Some properties of mesh reinforced cement slurry

Dr. Mohamed Raouf Abdul Kadir (Prof.)
Faculty of Engineering – University of Sulaimani
raoufkadir@hotmail.com

Dr. Atta Shekh. Karim (Lecturer)
Faculty of Engineering-University of Sulaimani
ferro140@ymail.com

Abstract— **Some properties of cement-slurry strengthened with meshes was investigated. Eighteen simply-supported laminated beam like specimens (500x100x20mm in dimensions) were tested under point load at mid-span. Thirty six prisms and fifty four cubes were tested to conduct rupture and compressive strength of specimens respectively. The variables were type and number of mesh. Two type of meshes were used, galvanized and plastic. Performance was gauged in terms of cracking characteristics, mid-span deflection, stiffness, and ultimate load capacity. The experimental results showed that increasing volume fraction of meshes improved serviceability and flexural strength capacities. Plastic meshes had significant effect on deflection and stiffness more than galvanized meshes.**

Keywords: Mesh; Reinforcement; Slurry; Compressive and Flexural strength; Stiffness; Strength/weight ratio.

Introduction:

Cement slurry is one of the important composites which have interested investigators to have more information about its response to loads. Researchers reinforced this brittle material by some type of fibers to improve its properties and evaluating test results of bending, shear, cracks, and toughness….etc. The use of fiber-reinforced cement composite (FRCCs) to enhance the performance of structural elements has been the subject of many research projects during the past few decade. [1, 2, 3]

In general fiber-reinforced cement composites (FRCCs) are effective in improving structural behavior of members under vertical loads, as well as in increasing shear resistance, ductility, and many other properties. Different type of steel, polymeric, glass, carbon fibers have been used to reinforce cement-slurry. Each type behave in a different manner. [4]

Also the application of materials with large fiber volume fraction, however, was very limited due to the tremendous difficulty in material mixing and casting, and thus the structural engineers have been basically restricted to using regular (FRCCs). Therefore a procedure has been introduced where a high percentage of fibers up to 20% may be added. The fibers are dispersed then a cement slurry is added, this is called (SIFCON), [4] the composite exhibits high strength and ductility.

Researchers have made tests also on a new high-performance fiber reinforced concrete called slurry infiltrated mat concrete (SIMCON) which is made by first placing continuous stainless steel fiber mats into the form and then infiltrating the dense fiber network with a cement-based slurry. [5] (SIMCON) with very high fiber aspect ratio exhibits a high increase in strength, toughness and crack control, reaching tensile strengths of up to 17MPa at strains of up to 1.5 percent with only 5-29 percent fiber volume fraction. Also, using fiber-mats in cement slurry decreases construction related shortcoming. [6]

The use of mats rather than discrete fibers increases flexural strength. Stainless steel or other alloys can be used for the mats where high corrosion resistance or high strength are required. [7]

The main objective of this research is to show the strength and behavior of cement paste reinforced with meshes. This type of lamination units may be used in retrofitting of buildings, covering the walls and also as a form to cast reinforced concrete structures.

Research significance:

In this work two types and different weight fractions of wire meshes are added to the cement slurry to produce new reinforced composites for the first time in order to determine the effect of different type of meshes on the properties of the composites. Compressive strength, flexural, crack patterns, stiffness and modulus of rupture for these composites are investigated.

Experimental program:

Eighteen rectangular cement slurry specimens were tested for flexural strength, the specimens had the same dimensions 500mm×100mm×20mm and different in type and volume fraction of wire mesh. Whereas fifty four cubes and thirty six prisms were cast to predict the compressive strength and modulus of rupture of the reinforced cement paste, respectively.

The details of the specimens are shown in table (1). The capital letters refer to the material of wire mesh, the subscript letters refer to the opening type of mesh, while the last letter refers to the percentage content of wire. The same designation is applied to classify the tested cubes and flexural prisms.

