Mechanical Properties of Lightweight Aggregate Moderate Strength Concrete reinforcement with Hybrid Fibers

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Abstract. This study aims to detect the mechanical properties of lightweight aggregate moderate strength concrete (LWAMSC) reinforced with single and hybrid fibers in various types and sizes. Moderate strength pumice lightweight aggregate concrete mix with compressive strength 40 MPa at 28 day age with silica fume and superplastizier was used. The fibers used include macro hooked steel fiber with aspect ratio 80, steel fiber with aspect ratio 60, and polypropylene fiber (P.P.F). Two groups of (LWAMSC) mixes were made with reference concrete mix (without fibers). The first group of mixes were substituted three (LWAMSC) mixes with different single fiber including, concrete mix reinforced with Polypropylene (P.P.F) about 0.75 % volume fraction (P1), concrete mix reinforced with macro hooked steel fiber type SF1 with volume fraction 0.75% mix (M1) and concrete mix reinforced with macro hooked steel fiber type SF1 volume fraction 1.5% mix (M2). The second group of fiber reinforcement (0.75% steel fiber type (SF1) + 0.75% steel fiber (SF2) mix (H1), (1% steel fiber (FS1)+ 0.5% steel fiber type (SF2) mix (H2)),and finally (1% steel fiber type (SF1)+0.5% PPF mix (H3)). Dry density, strengths of compressive, splitting tensile, and flexural of (LWAMSC) were examined. Generally single and hybrid reinforcement fiber of (LWAMSC) show important increase at flexural strength and splitting tensile strength in comparison with reference concrete. The results also show that, the optimum added proportion of fiber steel type (SF1) was (1.0%) and with (0.5%) steel fiber type (SF2) that portion raised the strengths of compressive, flexural, and splitting tensile around (4.34%), (52.93%), and (297%) respectively comparison with control mixture.

Keywords: moderate-strength concretes, lightweight aggregates; dry density, hybrid fibers.

1. Introduction

In a new moderate rise building, the size of columns and the wide of the span between beams concrete structures were increased, it is needed lightweight moderate strength for low stiffness concrete. A diminished concrete density for a similar strength level allows a sparing in dead load for basic foundations, but increase the strength of lightweight concrete lead to moderate brittle behavior [1]. Lightweight aggregate moderate strength concrete (LWAMSC) is structural lightweight concrete utilize at concrete building structure with a 28-day compressive strength of (40 MPa) or greater, and has a density less than 1500 kg/m³ [2], high brittleness low tensile/compressive strength ratio, low flexural strength, larger shrinkage. Therefore, steel fiber is needed for enhanced the mechanical properties of lightweight moderate strength mixture for increasing the tensile/compressive ratio, toughness, and resistance against deformation.[3],[4].To keep on the workability of concrete, a moderate-range water-reducing admixture (superplastizicizer) was used within mixing operations with water-cement ratio lower than 0.4 Pumice is a porous, volcanic rock. It is light grey in colour, cheap lightweight aggregates used
as lightweight coarse aggregates. The especial application of this type of concrete in the area of ocean engineering structures, long-span bridges and moderate buildings, etc [5].

2. Literature review

Although little knowledge for mechanical properties (LWAMSC) with hybrid fibers, some authors have got adequate results in this field, Jianming Gao, et al. in (1997) [6], found the effect of fiber volume and aspect ratio on the mechanical behaviour is extremely prominent, but strength of compressive is little improved and varied from 70.2 to 85.4 MPa. The ratio of tensile/compressive strength is improved. Strength of flexural varied from 4.94 to 8.7MPa.

While O. Kayali, et al. in (2003) [7] studied the effect of polypropylene and steel fibers on lightweight moderate strength aggregate concrete with Sintered fly ash were used as lightweight aggregates, polypropylene fiber with 0.561% at concrete volume, lead to a 90% addition to the tensile strength and a 20% to the rupture modulus and 1.7% by volume of steel fibers addition at the indirect strength of tensile about 118% and the rupture modulus by about 80%.

