Study of Shear Joints of Fiber Reinforced Plastic (FRP) Ferrocement Bolted Connections+

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This paper presents a study of the behavior of Fiber Reinforced Plastic (FRP) ferrocement bolted shear joints. In an experimental program 18 pin-loaded ferrocement plates and 10 control specimens were tested under tension. The main test variables were the type of mesh, the number of meshes, the type of fiber and the end distance. Three types of failure were observed in pin-loaded ferrocement plates: a cleavage failure ahead of the bolt initiated by some tensile cracks along the net-section width (cleavage-tensile), a well defined tensile failure along the net-section width, and a crushing (bearing failure) of the ferrocement plate in the vicinity of the hole. For ratios of end distance to hole diameter with a value of 4 (e/d=4), the cleavage-tensile failure mode occurred for all the pin-loaded specimens. This failure mode was related to the geometry of the plates and seemed to be indifferent to the type and total amount of reinforcement. For e/d ratios higher than 6, the failure mode changed from cleavage-tensile to net-section for specimens reinforced with 2 layers of mesh and with 2 layers of mesh plus fibers. This change in failure mode also involved an increase of 20% in the ultimate strength value. The only specimen that exhibited a bearing failure was the specimen with 6 layers of Aramid mesh.

INTRODUCTION

Ferrocement is considered a highly versatile construction material. Research and development have shown that ferrocement construction can be cost-competitive in both developed and developing countries through the use of advanced construction technologies such as precast construction. In using ferrocement precast elements, one of the most important issues is connecting these elements to arrive at the most efficient design of the precast structure. One of the easiest and most economical ways of assembling individual precast elements is by the use of bolted connections. To the best of the authors knowledge only two investigations were carried out so far on the use of bolted connections in ferrocement: one at the National University of Singapore [1] and one at the University of Michigan [2]. This paper presents a study of the behavior of Fiber Reinforced Plastic (FRP) ferrocement bolted shear joints. It is similar to a study carried out in 1993 dissertation by Hassen Hammoud in which steel meshes were used [2], and is part of a continuing investigation of prefabricated ferrocement housing systems at the University of Michigan [3-8]. In the experimental program 18 pin-loaded ferrocement plates and 10 control specimens were tested under tension. The main test variables were the type of mesh, the number of meshes, and the end distance. This paper reports the results of the experimental program and draws conclusions.

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EXPERIMENTAL PROGRAM

Parameters of Study

The purpose of the experimental study was to investigate the effects of plate geometry (edge effects), mesh characteristics, and volume fraction on the behavior of ferrocement shear joints. Special attention was given to the effect of these parameters on strength, deformation of the joint and failure mode.

Specifically, the parameters were defined as follows:

1. **Ratio *e/d*:** This is the ratio of the end distance *e* (distance between the center of the bolt and the plate edge) to the hole diameter *d*. Two ratios were investigated $e/d=4$ and $e/d=6$, corresponding to end distances of 2 inches (50.8 mm) and 3 inches (76.2 mm) with a hole diameter constant at d=0.5 inches (12.7 mm).
2. **Type of mesh:** Two types of mesh were used: Aramid fiber square mesh with wire spacing of 10.5 mm (trade name ARAGRID) and PVA (polyvinyl alcohol) fiber square mesh with wire spacing of 5 mm. Illustration of some test parameters such as *e/d* and the type of mesh are presented in Fig. 1. Mechanical properties are described in Table 1.
3. **Type of fiber:** PVA fiber (12 mm length and 0.19 mm diameter) and steel fiber (12 mm length and 0.15 mm diameter) were utilized in a 2% volume fraction.
4. **Number of mesh layers:** For Aramid mesh, specimens reinforced with 2 and 6 layers of mesh were tested. For PVA mesh, specimens with only 2 layers of mesh were tested.

Table 1 Mechanical Properties of Reinforcing Meshes and Fibers

Properties	Aramid mesh	PVA mesh	Steel fiber	PVA fiber
Elastic modulus	45 GPa	NA	200 GPa	29 GPa
Tensile strength	2030 MPa bundle	NA	2000 MPa	900 MPa
Elong. at failure	4.5%	NA	NA	NA
Density	1.5 g/cc	1131.13 g/m2 (unit weight)	7.8 g/cc	1.3 g/cc

Material Properties

The same type of mortar was used for all tests. It consisted of ASTM Type III high early strength cement and a graded silica Ottawa sand, ASTM C778. The mix proportions in weight were: Cement = 1.0, Sand = 2.0, Water = 0.4 and Superplasticizer = 2.5%. A summary of the results of the compression strength of each mix is presented in Table 2.

Test Set-up and Instrumentation

Pin-loaded specimens were 12 inches long (304.8 mm), 5 inches wide (127 mm) and 0.5 inches thick (12.7 mm). The control specimens were 12 inches long (304.8 mm), 2 inches wide (50.8 mm) and 0.5 inches thick (12.7 mm). The reinforcing mesh was cut into the proper dimensions and slotted in the specimen molds of the pin-loaded specimens. Due to the special way the Aramid mesh is fabricated, it was cut so that the twisted fibers were perpendicular to the tensile force.