Table 1: Specimens designation and properties

Groups	Specimens Designation	Wire Mesh Detail		
		Mesh type	*Weight fraction*	*Detail*
A	Ssa	Galvanized	8.15%	Galvanized type with square opening
	Ssb		16.30%	
B	Sha		8.15%	Galvanized type with hexagonal opening
	Shb		16.30%	
C	Psa	Plastic	8.15%	Plastic type with square opening
	Pb		8.15%	

Materials:

The first type of reinforcement added to the cement slurry was hexagonal galvanized steel wire mesh, the equivalent diameter was 0.5mm smooth wire. The second type of galvanized steel mesh was squared with small and large openings, whereas two different types of plastic meshes were used with the same percentage content. The matrix was mixed to yield a good flowability. With water cement ratio for all mixes, 0.45.

Cement:

The cement used was of Portland Cement Type -I-obtained from local market in sacks covered with plastic protective covers to prevent prehydration .The fineness modulus was 12.5gm/cm^2.

Wire mesh reinforcement:

Five types of wire meshes were used, hexagonal galvanized woven, square opening galvanized both of 0.5mm equivalent diameter, square opening galvanized, and square opening plastic of 0.1mm equivalent diameter with two various openings. The first one square plastic with small openings 100/cm^2 and the second with larger openings 4/cm^2 were taken from local market as shown in Fig (1).

Lamination process:

The specimens casting consisted of separate sequential layers of cement slurry matrix followed by required mesh layers calculated as a weight fraction of the cement paste, then covered with another layer of slurry. This procedure was repeated up to finished surface layer of specimens. The amount of mesh was measured as a percentage of cement content by weight. (0.0%, 8.15%, and 16.30%).

Casting and curing:

The steel mould was oiled and placed on a table. After the first layer of cement slurry was cast, the prepared mesh layers were held in position and straightened by hand inside the mold. The specimens were cast in adequate layers, and each layer compacted by hand using Tampers according to ASTM C384-02[11] until no further air bubbles appeared on the surface. The specimens were demoulded after 24 hours and immersed in water for 28days of curing.

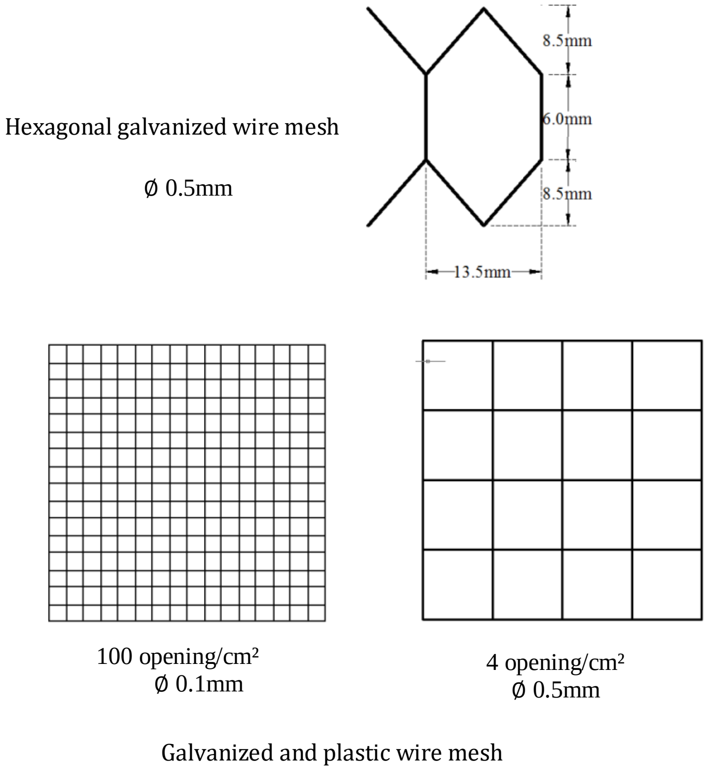


Fig.1 Details of wire meshes

The same procedure was repeated for cubes and prisms, casting by adding layers of cement slurry followed by mesh layers.