In 2011, N.A. Libre et al. [8] observed the increase in mechanical properties and energy absorption capacity when the addition of steel fibers. Polypropylene fibers have a minor effect in mechanical properties of hardened concrete made with both steel and polypropylene fibers. The steel fibers volume fraction at 0.5% 1% but the PP fibers various 0.2% and 0.4%. Furthermore, H.K. Ahmed, et al. in (2017)[9] studied the influence of three types of polypropylene fibers with different volume fraction (Vf) on compressive strength, flexural strength, splitting tensile strength, and static modulus of elasticity. Results show significantly increased in all types of strength with all types of polypropylene fibers and compressive strength it was improved at Vf =0.25% and decrease at Vf =0.75%.

3. Materials and methodology

3.1. Cement

For experimental work, the ordinary Portland cement was used from Al-Douh refectory. Tables 1 and 2 show that the cement test results according to the ASTM standers C150-02 [10].

Table 1. Chemical analysis of cement

| Oxides | percentage | Limit of ASTM Specf.C150-02a/2002 |
|--------|------------|----------------------------------|
| CaO    | 63.2       | -                                |
| SiO2   | 18.9       | -                                |
| Al2O3  | 3.8        | -                                |
| Fe2O3  | 4.6        | -                                |
| SO3    | 1.5        | ≤ 2.3                            |
| MgO    | 1.7        | ≤ 6.0                            |
| L.O.I  | 1.9        | ≤ 3.0                            |
| L.S.F  | 0.9        | -                                |
| I.R.   | 0.4        | ≤ 0.75                           |
| C3A    | 2.32       | ≤ 5.0                            |

Table 2. Physical properties of cement

| Physical properties | Test results | Limit of ASTM Specf.C150-02a/2002 |
|---------------------|--------------|-----------------------------------|
| Initial setting time (vicat) | 65 min. | 45min.(Min.) |
| Final setting time (vicat) | 170 min. | 375 min. (Max.) |
| Compressive strength of mortar (MPa) 3-days | 19.0 | 15 (Min.) |
| Compressive strength of mortar (MPa)7-days | 30.5 | 21 (Min.) |
3.2. Aggregate

3.2.1. Fine aggregate

Natural river sand was used as a fine aggregate which is passing through the sieve aggregate of 4.75 mm. Table 3 shows the gradation of the aggregate which is compatible to the required specifications of ASTM C33-01[11].

| Sieve size (mm) | Passing ratio (%) | Limit of ASTM C33-01 |
|----------------|-------------------|----------------------|
| 9.5mm          | 100.00            | 100                  |
| 4.75mm         | 94.56             | 95-100               |
| 2.36mm         | 72.45             | 80-100               |
| 1.18mm         | 68.40             | 50-85                |
| 600µm          | 53.32             | 25-60                |
| 300µm          | 16.60             | 5-30                 |
| 150µm          | 2.12              | 0-10                 |

Table 3. Sieve analysis of fine aggregate

3.2.2. Pumice lightweight coarse aggregate

Pumice was used to make preparations for the (LWAMSC) mixtures. The quarry of this stone is found in the north of Iraq in AL-Sulaymania governorate. Pumice stone has a dark color, moderate permeability, and low density, porous form of vitrified volcanic rock and moderate silicon oxide (SiO2) concrete. Crushed Pumice stone was used as a coarse lightweight aggregate of nominal size (12.5 - 4.75) mm in this work as shown in Figure 1. Pumice pieces were broken manually and graded as per the requirement of ASTM C 330-04 [12]. Table 4 and 5 illustrate the physical properties and the grading for pumice, and the Figure 2 shows the graph of the grading of pumice aggregates.