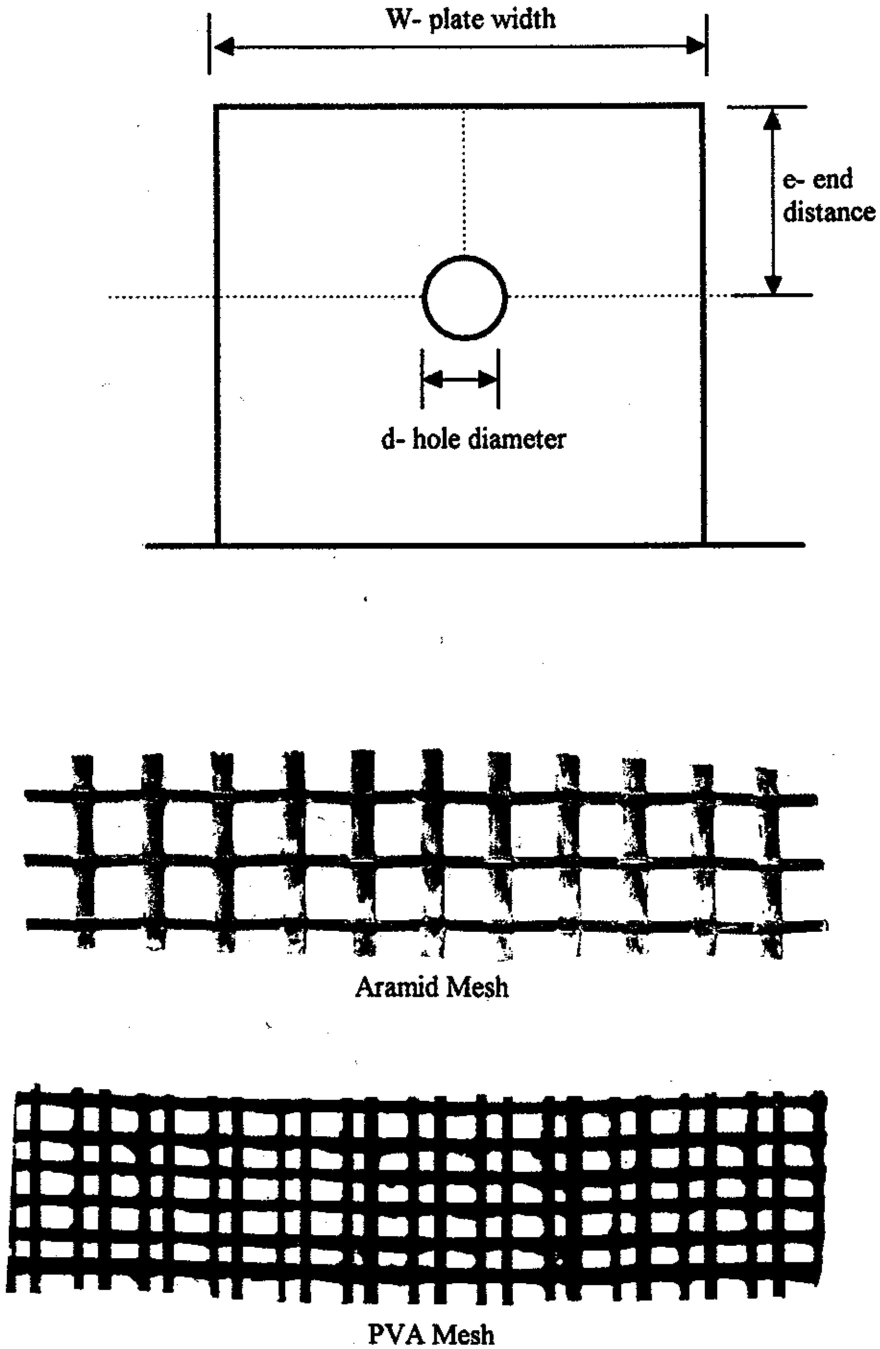

Fig. 1. Illustration of test parameters on shear joints.

Table 2 Characteristics of the Mix Used for Test Specimens

Mix	Type of specimen	Compressive strength psi (MPa)	Modulus of elasticity ksi (MPa)
A	2 layers of Aramid mesh	7300 (50.30)	4770 (3287)
B	2 layers of Aramid mesh 2% PVA fiber	7000 (48.23)	3927 (2708)
C	2 layers of PVA mesh 2%PVA fiber	7000 (48.23)	3927 (2708)
D	2 layers of Aramid mesh 2% steel fiber	8760 (60.36)	4560 (3142)
E	6 layers of Aramid mesh	7300 (50.30)	4770 (3287)

Note: The mortar properties were obtained by testing 3x6 inch cylinders. The average compressive strength was obtained at 21 days.

