SUST J Sci Tech, Vol 33 (2) 2023, 16 - 24 ISSN- 2959-3522

Strengthening of Concrete Cylinder Using Various Stainless-Steel Wire Mesh

(Received: 7 February 2024 ; Accepted: 24 August 2024)

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Abstract

Using of locally available materials, such as, Stainless-Steel Wire Mesh (SSWM) can be a sustainable and cost-effective solution for strengthening of concrete. In this study, an experimental work was performed with concrete cylinders confined with eight kinds of locally available SSWM to evaluate compressive strength variation. Specimens were divided into four groups according to mesh opening shape and wrapping alignment:1) unwrapped specimens, 2) specimens wrapped with 00 aligned rhombus shape opening SSWM, 3) specimens wrapped with 90? aligned rhombus shape opening SSWM, and 4) specimens wrapped with square shape opening SSWM. The result shows that SSWM wrapping with any type of openings and alignment over the concrete cylinder increase the load-carrying capacity of the cylinder (1.3% to 32.6% more than unwrapped cylinders). As an individual case, specimen confined with rhombus shape opening SSWM (thickness- 1.5 mm, opening cross-section- 14mm X 5mm, and weight 2.004 kg/m2) in 90o alignment takes the highest compressive strength (19.5 MPa) and that is 32.6% higher than the unwrapped specimen. But, considering group wise results, square shape opening SSWM carries a higher load-carrying capacity than rhombus shape opening SSWM. This type of SSWM increases compressive strength 11.9% to 21.1% compared to the unwrapped specimens. It was also revealed that, wrapping alignment variations of rhombus shape opening SSWM do not change the specimen's compressive strength significantly.

Keywords: Concrete; Compressive strength; Stainless-Steel Wire Mesh; Openings, Rhombus shape, Square shape; Mesh alignment.

1. Introduction

1.1 General

Concrete is a heavy, rough, and heterogeneous widely used man-made construction material that can take mainly compressive load. The capacity of the existing concrete column needs to be enhanced when an extra load is applied to it and needs to prevent cover spalling that reduces structure strength. Two possible ways for strengthening the structure to sustain against increased loads are reconstruction and retrofitting. Reconstruction is much more expensive, and the demolition of structures causes environmental pollution. Some general methods of strengthening/retrofitting of concrete columns are steel plate bolting, steel jacketing, reinforced concrete cement jacketing etc. [1]. But use of steel plate or concrete increases the weight to strength ratio, and steel may get corroded as it is used as external wrapping. A newly adopted technique is composite fiber systems like carbon fiber-reinforced polymer (CFRP), glass fiber-reinforced polymer (GFRP), aramid fiber-reinforced polymer (AFRP). Among them, CFRP is mostly used and its wrapping over concrete increases ductility and strength of column [2]. It is demonstrated analytically by the authors of [3] that it is possible to effectively strengthen the compressive strength of RCC columns with GFRP. GFRP wrapping is also effective in terms of increasing the seismic capacity of the structure [4]. Another study [5] showed that continuous AFRP wrapping on columns increases both the strength and ductility greatly; whereas discontinuous AFRP wrapping increases the strength of the columns, but not the ductility.

Although these FRP composites are accounted for strengthening, its bonding behavior with concrete is very poor and needs additional material (resin concrete) [6].

On the other hand, Stainless-Steel Wire Mesh (SSWM) is an extremely popular and versatile item that is used for many different applications. SSWM is cheaper than CFRP and GFRP as well as it is locally available in Bangladesh. It firmly attaches with concrete and cement mortar. Its wrapping over concrete column also prevents sudden split of column [7].