Figure 1. Pumice pieces

| Tests, ASTM C 127 | Test Results | Limits |
|-------------------|--------------|--------|
| Loose bulk density (kg/m3) | 569          | 880 (max) |
| Oven dry bulk specific gravity | 1.88        |        |
| Absorption % (24 Hours) | 2.51         |        |
| specific gravity | 2.53         |        |

Table 4. Physical properties of lightweight coarse aggregate (pumice)

| Sieve size (mm) | Percent Passing | Limit required by ASTM Standard C330-04 |
|----------------|-----------------|----------------------------------------|
| 12.5           | 100             | 100                                    |
| 9.5            | 97              | 80-100                                 |
| 4.75           | 12              | 5-40                                   |
| 2.36           | 2               | 0-20                                   |
| 1.18           | 0               | 0-10                                   |

Table 5. Pumice grading of coarse lightweight aggregate
3.3. **High range water reducing admixture (Superplasticizer)**

High range water reducing admixture (HRWRA) superplasticizer is a chemical compound used to reduce the amount of water with the same workability for producing moderate strength concrete, according to ASTM-C494 Type G [13]. Because of the fibers addition reducing the workability of mixtures[5]. So (HRWRA) must be used. Table 6 shows the typical properties of superplasticizer.

| Table 6. Typical properties of superplasticizer |  |
|-----------------------------------------------|--|
| properties                                | Specifications |
| Specific gravity                          | 1.2            |
| Form                                       | Liquid         |
| PH                                         | 7-9            |

3.4. **Fibers**

Table 7 shows the physical and technical properties of fibers used in this work. Two types of macro hooked steel fibers (SF1 and SF2) with an aspect ratio of 80, and 60 and Polypropylene fiber (PPF) with aspect ratio 677 complied with requirements of ASTM C1116-02[14]. Figure 3 shows the two types of fibers that used in this work.

| Table 7. Properties of fibers |
|-------------------------------|
| Property                     | Steel Fiber, SF1 | Steel Fiber, SF2 | Polypropylene Fibers (P.P.F) |
| Density (Kg/m3)              | 7880             | 7880             | 7900                        |
| Tensile strength (MPa)       | 1100             | 1100             | 360                         |
| Diameter (mm)                | 0.5              | 0.5              | 0.018                        |
| Length (mm)                  | 40               | 30               | 12                          |
| Geometry                     | hooked           | hooked           | Fibrillated                 |
| Aspect ratio                 | 80               | 60               | 677                         |

(a) Standard hooked-end steel fibers  (b) Polypropylene fibers.

**Figure 3.** Types of fibers
3.5. Silica fume

Silica fume utilized in this work was purchased from Sika Company. The chemical composition and physical requirements of the purchased silica fume satisfied the requirements of ASTM C 1240-06-06[15].

3.6. Mix Proportions

The volumetric method ACI 211.2 [2] was used for mix design with proportions as 1: 1.33: 0.89 (cement: sand: aggregate) by weight. The reference lightweight aggregate moderate strength concrete mix to give at 28-day age a compressive strength (42 MPa), after many tries, used the mixes with cement content 490 Kg/m3, silica fume 53kg/m3, water-cement ratio 0.31 and slump (80 mm) for good workability was used. (HRWRA) 1.2 liter per 100 kg of cement without fiber (0F) as shows in table (8). The high absorption of pumice aggregates directly affects on the quality of the LW concrete. In order to solve this problem, the pre-soaking method was used for pumice aggregates to control the high absorption of pumice aggregates for a fixed time. Generally, 24 hours the time was needed to achieve the 80% of the water absorption [16]. Two groups of concrete were made, the first group of mixes were substituted three (LWAMSC) with different single fiber including, concrete mix reinforced with Polypropylene (P.P.F) about 0.75 % volume fraction (P1), concrete mix reinforced with macro hooked steel fiber type SF1 with volume fraction 0.75% mix (M1) and concrete mix reinforced with macro hooked steel fiber type SF1 volume fraction 1.5% mix (M2). In the second group, three (LWAMSC) with hybrid fiber including concrete mix reinforced with a combination of (SF1) steel fiber 0.75% volume fraction + (SF2) steel fiber 0.75% volume fraction (H1). Concrete mix reinforced with a combination of macro (SF1) steel fiber with 1.0 % volume fraction +(SF2) steel fiber and 0.5% volume fraction (H2). Finally, the concrete mix contains a combination of (SF1) macro steel fiber 1.0% volume fraction + micro PPF with 0.5% volume fraction (H3).