The meshes were located into vertical molds, close to both external surfaces of the specimen. The mortar was mixed in a Hobard type food mixer. Fibers were added as needed to the mortar before it was poured in the molds. A table vibrator was used during pouring of the mortar into the molds. All the specimens were removed from the molds 24 hours after pouring, and were moist cured for an average of 21 days (100% relative humidity). Prior to the tensile testing, 2.5 in. x 3 in. (63.5 mm x 76.2 mm) aluminum plates were glued to both sides of the control specimens. The plates were glued at the end portions of the specimens using a fast curing Epoxy adhesive. Finally, all specimens were painted with a lime solution for better observation of cracks during testing.

The set-up utilized to test the pin-loaded specimens under tension was meant to reproduce the behavior of a shear connection. The ferrocement plates were pin loaded in tension by two bolts (standard grade 2 Hex Cap Screws with a 0.5 in. (12.7 mm) diameter and 2.5 in. (63.5 mm) in length (Grade 2, 1/2 in., 2.5 in.) inserted in the holes. Both the bolt's shank and threaded portions had a length of 1.25 in. (31.75 mm). One of the bolts was fixed to the base of the testing machine while the other one was tied to its cross head, transferring the load to the specimen. This driving bolt was attached to steel plates that transferred the load from the grip. The grip was connected to the load cell and the actuator. All specimens were tested in an Instron machine, Model 4206, with a load cell capacity of 30 Kips in tension and compression; the specimens were tested under displacement control. The rate of loading was 0.01 in./min (0.254 mm/min).

The displacements of the pin-loaded specimens were measured by two LVDT's. One LVDT was attached to a fixture connected to the bolts, measuring the displacement between the bolts. The other LVDT was attached to a fixture attached directly to the plate. The displacement was measured along the mid portion of the plate (Fig. 2).

The control specimens were subjected to a direct tensile test. They were used to obtain the strength and deformation characteristics of the mesh for the different geometry utilized. The end portions of the plates were placed in the grips of the set-up. The test was carried out under displacement control. Displacements between the two grips of the set-up were measured by one LVDT.

TEST RESULTS AND INTERPRETATION

Control Specimens

A total of ten control specimens was tested to failure under direct tension. The number of specimens for each particular mix, the average ultimate strength, and the total volume fraction of

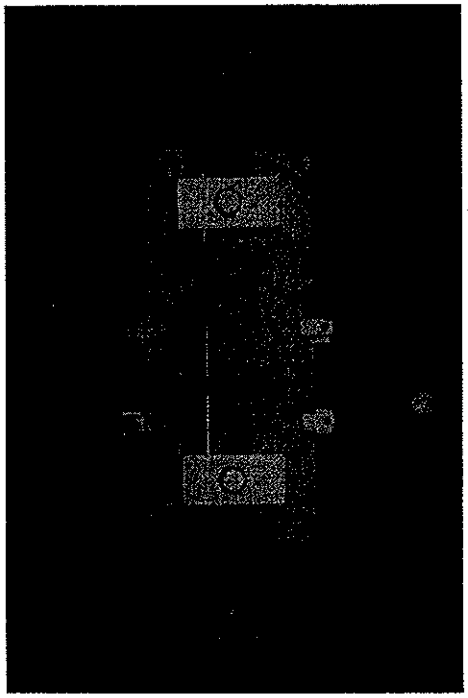

Fig. 2. Photograph of set-up of pin-loaded plates.

fiber V_f (mesh + fibers) are summarized in Table 3. Composite stress is defined as the load over the net area of the specimen for pin-loaded specimens or gross area for the control specimens. Strains are defined as the displacement of the LVDT over the net length between the grips of the setup. (Composite stress vs. strain curves of the control specimens are shown in Fig. 6).

Table 3 Composite Stress and Strain of Control Specimens

Mix	Volume fraction (V_f %) Vf_{mesh}	Vf_{fiber}	Vf_{tot}	Ultimate strength (lbs)	Displ. at ultimate (in)	Displ. at failure (in)	Max. stress (psi) (MPa)	Strain at ultimate (in/in)
2 Aramid	1.46	-	1.46	678	0.2138	0.2138	775 5.34	0.0276
2 Aramid 2%PVA	1.46	2	3.46	694	0.13	0.181	793 5.47	0.0234
2 Aramid 2% Steel	1.46	2	3.46	1016	0.1333	0.16	1161 8.00	0.0206
2 PVA 2%PVA	1.35	2	3.35	1065	0.1985	0.205	1217 8.40	0.0265
6 Aramid	4.38	-	4.38	1332	0.34818	More than 0.4	1522 10.50	>0.0516

For the specimens with Aramid mesh, it was observed that the ultimate strength was total volume of reinforcement. Moreover the mesh was more effective than the fiber. This change was more significant for an increase in the number of layers (6) than for a greater volume of fibers. The maximum strength was exhibited by the specimen with 6 layers of Aramid mesh (1332 lb.); this value represents almost twice the value of the specimen with 2 layers of Aramid mesh. Specimens with 2% steel fiber show a higher value of ultimate strength (1016 lb.) than specimens with 2% PVA fiber (694 lb.) but also a less ductile post-pick behavior.