Strengthening of RC column with ferrocement and wire mesh wrapping was studied by the authors of [8]. The study revealed that reinforced concrete columns behaviors confined with longitudinal steel and ferrocement under static axially loading conditions. It was found a considerable strength and ductility improvement of the strengthened column compared to the unconfined specimen. Almost similar kind of study was conducted by the authors of [9] to find out influence of number of wire mesh layers on the behavior of strengthened reinforced concrete columns. The authors of [10] presented the most advanced and cheap technology of retrofitting the reinforced column using SSWM. The strengthened column in this experiment manifested 30-35% higher load carrying capacity compared to the unconfined specimen. The observation also implied that the strengthened column could be used in earthquake resisting buildings. Authors of [11] carried out a test installing relatively cheap materials such as household fly screen and wire mesh (fiberglass fly mesh, standard aluminum fly mesh, and galvanized steel wire mesh) in the formwork of RC columns to reduce the cover spalling of high-strength concrete columns. They concluded that galvanized steel wire mesh wrapping significantly improved the load-carrying capacity under both concentric and eccentric loading but did not significantly increase the ductility of the columns for each load case. The authors of [12] performed research on the RCC column wrapped with welded wire mesh around the external and internal concrete core and found that the column axial capacity of the confined specimen was higher than the unconfined one.

Authors of [13] experimented with a method of repairing earthquake damaged reinforced concrete columns with inadequate lap splice in longitudinal reinforcement using Stainless-Steel Wire Mesh composite materials comprised of SSWM, and permeable polymer concrete mortar. The experiment demonstrated that flexural strength, ductility, energy dissipation, and stiffness were increased and a slower rate of stiffness degradation. The authors of [14]-[16] found in their investigations that strengthened RC columns by ferrocement jacket had no development in flexural strength, but ductility increased significantly.

Not only columns, SSWM wrapping is effective for strengthening of other structures too. Use of SSWM in slab can increase the punching load-carrying capacity of the slab [17]. Another study conducted by the authors of [18] found that slab with steel wire mesh reinforcement shows better blast-resistant capability compared to slabs without steel wire meshes. Reinforced Concrete Beam strengthened by incorporating wire mesh and geotextile materials are sustainable in case of economic aspect and structural integrity [19]. Medium and high cord density galvanized steel mesh strengthening systems of RC beam can be used in harsh climatic conditions of elevated temperature, high salinity, and high humidity [20]. SSWM wrapping is also effective for strengthening unreinforced masonry structures [21].

It is clear from the above discussion that the SSWM wrapping over the concrete column significantly enhances compressive strength, ductility, and stiffness compared to other confinement models. But influence of mesh opening type and alignment of openings of locally available SSWM on strength of concrete column is not studied yet. This research will present a comprehensive idea about influence on strength of concrete cylinders wrapped with different kinds of SSWM locally available in Bangladesh, giving emphasis on shapes and alignment of mesh openings.

1.2 Objectives

The general objective of the study was to develop a sustainable technique for strengthening concrete cylinders using locally available materials. The specific objectives were:

- to observe compressive strength variation of the concrete cylinder using various Stainless-Steel Wire Mesh
- to determine the potential alignment of Stainless-Steel Wire Mesh for strengthening of concrete cylinder.

2. Methods

The methodology for this study mainly comprised of material collection and testing, specimen preparation and their compressive strength determination. All the tests were conducted at the Engineering Materials Laboratory of Sylhet Engineering College following ASTM standards.

2.1 Materials

Materials like coarse aggregate, fine aggregate, cement, and SSWM were used in this experiment. Their collection source and types are mentioned below (Table 1).

2.2 Coarse aggregate properties

The apparent specific gravity and the absorption capacity of coarse aggregate were found 2.66 and 0.57% respectively. Its unit weight was determined as 1643.33 kg/m3 in which 37.63% void was present. The resistance to degradation of small-size coarse aggregate by Abrasion and Impact tested by Los Angles Machine was found as 26.6%.

Table 1. Required materials

Materials	Type
Coarse aggregate	19 mm downgraded crushed stone
Fine aggregate	Sylhet sand
Cement	Ordinary Portland Cement
SSWM	Square, Rhombus shape opening

2.3 Fine aggregate properties

The Apparent specific gravity and Fineness Modulus (FM) of fine aggregate were found as 2.58 and 2.6 respectively. In addition, the absorption capacity was 4.36% and unit weight was 1662 kg/m^3.
The Ordinary Portland Cement (OPC) was used for this experimental study. Normal consistency of the used cement determined by Vicat's apparatus was 28.4%. Using the same equipment, its initial setting time and final setting time were found as 96 minutes and 195 minutes respectively.