The specimens were demolded carefully after 24 hours and cured in water ponds, they were tested at the end of 28 days for respective strength properties.

Preparing cubes and prisms:

Cubes of (50mm×50mm×50mm) to determinate the value of compressive strength were cast. The specimens of standard sizes were cast containing the lamination matrixes cement slurry and wire meshes. Prisms of (40x40×160mm in dimensions) were cast with each serial to establish the modulus of rupture of the specimens.

Casting and curing:

The steel mould was oiled and placed on a table. After the first layer of cement slurry was cast, the prepared mesh layers were held in position and straightened by hand inside the mold. The beams and cubes were cast in adequate layers, and each layer compacted by hand using Tampers according to ASTM C384-02[11] until no further air bubbles appeared on the surface.

The specimens were demoulded after 24 hours and immersed in water for 28days of curing.

Preparation for testing:
The specimens were prepared for testing; flexural strength, compressive strength, and modulus of rupture according to the following procedure:

The specimens were dried using a piece of cloth to get a saturated surface dry condition and weighted in this condition. Then they were transferred to a fan drying oven, to get oven-dry condition for 2 hours at 70°C, thus the amount of moisture content was determined. The specimens were left to cool down in room temperature 28°C for 3 hours. After that the specimens were tested for their related properties and strength.

Strength test:
Bending test instrumentation:
A general view of the test set-up is shown in plate (1), the testing frame facilitated bending through a self-balance loading frame. The transverse load arrangement for the loading case was available in structural engineering laboratory. The transverse load was applied through a hydraulic jack 20 kN capacity hung from the top girder of the loading frame. The jack transferred the load through a steel bar of Ø10mm as a load spreader.
Each specimen was tested to failure by applying loads by hand in a series of increments. It took about one minute to increase each load increment, after which, it was held constant, while deflections, were measured and cracks marked. The vertical deflection was measured at the center of the specimens through mechanical dial gauge of 0.01mm divisions fixed to the base of the specimens directly near the point load through steel hangers.
The holding period after each increment varied from 2 to 5 minutes. Smaller increments of load were used as failure loads were approached. Usually 10-20 increments were used to failure and the entire test for each specimen took about 2 hours. Photographs of the crack patterns and failure of specimens were taken at the end of each test.

Compressive strength:
Cubes with meshes tested to determine the compressive strength of reinforced cement slurry specimens using an electrical compression machine. The ultimate compressive strength (f'c) results are shown in table (2).

Rupture test:
To determine the flexural strength of mesh reinforced cement slurry, simple prisms of (160X40X40mm) in dimensions) with central-point loading was used under the same testing frame, same as flexure test of the strip specimens.
The results of rupture tests are also shown in table (2).

Measurement of ductility:
The ductility index of each specimen (defined in this work as the ratio of deflection at ultimate load to the deflection at yielding load) is calculated and presented in the same table (2).

Plate 1: Loading frame instrumentation

Table 2: Properties of cement slurry specimens

Series	Density (kg/m^3)		Flexural strength (MPa)			Compressive strength (MPa)			Ductility index (δu / δy)
	Control	*With mesh*	*Control*	*With mesh*	*% Increase compared to control*	*Control*	*With mesh*	*% Increase compared to control*	
Ssa	1722	2150	6.73	11.76	42.77	22.33	42.67	47.67	2.32
Ssb	1787	2210	6.54	12.99	49.65	22.69	48.00	52.73	2.00
Sha	1711	1830	6.82	12.74	46.47	19.8	49.73	60.18	2.60
Shb	1725	1830	7.03	11.98	41.31	21.87	56.63	61.38	3.27
Psa	1743	2140	6.92	11.15	37.94	20.72	44.93	53.88	1.60
Psb	1758	2230	6.85	12.83	46.61	22.15	27.60	19.75	5.46

Test results and discussions:

Deformation and ductility characteristics:

Results of stiffness calculated as (Load / deflection) of the linear part of (p /Δ) curves are shown in (table 3 and Fig. 2).