| Mix Design | Steel Fiber | Steel Fiber | (P.P) Fiber | Pumice coarse aggregates | Fine aggregates | Cement content | W/ C | Silica fume |
|------------|-------------|-------------|-------------|-------------------------|----------------|----------------|-----|-------------|
|            | % of vol. (SF1) | % of vol. (SF2) | % of vol. | (Kg/m3) | (Kg/m3) | (Kg/m3) |     | (Kg/m3) |
| Ref. - (RF) | 0.0 | 0.0 | 0.0 | 435 | 650 | 490 | 0.31 | 53 |
| 0.75% PPF - (P1) | 0.0 | 0.0 | 0.75 | 435 | 650 | 490 | 0.31 | 53 |
| 0.75% SF1 - (M1) | 0.75 | 0.0 | 0.0 | 435 | 650 | 490 | 0.31 | 53 |
| 1.5% SF1 - (M2) | 1.5 | 0.0 | 0.0 | 435 | 650 | 490 | 0.31 | 53 |
| 0.75% SF1 - 0.75% SF2 - (H1) | 0.75 | 0.75 | 0.0 | 435 | 650 | 490 | 0.31 | 53 |
| 1% SF1 - 0.5% SF2 - (H2) | 1.0 | 0.5 | 0.0 | 435 | 650 | 490 | 0.31 | 53 |
| 1% SF1 - 0.5% PPF - (H3) | 1.0 | 0.0 | 0.5 | 435 | 650 | 490 | 0.31 | 53 |

3.7. Casting and curing of (LWAMSC)

To produce of lightweight aggregate moderate strength with fiber reinforced concrete, pumice as coarse aggregates and fine aggregates were mixed at the beginning with dry case for one minute. Then, cement and silica fume were added to the mix. Amid the blending activity, the fibers were added and all the materials were mixed for 2 minutes together with the continuous addition of fibers. Hard and continuous mixing was made for the avoidance of fibers to be clumped. Finally, to get a specific mixture containing water, (HRWWR) was slowly added to the mixture during the mixing for 3 minutes.
After filling up the moulds, the concrete samples were to reduce the entrapped voids using a vibrating table for a period of 8 to 12 seconds. The samples were maintained in the laboratory for 24 hours, and then stored in the water of a constant 20±2 °C for 7 and 28 days, up to a time the day of the testing.

### 3.8. Concrete testing

According to ASTM C192-88 [17], the concrete resistance of compression of (LWAMSC) samples were examined during 7 and 28 days of treatment period. For strength of compression at (7) and (28) days in conformance to requirements for ASTM C39-98 [18], utilize six standard steel cubic moulds (150×150×150) mm for casting the samples, while for the strength of splitting tensile employed two cylindrical moulds of (100×200) mm and the concrete was evaluated according to ASTM C 496-90 [19]. Finally, according to ASTM(C78–98) [20], two prisms of (100×100×400) mm were used for the strength of flexural (Modulus of Rupture) for (28) days.

### 3.9. Air Dry Density

Air dry density test was performed in accordance with ASTM C567-85[21] by using (100×200) mm cylindrical specimens. The specimens left in moulds for 1 day inside a moisture cabinet, then they were stripped from the moulds and wrapped securely with a polythene bag for 6 days. After that, they were removed from the bag and immersed in water for 1 day. On the second day saturated surface dry and suspended-immersed weight were taken. The specimens were left in the laboratory for 21 days, then the dried specimens were tested at the 28-day. The air dry density was calculated by using the following equation:

\[
\text{Air dry density (kg/m}^3\text{)} = \frac{(A \times 997)}{(B-C)}
\]

where:
- \(A\) = weight of concrete cylinder, as dried (kg).
- \(B\) = saturated surface-dry weight of cylinder (kg).
- \(C\) = suspended-immersed weight of cylinder (kg).