2.4 Properties of cement

The Ordinary Portland Cement (OPC) was used for this experimental study. Normal consistency of the used cement determined by Vicat's apparatus was 28.4%. Using the same equipment, its initial setting time and final setting time were found as 96 minutes and 195 minutes respectively.

2.5 Stainless-Steel Wire Mesh properties

Total eight kinds of Stainless-Steel Wire Mesh with various opening shapes and wire thicknesses were selected for wrapping over the cylindrical concrete specimen.Their related properties were measured using Vernier scale and digital balance. Related technical information is listed in Table 2.

2.6 Specimen preparation

A mix ratio of concrete ingredients like cement, fine aggregate, and coarse aggregate by volume 1:2:4 respectively was calculated, and the water-cement ratio was taken as 0.6. The slump of concrete was considered 50 mm (Medium workability). Total 39 specimens were prepared for this experiment and among them, 3 specimens were cast as plain concrete (Figure 1). The specimens were cylindrical (diameter- 150 mm and height- 300 mm) as circular column carries higher load than square, rectangular, L-shape, or polygon [22]. After casting, all the cylinders were covered and placed in moist storage for 24 hours until removed from the mould. Then the specimens were removed from the mould and immersed into a water bath. The other 36 specimens of the same dimension were used as strengthened specimens wrapped with SSWM. The process of preparing strengthened specimen involved mesh preparation and casting with prepared mesh and curing for the required period. All the confinement meshes were cut according to the required width (300 mm) and they were rounded to make a case of 150 mm diameter (Figure 1). The mesh was overlapped at a length of 82 mm [11] to make it safe enough against loosening or slide. Furthermore, to make it stronger against loosening, two rows of sewing was provided throughout the whole length (S-1, S-2, S-5, S-7, and S-8) and tied (S-3, S-4, and S-6) with stainless-steel wire (SSW) that had a diameter of 0.5 mm (Figure 2). The sewing length and the gap between each tying were taken as 35 mm [11] (Figure 2). All the meshes were

Table 1. Stainless-Steel Wire Mesh properties

Type	Shape	Thickness (mm)	Diagonal Opening Dimension (mm)	Weight (Kg/m^2)
S-0	No Wire Mesh	-	-	-
S-1	Rhombus	0.5	10.5 x 4.5	0.491
S-2	Rhombus	1.2	11.15 X 5	1.713
S-3	Rhombus	1.15	18 X 4	1.097
S-4	Rhombus	1.5	14 X 5	2.004
S-5	Square	0.5	0.71 X 0.71	0.133
S-6	Square	1	14.28 X 14.28	1.308
S-7	Square	0.75	5 X 5	1.38
S-8	Square	0.2	4.24 X 4.24	0.764

placed into the mould and then concrete was poured. The concrete cover on the mesh was thin, about 2 mm. Such a thin layer was reported by the authors [23] where the fabric mesh was effectively used in the beam specimens with a 2 mm concrete cover. After 24 hours of casting, cylinders were demoulded and were kept in the water bath for curing.

2.7 Design of Experiment

Total 13 sets of the specimen (each set contains 3 concrete cylinders) were prepared based on properties of Stainless-Steel Wire Mesh, their opening shapes, and wrapping alignments. These sets were divided into four groups according to opening shape and wrapping alignment (Table 3). In group-1, specimens were unwrapped (1 set). In group-2, the specimens were wrapped with 0o aligned rhombus shape SSWM (4 sets), aligned rhombus shape opening SSWM (4 sets). The group-4 specimens were cast with 0^o aligned square shape opening SSWM (4 sets). Specimens were wrapped with various types of SSWM are shown in Figure 3. Afterward, STYE -2000 KN testing machine was used for determining the compressive strength of the cylindrical concrete specimen following ASTM C39. The machine was power operated that applied load continuously. Both ends of the specimen were levelled to assure full contact between the loading heads and the sample surface. The bottom of the specimen was then placed on the first loading head and the concrete cylinder was seated vertically upon it. While placing the bottom end, it was calibrated closely to ensure that it was placed at the centre of the testing machine. Then the highest value of crushing load for the corresponding specimen was noted.