Comparing strength and volume of reinforcement ratios showed that among the specimens with 2 layers of mesh and 2% fibers, the specimen with 2 layers of PVA and 2% PVA fiber had the most efficient reinforcement with a value of 318 lb./V_f. By comparison, the specimen with 6 layers of Aramid mesh had a value of 304 lb./V_f. This specimen also had the highest ultimate strength.

The presence of steel fiber led to a stiffer behavior of the specimen on the initial portion of the load-deformation curve. Among all the control specimens, the specimen with steel fibers had the highest value of modulus of elasticity.

Pin-loaded Specimens

Failure Modes

Eighteen pin-loaded ferrocement plates were tested under tension. Values of composite stress and strain are presented in Table 4. Among the pin-loaded ferrocement plates tested, different failure modes based on three fundamental failure modes were observed:

1. **Cleavage failure**: fracture of the plate along the section ahead of the bolt. A major crack, parallel to the plate in the longitudinal direction, extended from the hole to the plate edge.
2. **Tensile failure**: tensile failure along the net section of the plate.
3. **Bearing failure**: compressive crushing of the ferrocement material ahead of the hole. It was accompanied by spalling of the mortar in the vicinity of the hole and buckling of the outermost mesh layers.

Table 4 Composite Stress and Normalized Bolt Displacement of Pin-loaded Plates

Mix	Vf	Pin-loaded specimen *e/d=4*				Pin-loaded specimen *e/d=6*			
	(%)	Max. stress (psi) (MPa)	Bolt displ. at failure (in) (mm)	Stress/Vf (psi/% vf) MPa/%vf	Strain (in/in)	Max. stress (psi) (MPa)	Bolt displ. at failure (in) (mm)	Stress/Vf (psi/% vf) MPa/%vf	Strain (in/in)
2 Aramid	1.46	498 2.23	0.1643 4.17	341 1.41	0.0205	668 3.00	0.1634 4.15	458 2.05	0.0272
2 Aramid 2% PVA	3.46	801 3.59	0.1393 3.54	234 1.05	0.0174	971 4.35	0.13802 3.51	283 1.27	0.0230
2 PVA 2% PVA	3.35	410 1.84	0.08464 2.15	122 0.55	0.0106	688 3.08	0.09397 2.39	205 0.92	0.0157
2Aramid 2% Steel	3.46	NA	NA	NA	NA	1340 6.00	0.09071 2.30	390 1.75	0.0151
6 Aramid	4.38	910 4.08	0.12302 3.12	208 0.93	0.0154	1124 5.04	0.11333 2.88	257 1.15	0.0189

A combination of these basic failure modes was observed in specimens with fibers as shown in Fig. 3.

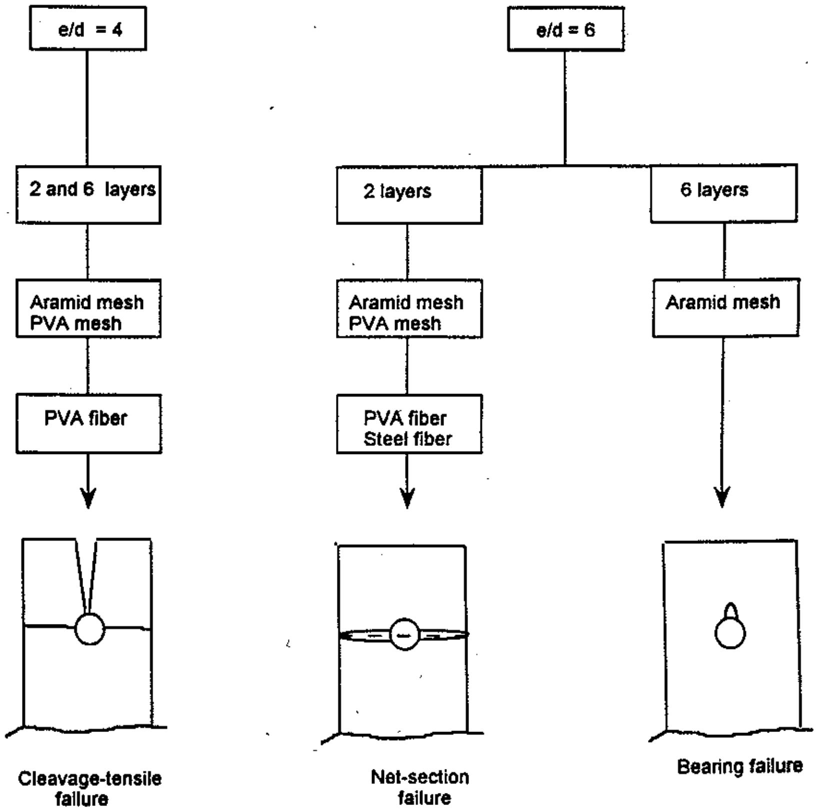

Fig. 3. Observed failure modes in FRP ferrocement shear joints.

