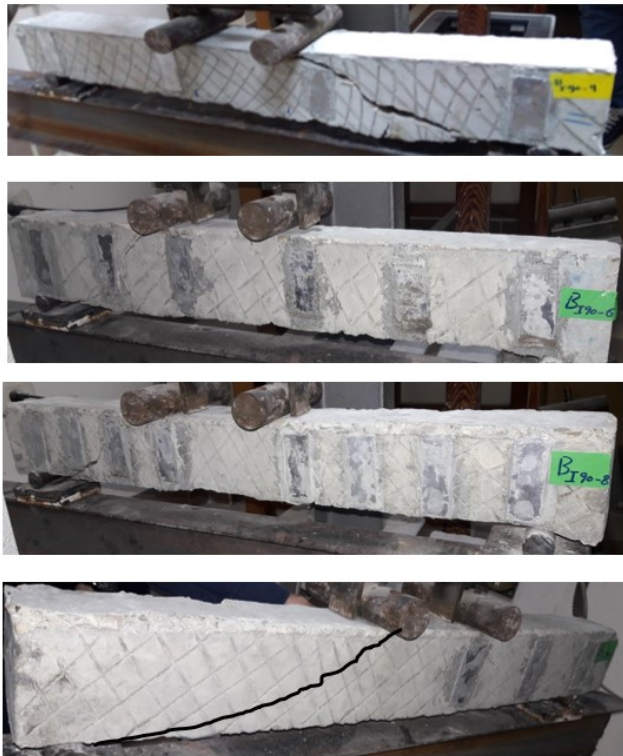
Fig. 10. crack pattern and mode of failure for the beams strengthen using strengthening technique (1).

Fig. 11 showed crack propagation and type of failure for the beams retrofitted using strengthening technique (2). For $B_{I\ 45-4}$, the ultimate load is 19.92 kN. The space between two AP in the left part was less than the space between two AP in the right part. This reason caused the failure in the right part. For $B_{I\ 45-6}$, the ultimate load is 31.24 kN. The failure was flexure type that it occurs at the top face of the beam due to crushing of concrete occurs at compression zone as shown in Fig. 11. For $B_{I\ 45-8}$, the shear failure in the right third occurred due to separation of AP about the concrete. Six AP concentrated on the expected crack were fixed per each side of the beam $B_{I\ 45-6c}$. The ultimate load is 30.21 kN. The failure took placed due to flexure failure by crushing of the concrete at compression zone as shown in Fig. 11. In addition to two flexure cracks from the bottom to up the beam at the middle span took placed. The beam $B_{I\ 45-6c*}$ was similar to the beam $B_{I\ 45-6c}$ exactly. Also the failure took placed due to compression-flexure failure as shown in Fig. 11.

For B_{ID-2}, the ultimate load is 22.73 kN. The failure took placed due to shear failure as shown in Fig. 12. Failure occurs without separation for AP and the crack width of this beam was similar than the crack width of the control beam.

Fig. 13 showed the crack propagation and types of

failure for the beams retrofitted using strengthening technique (4). For $B_{I\ H-1}$, the failure took placed due to shear failure (see in Fig. 13). The failure load was 25.71 kN. Parts of AP buckled and separated about the concrete at 20 kN. For $B_{I\ H-3}$, that has three horizontal AP (1*70 cm), the failure took placed due to shear failure. The failure load was 25.35 kN. When AP width decreased, the separation and buckling of the plates did not occur. for $B_{I\ H-2}$, that has two horizontal AP (1.5*70 cm) per each side, the failure took placed due to shear failure as shown in Fig. 13.

Fig. 11. crack pattern and mode of failure for the beams strengthen using strengthening technique (2).

Fig. 12. crack pattern and mode of failure for the beams strengthen using strengthening technique (3).

Fig. 13. *Crack pattern and mode of failure for the beams strengthen using strengthening technique (4).*

For all specimens of group II, stirrups of 6mm@175mm were used in all beams distributed on over all span. Control beam B_{II0} was designed to fail in the flexure. Flexure strengthening techniques were carried out this group to enhance the flexure strength. The control beam B_{II0} failed at 20.56 KN as flexure failure type. The crack path began from the beam soffit at middle span toward up. Fig. 14 show cracks and failure mode for control beam B_{II0}.

Fig. 14.   *crack pattern of control beam B_{II0}*

Fig. 15 showed the cracks and mode of failure for specimens that retrofitted using strengthening technique (5). For $B_{II\ 2-1.5-70*}$, the ultimate load is 33.39 kN. The failure took placed due to flexure. Crushing of the concrete occurred at compression zone at middle span. For $B_{II\ 2-1.5-70}$, the ultimate load is 31.35 kN . Fig. 15 showed that the failure took placed due to flexure. This may be because of the separation of AP about the concrete at beam soffit due to bad pasting of plates and bad roughness. For $B_{II\ 2-3-70}$, the failure took placed due to shear failure as shown in Fig. 15. For $B_{II\ 3-1-70*}$, the ultimate load is 32.73 kN. The failure occurred due to flexure failure-tension as shown in Fig. 15. It was showed that cut of AP due to tension force at beam soffit took place for $B_{II\ 3-1-70*}$. For $B_{II\ 3-1-70}$, the failure took placed due to shear failure. For $B_{II\ 1-3-70*}$, the failure took placed due to compression- failure accompanied to concrete crushing. In addition to three flexure cracks took placed. Fig. 15 showed the failure of beam $B_{II\ 1-3-70}$ that it take same trend in failure of beam $B_{II\ 1-3-70*}$. The failure load is 27.86 kN.

Fig. 15.   *crack pattern and mode of failure for the beams strengthen using strengthening technique (5).*

Fig. 16 showed the cracks and mode of failure for specimens that retrofitted using strengthening technique (6). For $B_{II\ 2-3-26}$, the ultimate load is 29.49 kN. The failure took placed due to flexure failure due to crushing of concrete and two flexure cracks. For $B_{II\ 1-3-26}$, the failure occurred due to flexure failure due to a lot of cracks at beam soffit. Failure occurs without cutting or separation in AP. For $B_{II\ 1-3-26*}$, the failure took placed due to shear failure as shown in Fig. 16. Failure occurs without cutting or separation in AP.

Fig. 16.   crack pattern and mode of failure for the beams strengthen using strengthening technique (6).

4. CONCLUSION

Twenty-five RC beams (1/5 scale) were used in the experiment, with 14 and 11 beams reinforced in shear and flexure, respectively. The beams were all the same size but had variable inside reinforcement. Several AP-based strengthening techniques were employed. APs were cemented vertically, tilted by 45^0 degrees, diagonally, and horizontally on the sides of the beams to boost shear strength. The influence of AP pitch, height, and quantity was studied. To increase flexure strength, APs of various length, number, and pitch were agglutinated at the beam soffits. The findings revealed that all APs increased shear and flexure capacities, but some altered the failure pattern.

ACKNOWLEDGEMENTS

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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