As the number of steel wire mesh layers were increased the initial elastic stiffness of the specimens were increased, ranging from 7.43% to 40.38% while the crack patterns were more numerous and less extensive with a good margin between first crack and ultimate. This is due to the extra bond between the matrix and wire reinforcements, also cracking of the slurry layer results in a redistribution of the internal forces and increases the axial force in each layer.

The specific weight of the specimens were increased as the mesh content increased, meanwhile the cracking load capacities were increased as the number of wire meshes increased leading to increase in strength / weight ratio ranging from 742.15 to 2944.92 as shown in Fig.3. Specimens with large openings plastic mesh had more ductility than other specimens even they contained of half percentage or volume fraction of wire mesh. As a result of more ductility of this type of plastic mesh, larger deflection of the specimens were observed. The large deflection and cracking might give sufficient warning before failure. The ductile behavior is likely caused by cracking in the connections between the plastic wires and the cement paste that leads to a gradual loss of matrix action and hence larger deflection.

Effect of type of mesh:

The specimens with plastic mesh had more than one crack starting from the location of the applied load and cracks were at both sides of point load location. More cracks were observed in the specimens with large openings plastic wire meshes. (See plates 2 and 3). Other specimens had a single crack at the center with sudden failure and no other cracks observed at the bottom. Some specimens with steel meshes did not split at failure load, whereas all specimens with plastic wires spilt in to two pieces at failure load (see plate 4).

Cracks were observed by naked eyes, so microscopic cracks may have occurred in the specimens with unique crack, as the tensile strength of the matrix reached. The stress in the matrix in between any two consecutive cracks cannot increase above its tensile strength (The distance is too short to allow additional load transfer by bond). Due to more elastic behavior of the plastic meshes, the specimens did not reach crack saturation state with early loadings and more than single crack observed at their surfaces.

Cube compressive strength was increased by increasing mesh percentage to for all type of meshes. The increase ranged from 26.81% for cubes with plastic meshes and up to 60.62% for cubes with steel meshes, as shown in Fig.4. Cubes with plastic meshes had a cone type failure mode with a huge edge crush without cutting the mesh wires (see plate 5). Whereas cubes with steel meshes reached the failure compression load with little crushing (see plate 6).

Table 3: Failure test results and stiffness of specimens

Series	Load (N)	Weight (N)	Strength ----------- weight	Stiffness (kN/mm)
Ssa	8750	5.40	1620.37	8.75
Ssb	11000	5.65	1946.90	16.42
Sha	6800	5.70	1192.98	3.48
Shb	4067	5.48	742.15	5.23
Psa	15667	5.32	2944.92	8.56
Psb	13900	5.67	2451.50	13.79

The prism test showed that flexural strength was increased from 47.44% to 56.35% for prisms with plastic and steel meshes respectively, as shown in Fig. 5. Tests for flexural prisms showed that some steel meshes remained after rupture load but prisms with plastic meshes were cut into two pieces suddenly when the specimen reached failure. Cracks happened under point load for all types of meshes and propagated upwards (see plate 7).

When the applied load increased, the stress in the wire meshes increased and slip occurs between the reinforcement and the matrix. Due to the more frictional bond between plastic wires and matrix, they characterized as a unit in case of steel mesh even wires elongated without rupture.

Conclusion:

The structural behavior of cement – slurry was improved with mesh reinforcing. The following conclusions can be drawn:

1- Two types of damage were observed on the reinforced cement - slurry specimen's namely flexural cracks and paste spalling.

2- Ductility of reinforced cement-slurry with galvanized mesh improved for specimen with small square openings.

3- The higher volume fraction of plastic mesh resulted in more severe visible cracking on the cement-slurry specimens.