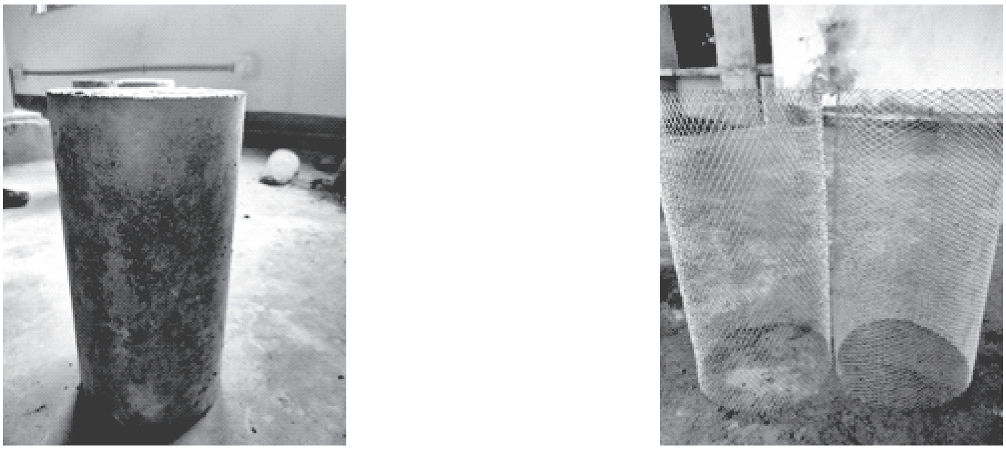

Figure 1. Specimen preparation: unwrapped specimen (left), Stainless-Steel Wire Mesh cases (right)

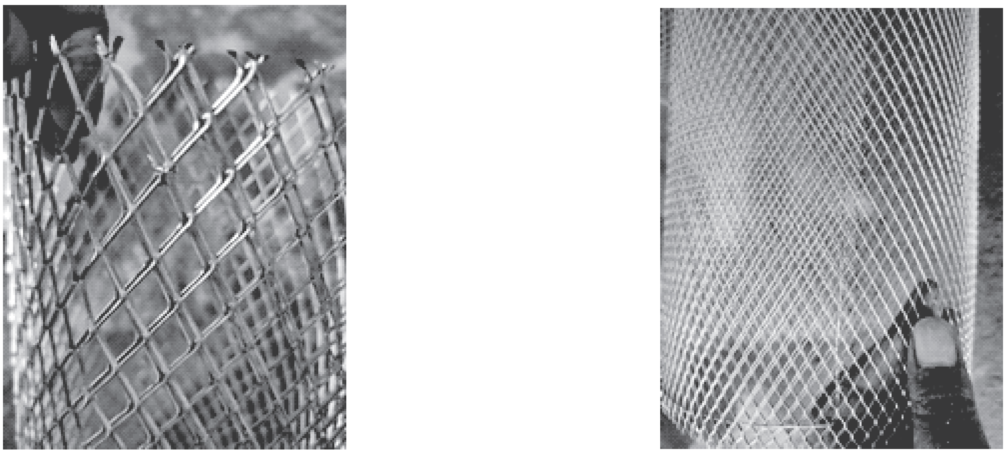

Figure 2. SSWM case preparation: tying with SSW (left), sewing with SSW (right)