### 4. Resultant and Discussion

#### 4.1. Bulk density

The hardened concrete densities which were tested at 28-day are shown in Table 9 and Figure 4. The results of the bulk density of the (P.P.F) fibers did not have a significant effect on the concrete density. While, the density of concrete is directly influenced at fibers of steel, but the mean density of concrete that not contain steel fibers was 1760 kg/m³, the average density of hybrid fibers concretes of H1, H2, H3 were 1862, 1856, and 1843 kg/m³. This is clearly due to the moderate specific gravity of steel fibers, the density of (LWAMSC) shows the increment of 1.5% steel fiber greater the concrete density at about 116 kg/m³. The influence fibers steel on growing the concrete density samples very important in the case of lightweight concrete in which the reduction of the density is very significance.

| Mix Design | Average Bulk density (kg/m³) | Comp. strength 7 days MPa | Comp. strength 28-day MPa |
|------------|------------------------------|---------------------------|---------------------------|
| Ref.- (RF) | 1768                         | 32.75                     | 41.45                     |
| 0.75%PPF- (P1) | 1769                     | 33.12                     | 42.12                     |
| 0.75%SF1- (M1) | 1840                     | 34.45                     | 44.35                     |
| 1.5%SF1- (M2) | 1860                     | 30.11                     | 37.64                     |
| 0.75%SF1-0.75%SF2- (H1) | 1862                    | 30.89                     | 38.76                     |
| 1.0%SF1-0.5%SF2- (H2) | 1856                     | 34.52                     | 43.25                     |
| 1.0%SF1-0.5%PPF- (H3) | 1843                     | 34.35                     | 43.05                     |
Figure 4. Dry density test resultants of (LWAMSC) at 28-day

4.2. Compressive Strength

Table 9 and Figure 5 explain the increment of the compressive strength results of all (LWAMSC) at 7-day and 28-day within the age. It was noted that the compressive strength of polypropylene fiber type (P1) with volume fraction of 0.75% was slightly better than the reference concrete (RF) in about 1.13% at 7 days and 1.6% at 28 days respectively. Concrete mixes containing single fiber, steel fiber of M1 is showed the higher compressive strength about 5.19%, and 6.97% for 7 and 28 days respectively in comparison with reference concrete. This is due to the small amount of fibers enhanced the cement paste for micro crack phases and improved the crack strength.

It has been noticed that the addition of fibers in concrete mix of (M2) come to be very hard at 1.5% of steel fiber volume fraction and mixture can not completely compacted, thus the compressive strength of concrete become smaller than to the reference concrete. The partly exchange to steel fibers type (M2) of 1.5% steel fiber type (SF1) with hybrid fiber (H1, H2, and H3) of low volume fraction of steel fiber type SF2 (0.75% and 0.5%), polypropylene fibers (0.5%) shown that increasing in the compressive strength by about 2.97%, 14.9%, %, and 20.21% respectively at 28-day. This is because of the hybrid fibers with varying types and sizes would suggest different put down conditions. Moreover, this social position can be ascribed to the becoming better in the mechanical strength of bond as the fibers both have the capacity gaudily the microcrack arrangement and to detain their diffusion afterwards up to a certain scale [22].

(LWAMSC) Hybrid fibers mixes with 1.0% of steel fiber type SF1 and 0.5% fraction of volume of (P.P.F) show the moderately advancing in compressive strength. This is because, in comparison with longer and moderate specific gravity fibers, shorter and low specific gravity are more efficient in delaying cracks owing to the moderate specific contact surface of nonmetallic fibers [23].

The using of two types of macro steel fibers in (LWAMSC) with volume fraction 0.75% for each (mix H1), shows decreasing in compressive strength in comparison with reference mix (mix RF). This is due to the pores and honeycombs which can be formed during placing of moderate volume fraction of steel fibers as a result of not completed consolidation [24].
Fig. 5. Compressive Strength test of (LWAMSC) results at 7-day and 28-day

4.3. Splitting Tensile Strength

Table 10 and Figure 6 list the effects of fibers in (LWAMSC) appreciably, increasing the splitting tensile strength for alone type and hybrid fibers concrete mixtures compared to the reference concrete. The amount of increase in splitting tensile strength for (LWAMSC) mixes containing single steel fiber type (M1) with volume fraction 0.75%, and 0.75% polypropylene fiber (P1) is 295.8%, and 221.6% successively comparison to the reference concrete. This is ascribed to the mechanism of fibers in detention cracking progression and the improvement of the bond between fibers and matrix due to the extra dense calcium silicate hydrate gel obtained from silica fume addition [25].