For all the specimens with e/d=4, the dominant failure mode was cleavage with some tensile cracks. This failure mode was indifferent to the volume of reinforcement or number of layers. Some differences in the distribution pattern of the cracks and the sequence of their development were observed for each type of specimen.

For specimens with 2 layers of Aramid mesh, an initial crack developed between one of the bolts, parallel to the loading direction. This crack continued to the edge of the plate with an increase in the load. The same type of crack developed from the opposite hole a few seconds later. For the specimens with 2 layers of Aramid and fibers (steel and PVA), more radial cracks developed around the holes. It was also observed that the spacing between tensile cracks in the middle section of the specimen diminished and more cracks developed. The specimens with 2 layers of PVA mesh and 2% PVA fiber also had a cleavage type of failure but did not develop tensile cracks. For the specimen with 6 layers of Aramid mesh, the failure mode was primarily cleavage without visible tensile cracks on the sides of the holes around the net section of the specimen (Fig. 4).

For specimens with e/d=6, two major failure modes were present: a tensile failure and a bearing failure.

The tensile failure occurred in the specimens with 2 layers of mesh (Aramid and PVA) and fibers (PVA and steel). For specimens with only 2 layers of Aramid, a major crack developed from the hole along the net section. Secondary cracks in the mid section of the specimen also developed but their thickness was on the order of 0.05 mm whereas the main crack continued to open until the specimen attained the final load carrying capacity. For specimens with 2 layers of Aramid and 2% PVA fiber, the effect of the fibers was remarkable. A larger number of multiple cracks was present all along the length of the specimen and also in a radial direction from the hole to the edges. The specimens with 2 layers of Aramid mesh and 2% steel fiber did not develop this multiple crack pattern. A clear tensile failure was observed on the sides of the holes. Specimens with 2 layers of PVA mesh and 2% PVA fiber developed a main crack along the net section of one of the bolts and a few tensile cracks in the mid-section of the specimen (Fig. 5).

Finally, the specimens with 6 layers of Aramid mesh had a failure mode corresponding to crushing of the mortar ahead of the bolt. This bearing failure mode was well defined. No visible cracks were observed in other parts of the specimen.

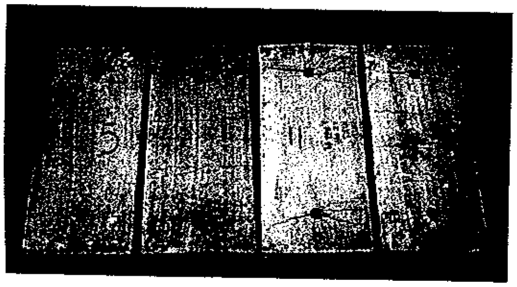

Fig. 4. Photograph of specimens with *e/d*=4. From left to right: 6 layers of Aramid mesh, 2 layers of Aramid mesh with 2% PVA fiber, 2 layers of PVA mesh with 2% PVA fiber, and 2 layers of Aramid mesh.

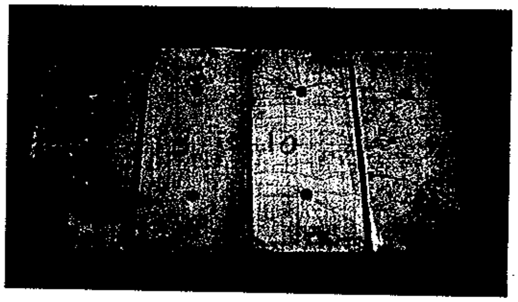

Fig. 5. Photograph of specimens with *e/d*=6. From left to right: 2 layers of Aramid mesh and 2% steel fiber, 6 layers of Aramid mesh, 2 layers of Aramid mesh with 2% PVA fiber, and 2 layers of Aramid mesh.

Effect of Ratio *e/d*

For all the specimens tested, the increase from *e/d*=4 to *e/d*=6 changed the failure mode (from one of pure cleavage or cleavage with some tensile cracks, to one of tensile net section, or bearing, or a combined failure mode). This change in failure mode accompanied a change in the ultimate strength and in the load-displacement response.

As was previously stated, a change in failure mode is directly related to a change in the ratio *e/d*. It was observed that an increase from *e/d*=4 to *e/d*=6 changed the failure mode from one of cleavage-tensile to one of tensile net-section or bearing failure. Also, a change in failure mode implied a change in the ultimate strength and in the load-displacement response.