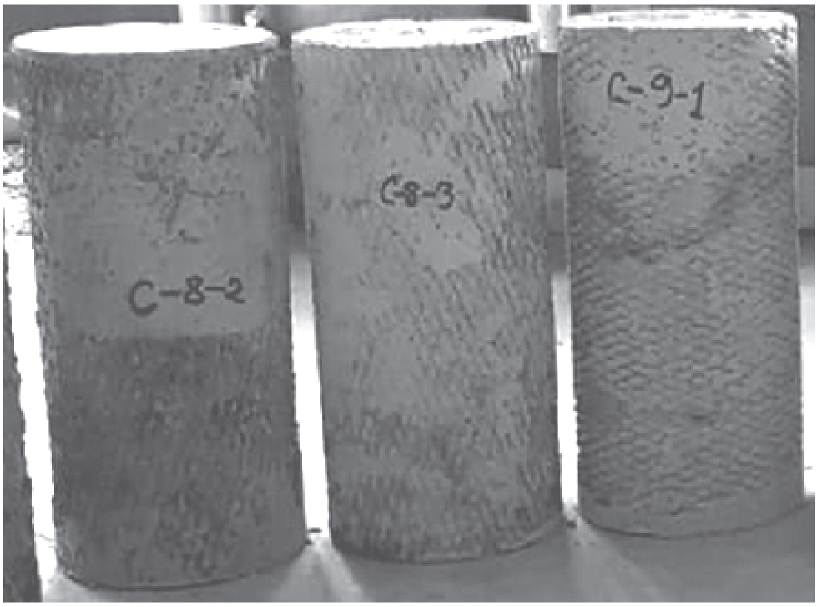

Figure 3. Specimens wrapped with various types of SSWM

Table 3. Specimen groups

Groups according to opening shape and wrapping alignment	Specimen set	Mesh type according to properties
G-1 (Group-1: without wrapping) [Reference Specimen]	G-1 S-0	-
G-2 (Group-2: wrapping with SSWM, rhombus shape opening, 0^0 aligned)	G-2 S-1	S-1
	G-2 S-2	S-2
	G-2 S-3	S-3
	G-2 S-4	S-4
G-3 (Group-3: wrapping with SSWM, rhombus shape opening, 90^0 aligned)	G-3 S-1	S-1
	G-3 S-2	S-2
	G-3 S-3	S-3
	G-3 S-4	S-4
G-4 (Group-4: wrapping with SSWM, square shape opening)	G-4 S-5	S-5
	G-4 S-6	S-6
	G-4 S-7	S-7
	G-4 S-8	S-8

3. Result and Discussion

3.1 Strength of specimen strengthened with rhombus shape opening SSWM, 0^o aligned

Four sets of the specimen (G-2 S-1, G-2 S-2, G-2 S-3, G-2 S-4) were prepared confined with four types of 0^o aligned rhombus shape opening SSWM marked as S-1, S-2, S-3, and S-4. Among them, G-2 S-4 specimen took the highest stress (17.67 MPa) that was 20.1% higher than the reference specimen (G-1 S-0), whereas other specimens carried only 2.65% to 4.5% higher (Figure 4).

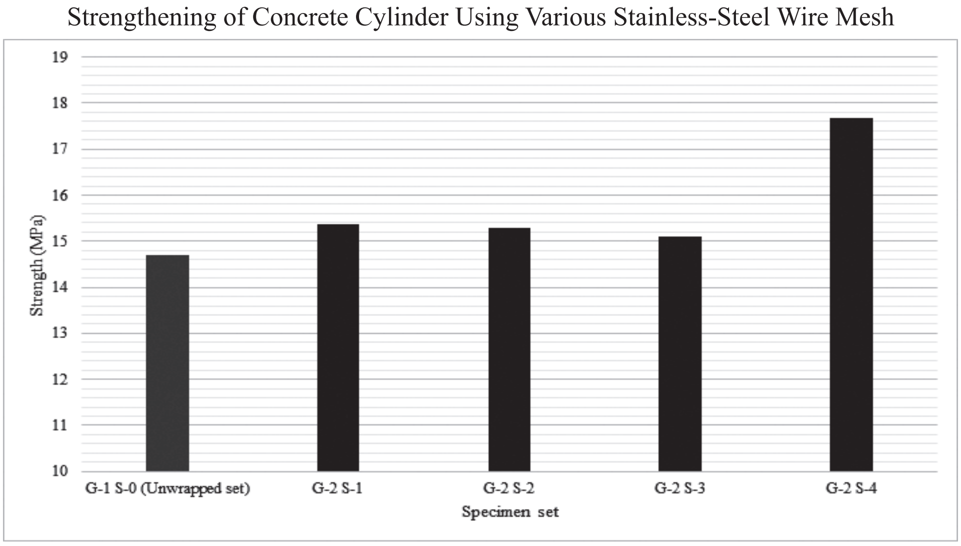

Figure 4. Strength variation of specimen strengthened with rhombus shape opening SSWM, 0^o aligned.