4- Most specimens with galvanized meshes showed more strength than plastic mesh of same volume percentage.

5- Sudden failure was observed for specimens with galvanized steel wire mesh, whereas the failure were more gradual and ductile for specimens with plastic wire mesh.

6-Under compression load, the cubes with plastic meshes exhibited more cracks and mortar crushing than the cubes with steel meshes which showed only cracking.

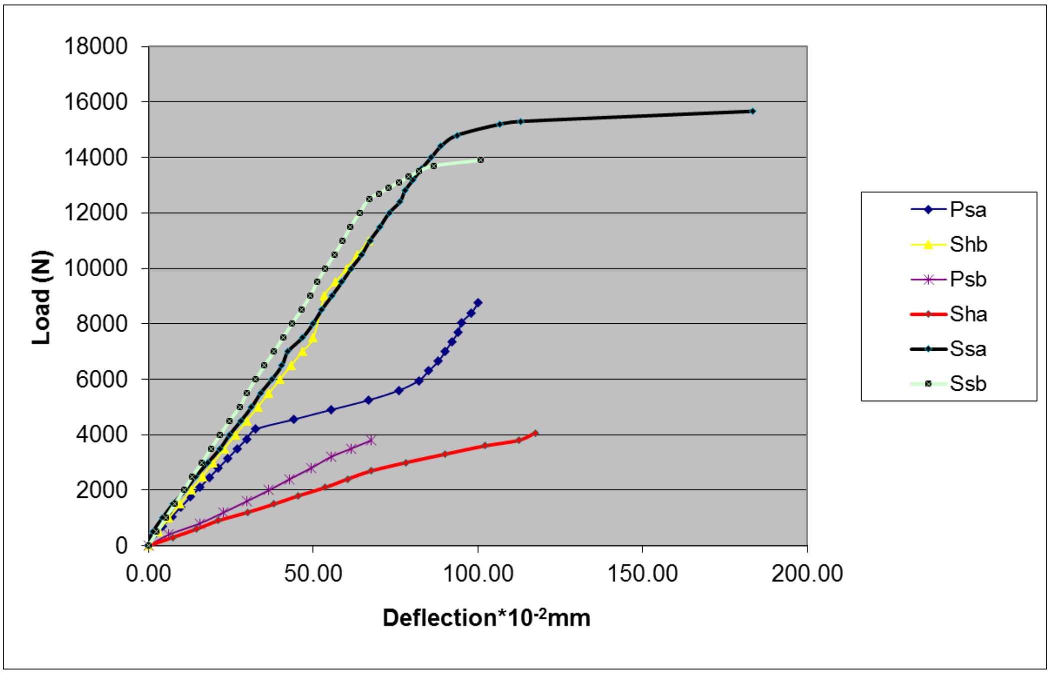


Fig.2 Load-deflection diagram for series

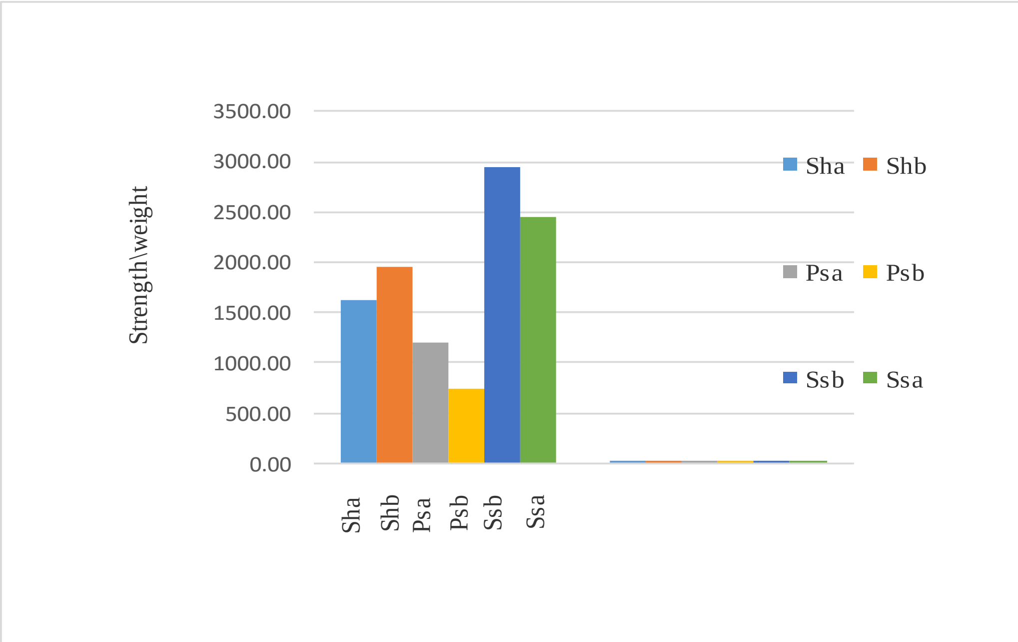


Fig.3 Strength / weight ratio for series

Plate: 2 Failure mode of Psa specimen

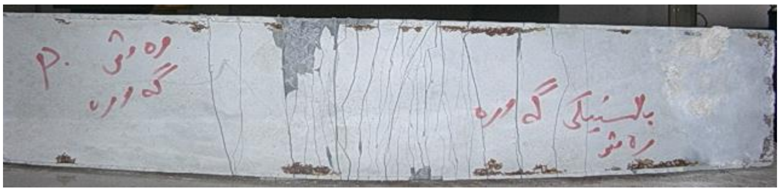


Plate: 3 Crack pattern of Psa specimen

Plate: 4 Failure mode of specimens

Plate 5: Failure mode of cubes with plastic mesh