An increase in the *e/d* ratio caused an increase in the ultimate strength in all of the specimens tested. The percentage of strength increase changed with each specimen and can be related to the total volume of reinforcement of each one. For specimens with 2 layers of Aramid mesh, the change in *e/d* ratio from 4 to 6 resulted in a 35% increase in strength, while for 6 layers the increase was 23%. For the specimens with 2 layers of Aramid mesh and 2% PVA fiber, the change in *e/d* ratio from 4 to 6 resulted in a 21% increase in strength. Specimens with 2 layers of PVA mesh and 2% PVA fiber showed the most significant increase in strength, 68%, for a change in *e/d* ratio from 4 to 6.

To analyze the effect of e/d in the load-deformation response, a normalized bolt displacement was used. The normalized displacement was defined as the total measured displacement of the driving bolt divided by the initial distance between bolts. Because the range of load-displacement data was not the same for all the curves, the normalized displacement at failure was calculated as the one corresponding to the ultimate strength of the specimen.

For specimens with 2 layers of Aramid mesh, the increase in the ratio e/d changed the failure mode from cleavage-tensile to tensile and also caused an increase in the normalized bolt displacement at failure. However, for specimens with 6 layers of Aramid, for which bearing failure occurred, there were no significant differences in the normalized displacement at failure (the same behavior was observed by Hammoud H. [2] with steel meshes).

For specimens with fibers, 2 layers of Aramid and 2% PVA fiber the increase in the normalized bolt displacement was of the same order as the specimen with 2 layers of Aramid mesh (Table 4).

For specimens with 2 layers of PVA and 2% PVA fibers, the normalized displacement at failure is not well defined, but it seems to follow the same behavior as the specimen with 2 layers of Aramid mesh. Figs. 8 and 9 show the stress-normalized displacement curve for pin-loaded specimens with e/d=4 and e/d=6.

Effect of the Volume of Reinforcement

The total volume of reinforcement (defined as the sum of the volume given by the number of layers plus the volume of fibers in the mix) was the most important factor affecting the strength, failure mode and deformation.

First, for all types of mesh and fibers, an increase in the total volume of reinforcement increased the ultimate strength of the specimen tested (Table 4).

For specimens with e/d=4, an increase in the volume of reinforcement, either by addition of layers of mesh or by addition of fibers, increased the ultimate strength of the specimen with no modification of the failure mode. However, for the specimens with 2 layers of PVA mesh and 2% PVA fiber, the ultimate strength was smaller than the specimens with only 2 layers of Aramid mesh. This result may be due to the premature failure of the PVA mesh.

For specimens with e/d=6, the increase in volume of reinforcement affected both the strength and the failure mode. For specimens with only layers of mesh, an increase in the number of layers from 2 to 6 caused a change in the failure mode from tensile to bearing (crushing). For specimens with mesh of reinforcement and fibers, the failure mode was by tensile net-section failure.

For specimens with e/d=4, the strength per layer of mesh for specimens with 2 layers of Aramid mesh had a higher value (560 lb./ layer of mesh) than the one for the specimen with 6 layers of Aramid mesh (341 lb. / layer of mesh). This result showed that Aramid mesh was more effective per layer when the specimen only has 2 layers of mesh. This result was predicted intuitively when it was decided to try combinations of 2 layers of reinforcement and addition to different types of fibers in the matrix.

To calculate the stress per unit volume of reinforcement for specimens with layers of mesh and fibers, the ultimate stress of the specimen was divided by the total volume of reinforcement. These values suggested that the specimens with only 2 layers of Aramid fiber had the highest stress per volume of reinforcement. A more precise model must be defined to make a valid comparison among the specimens.

What can be analyzed is the stress of the specimens with 2% fibers and 2 layers of mesh, because the volume of reinforcement for all the specimens falls within a narrow range. Specimens with 2 layers of PVA mesh and 2% PVA fiber had the lowest ratio for both e/d=4 and e/d=6

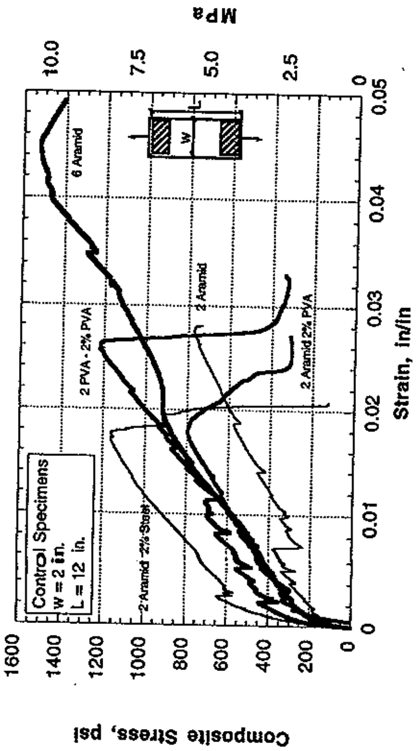

Fig. 6. Composite tensile stress-strain curves for control specimens.