3.2 Strength of specimen confined with rhombus shape opening SSWM, 90^o aligned

Sets G-3 S-1, G-3 S-2, G-3 S-3 and G-3 S-4 wrapped with rhombus shape opening SSWM that was aligned 90^o were tested and it was found that the specimen set G-3 S-4, confined with S-4 took the highest stress (19.50 MPa), which is 32.6% higher than the reference specimen (G-1 S-0).

Whereas other specimens took only 1.3% to 6.1% higher than the reference specimen (Figure 5).

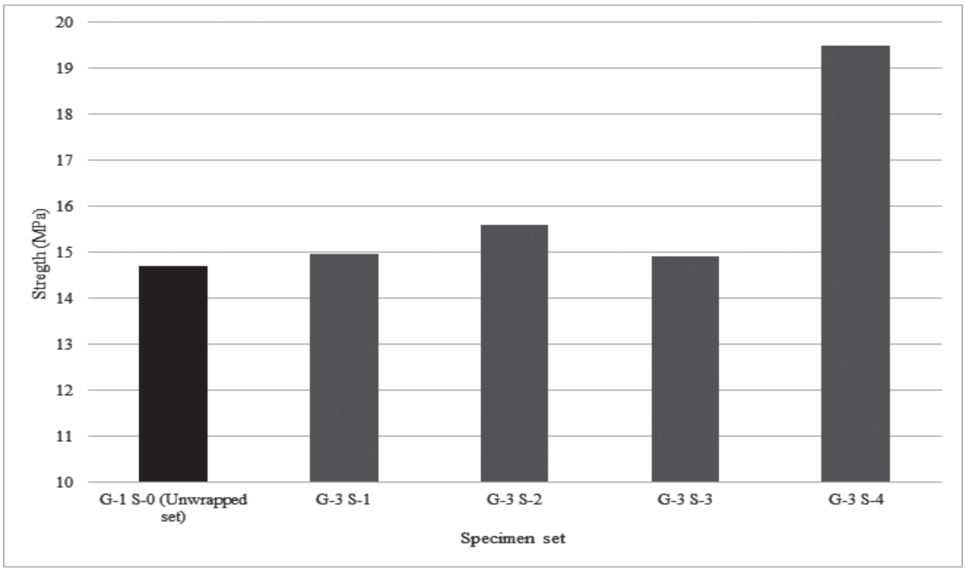

Figure 5. Strength variation of specimen strengthened with rhombus shape opening SSWM, 900 aligned

3.3 Strength of specimen confined with square shape opening SSWM, 0o aligned

Four kinds of square shape opening 0o aligned SSWM were used to prepare specimen set G-4 S-5, G-4 S-5, G-4 S-7 and G-4 S-8. Test results of this group have shown comparatively better and consistent performance than other groups (11.9% to 21.1% higher than the reference specimen). It was revealed that the set G-4 S-7, specimen confined with S-7 carried maximum compressive stress (17.82 MPa) and the lowest stress, taken by G-4 S-5 was 16.46 MPa (Figure 6)

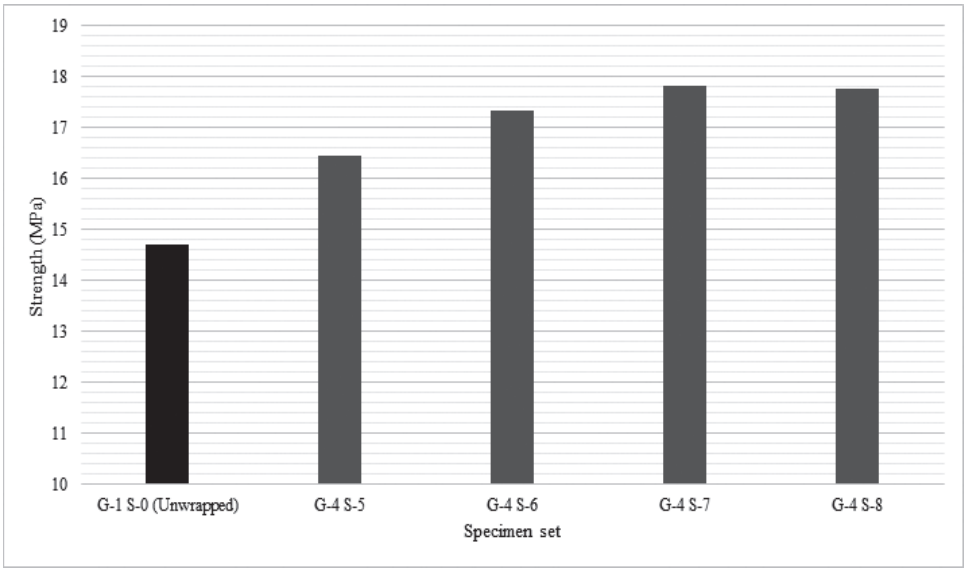

Figure 6. Strength variation of specimen confined with square shape opening SSWM, 0^{o} aligned