Plate 6: Failure mode of cubes with galvanized mesh

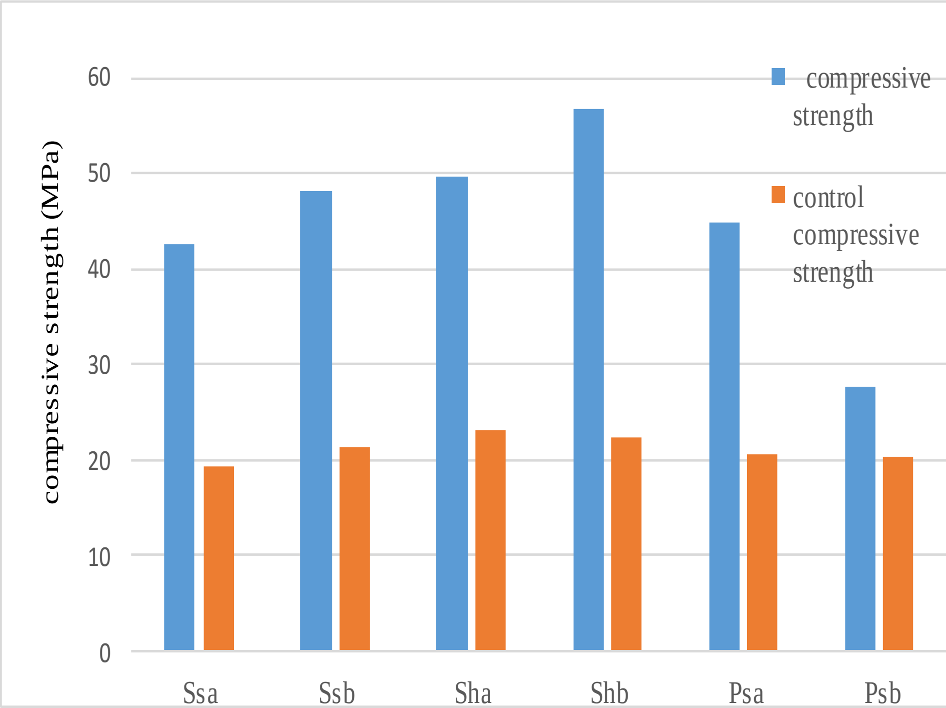


Fig.4 Compressive strength of test specimens

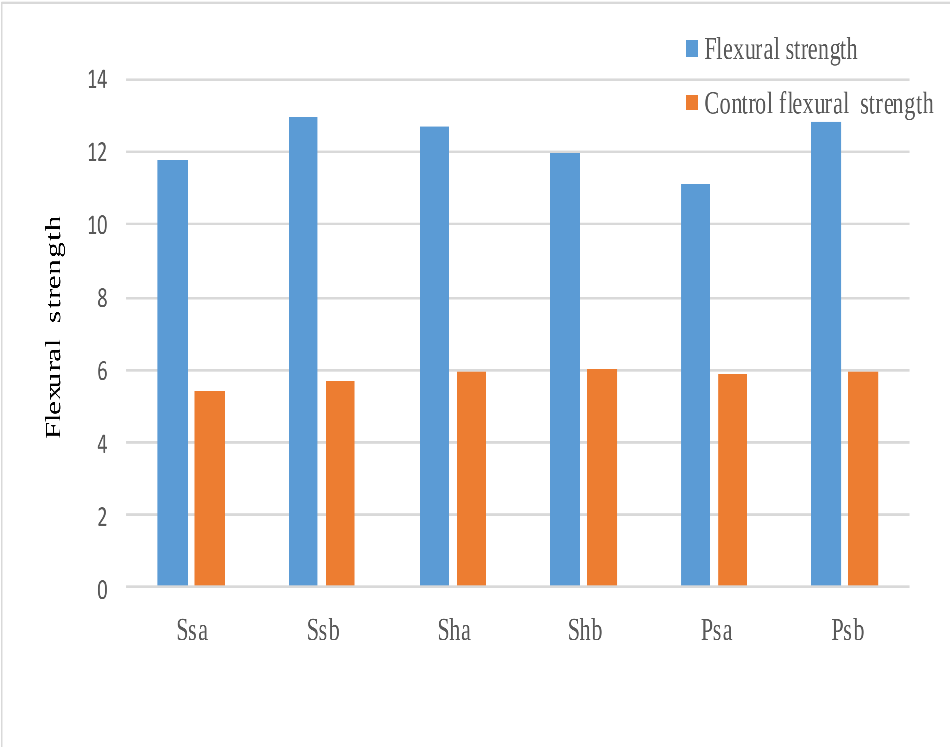
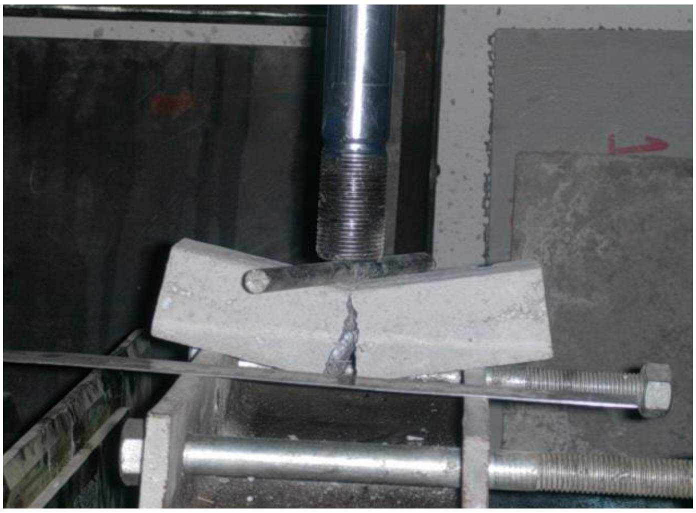


Fig.5 Flexural strength of test specimens

a-



b-

c-

Plate 7: Shape mode of prisms
a-plastic mesh content   b-galvanized mesh content   c-all prisms

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