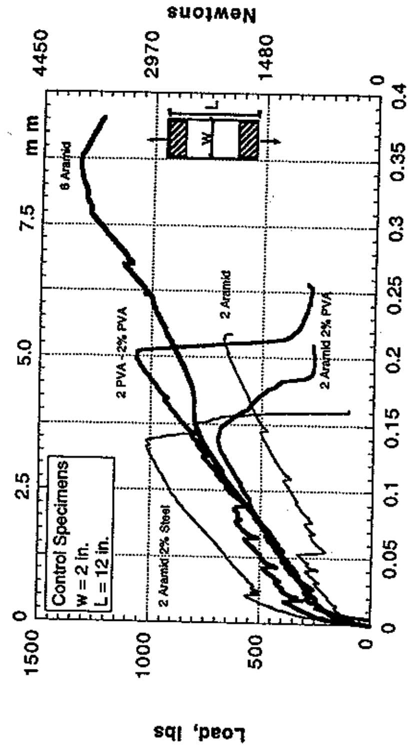

Fig. 7. Load-deformation curves for control specimens.

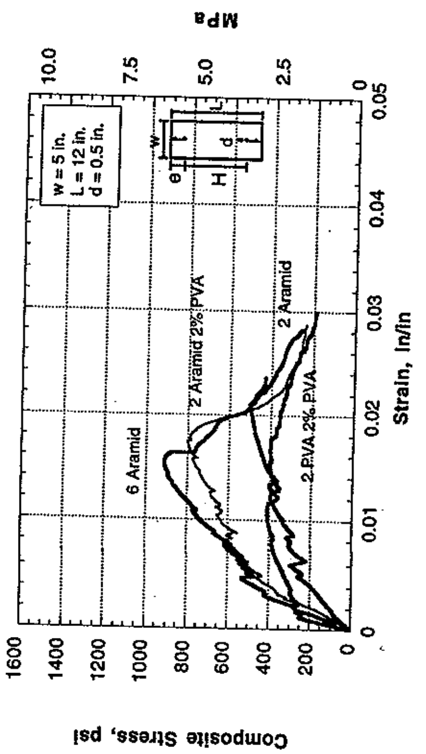

Fig. 8. Composite tensile stress-strain curves for pin-loaded plates with $e/d=4$.

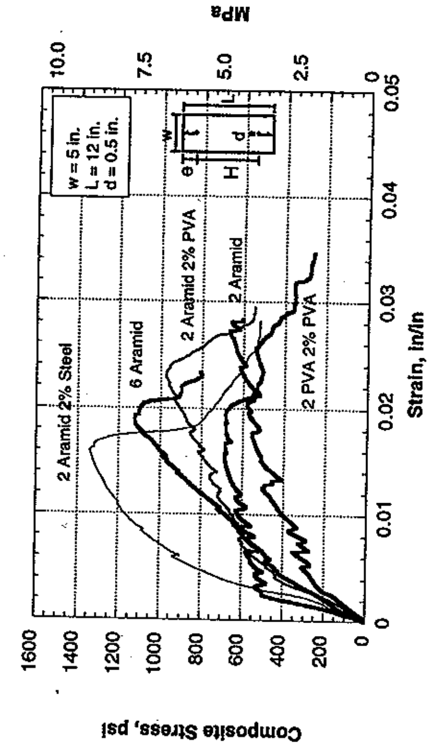

Fig. 9. Composite tensile stress-strain curves for pin-loaded plates with $e/d=6$.

configurations, suggesting that this type of combination is the least efficient. Specimens with 2 layers of Aramid mesh and 2% PVA fiber performed better. This may confirm the assumption that the configuration of the PVA mesh is not appropriate for shear joints..

For specimens with e/d=6, all specimens with 2 layers of mesh and 2% fiber showed a net-section failure. In the case of specimens with e/d=4 , the values of stress/volume of reinforcement were different for every case.

A similar explanation for a more refined model can also be suggested. It can be said that the difference in the values is due to a change in the failure mode. As we saw for the specimens with e/d=4, for 2 layers of mesh and 2% volume of fiber, the specimens with 2 layers of Aramid and 2% steel fiber showed the highest value, giving the most efficient combination of 2 layers of mesh and fibers. Poor performance of the specimens with 2 layers of PVA mesh and PVA fiber was also observed. As stated previously, a new configuration of the PVA mesh may lead to a better performance of the pin-loaded specimens.

As stated before, the specimen with 6 layers of Aramid mesh was the only one that led a bearing failure mode. However, comparing the stresses per volume of reinforcement with the value obtained by the specimen with 2 layers of Aramid mesh, it can be concluded that the contribution per layer decreases with an increase in the number of layers. This fact suggests that the reinforcement is working ineffectively to resist the bearing failure mode.

Comparison with Control Specimens

Comparing results obtained from testing control and pin-loaded specimens is important for obtaining relevant information regarding the deformation characteristics and strength predictions for the pin-loaded specimens.

Since the dimensions of the pin-loaded specimens were different from those of the control specimen, they were compared on the basis of composites stress and average strains. Plots of composite stress vs. average strain are shown in Figs 6-9.