3.4 Increase of strength of specimens confined with various SSWM compared to unconfined specimen

It is clear from this study that, all eight kinds of SSWM wrapping over the concrete cylinder increase compressive strength. Among them, the square shape opening SSWM significantly increases the compressive strength of the concrete cylinder. Reason behind this is its horizontal wires, that firmly confine the specimen. The specimen wrapped with rhombus shape opening SSWM also increases the strength though its alignment does not affect too much in attaining more strength (Figure 7)

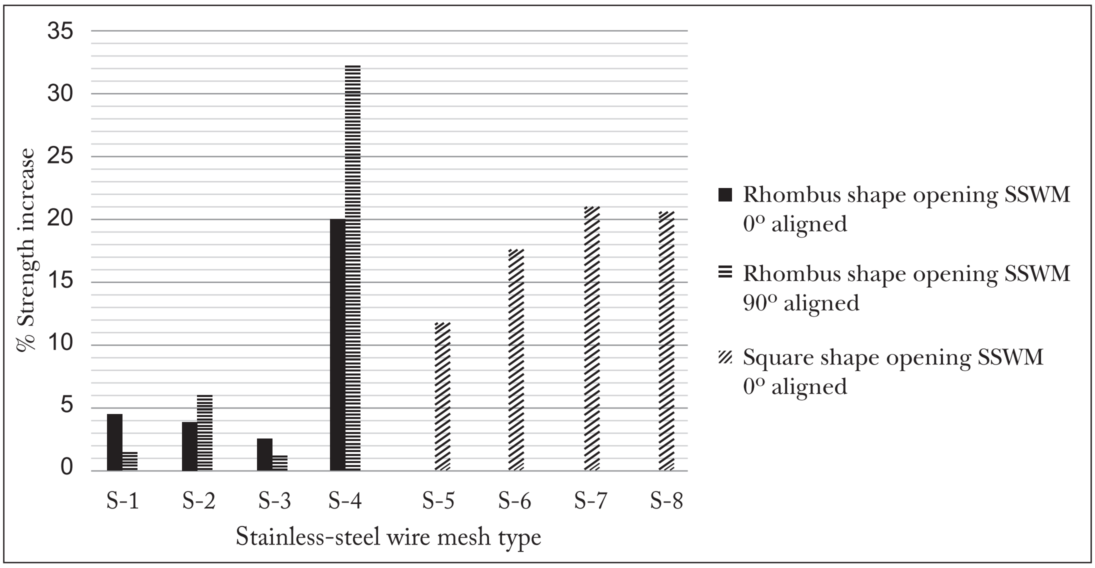

Figure 7. Strength comparison among specimens with different SSWM wrapping

4. Conclusions

The main objective was to find the compressive strength variation of the concrete cylinder using locally available SSWM. From the results, it is concluded that SSWM wrapping with any opening shapes (rhombus and square) and alignment over the concrete cylinder increase the load-carrying capacity of the cylinder (1.3% to 32.6% more than unwrapped cylinders).

As an individual case, specimen confined with rhombus shape opening SSWM (thickness- 1.5 mm, opening cross-section- 14mm X 5mm, and weight 2.004 kg/m2) in 90o alignment takes the highest compressive strength (19.5 MPa) and that is 32.6% higher than the unwrapped specimen. But, considering group wise results, square shape opening SSWM carries a higher load-carrying capacity than rhombus shape opening SSWM. This type of SSWM increases compressive strength 11.9% to 21.1% compared to the unwrapped specimens.
Wrapping alignment variations of rhombus shape opening SSWM do not change the specimen's compressive strength significantly.

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