As a first observation, control specimens showed a stiffer behavior than the pin-loaded plates. This behavior is represented by the slope of the curves in its initial linear range. The pin-loaded specimens showed a more flexible behavior. For the case of the specimen with 2 layers of Aramid mesh and 2% steel fiber, the increase in stiffness was due to the presence of the steel fibers. On the other hand a non ductile post pick behavior was observed for the control specimens, whereas for the pin-loaded plates, the post pick behavior was more ductile. The same change in post pick behavior was also observed for specimens with 2 layers of PVA mesh and 2% PVA fiber.

It can be concluded that the post pick behavior for the control specimens will be dominated by the pullout of the fibers for specimens with mesh and fibers, or by the tensile failure of the mesh for specimens with only layers of mesh. For the pin-loaded specimens, strains in the area around the bolts and between the bolts and the edge of the plate may influence the response of the specimen, causing a more ductile post pick behavior. The post pick behavior also may be influenced by the effective volume of reinforcement working at this stage, which may explain why the specimen with PVA mesh did not perform as well as the control specimens.

For control specimens, the total volume of reinforcement was directly related to high stress, with a more efficient relation stress/volume of reinforcement for the specimen with 2 layers of PVA mesh and 2% PVA fiber among the specimens with fibers.

For the pin-loaded specimens, the contribution of the fiber in the specimens with Aramid mesh was important, giving a higher stress than for control specimen. The most efficient stress per volume of reinforcement ratio was given by the specimen with 2% steel fiber.

In both cases, the ratio of stress per volume of reinforcement was significantly lower for specimens with 6 layers of Aramid mesh than those with 2 layers. This value was surpassed by the specimens with layers of PVA mesh and 2% PVA fiber for the control specimens, and for 2 layers of Aramid and 2% PVA fiber for the pin-loaded specimens (Table 3 and 4).

Specimens with failure mode corresponding to a net section failure (e/d=6) showed an interesting behavior. For only 2 layers of Aramid mesh, the differences in values between the ultimate stress for the control specimens and for the pin-loaded specimens was 16%. For all the specimens with meshes and fibers, the ultimate strength was increased by the addition of fibers. This was also supported by the presence of radial cracks running between the bolt and the edges of the plate. Specimens with layers of Aramid mesh and fibers, showed a good correlation between the effective load carried and the volume of reinforcement. The difference between the stress given by the control specimens and that given by the pin-loaded specimens for this case was 13%-20%.

For cleavage failure, a comparison can be made by computing the stress (obtained by taking the failure load and dividing it by the cleavage section.) These differences, which range from 0.17 to 0.30 indicated a strong relationship between the applied load and the resistance along the cleavage section.

It can be concluded that to predict the behavior of the pin-loaded specimens, an analytical model should be formulated which considers the influence of the fibers in the post cracking stage of the specimen.

CONCLUSIONS

1. Three types of failure were observed in pin-loaded ferrocement plates reinforced with FRP meshes: a cleavage failure ahead of the bolt initiated by some tensile cracks along the net-section width (cleavage-tensile), a well defined tensile failure along the net-section width, and crushing (bearing failure) of the ferrocement plate in the vicinity of the hole.
2. For ratios of end distance to hole diameter with a value of 4 (e/d=4), the cleavage-tensile failure mode occurred for all the pin-loaded specimens, indifferent of the type of FRP mesh used for reinforcement. We can conclude that this failure mode was related to the geometry and is indifferent to the type and total amount of reinforcement.
3. For e/d ratios equal to 6, the failure mode changed from cleavage-tensile to net-section for specimens reinforced with 2 layers of mesh and with 2 layers of mesh plus fibers. This change in failure mode also involved an increase in the ultimate strength value of 20%.
4. The only specimen that exhibited a bearing failure was the specimen with 6 layers of Aramid mesh.
5. In both control and pin-loaded specimens, an increase in the volume of reinforcement (either by increasing the number of FRP meshes or by addition of fibers) led to a direct increase in the ultimate strength of the specimen. However, for control specimens the increase in the number of layers of FRP mesh was more significant than the addition of a volume of fibers to the matrix.
6. In terms of composite stresses, it was observed that the amount of fibers in pin-loaded specimens with Aramid mesh improved the behavior of the shear joint. Higher values of maximum stress than for tensile control specimens were obtained. The most efficient stress per volume of reinforcement ratio was given by the specimen with 2 layers of Aramid mesh and 2% steel fiber.
7. For the net section failure mode, a good correlation was observed between the ultimate capacity of the specimens with only layers of mesh as reinforcement and the ultimate stress capacity of the control specimen.

8. In general, the increase in the *e/d* ratio also increased the normalized bolt displacement at failure.
9. In general, the control specimens showed a stiffer behavior than the pin-loaded ferrocement plates during the elastic portion of the load-deformation curve.
10. The PVA mesh used in this experimental program had its longitudinal and transverse fibers "glued" together like a weld. It seems that changing the mesh configuration such as twisting (linen fabric) will lead to a better behavior.

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