The comparison between splitting tensile strength values of (LWAMSC) mix having one steel fiber type (M2) with a volume fraction of 1.5% and the hybrid fiber mixes H1, H2, and H3 shows that the increase ratio in strength of splitting tensile of hybrid fiber (LWAMSC) is about 6.85%, 20.25%, and 7.47%, respectively.

Similar to the case of compressive strength, steel-polypropylene fibers mix (H3) shows the moderateest splitting tensile strength relative to all fibrous (LWAMSC) mixes (with mono or hybrid fiber). This is because of the cooperation of hybrid fibers, small fibers may bridge the microcracks more qualification, because they are not thick and their amount in mixture is much paramount than tof the great thick fibers, for the same fiber quantity. As the microcracks grown and join upto very large macrocracks, the long hooked-end fibers become more and more active in crack bridging. In this way, the strength of tensile and ductility can be improved. Long fibers can therefore provide a stable post peak response, but short fibers will be less active because they are being more pulled out, therfore the width of crack increasing [26].

4.4. Flexural Strength

The flexural resistance test proceeds for all (LWAMSC) combined are coincident in Table 10 and Figure 7. The conclusion show that the incorporation of fibers increment the flexural strength in single and multi-fibers heterogeneous suitable to mix together. The percentages of increased in parameter of breach for single steel fibre (LWAMSC) at fragment 0.75%, 1.5% of M1, and M2 are 52.37%, 29.52% and 60.64% for 0.75% of polypropylene fibers (P1) compared with reference concrete. The purpose for this improvement in parameter of fracture is that after table bully, the fibers will move the cargo that the concretion uniform until great by interfacial fetters between them. The principle for this increase in modulus of rupture is that after cement paste cracking, the fibers is carried the load that the concrete without changing up to cracking by means of bond of interfacial between the fibers and the matrix. Therefore, the fibers resist the dissemination of cracks and do not fail without warning, which source an increase in load carrying ability [27].
The comparison between strength of flexural values for (LWAMSC) samples containing 1.5% of steel fiber type (M2) and hybrid fiber samples H1, H2, and H3 shows that the increase ratio of strength of flexural for hybrid fiber (LWAMSC) samples is 20.9%, 35.61%, and 12.02% respectively. It can be observed that (LWAMSC) samples containing a merge of steel and polypropylene fibers (mix H3) show the lowest percentage increase in modulus of rupture relative to mono steel fiber mix (M1). This is because of the lower strength of (P.P.F) tensile and also the not strong bonding between cement matrix and (P.P.F) [28].

**Table 10.** Results of tensile of splitting and flexural strengths tests for (LWAMSC) mixtures

| Mix Design | Splitting tensile resistance 28 day MPa | Flexural strength 28 day MPa |
|------------|----------------------------------------|-------------------------------|
| Ref. - (RF) | 0.97                                   | 3.76                          |
| 0.75%PPF- (P1) | 3.12                                   | 3.87                          |
| 0.75%SF1- (M1) | 3.84                                   | 5.53                          |
| 1.5%SF1- (M2) | 3.21                                   | 4.24                          |
| 0.75%S1F- 0.75%S2F- (H1) | 3.43                                   | 5.12                          |
| 1.0%SF1- 0.5%SF2- (H2) | 3.86                                   | 5.75                          |
| 1.0%S1F-0.5%PPF- (H3) | 3.45                                   | 4.75                          |

**Figure 6.** Strength of splitting tensile for overall (LWAMSC) mixtures of 28-day

**Figure 7.** Strength of flexural and ratio of single and hybrid fibers
5. Conclusion

- The addition of steel fibers to (LWAMSC) increases its oven dry density of all mixes. Hybrid (LWAMSC) mix containing a combination of steel fibers 0.75% steel fiber type (SF1) + 0.5% polypropylene fiber show densities less than that containing 1.5% of mono steel fiber type (SF1).
- The use of 0.75% volume fraction of macro steel fiber type (SF1) and polypropylene fibers increases the cube compressive strength at 28 day by about 5.19%, and 6.97% relative to the reference concrete, and the partial replacement of macro steel fibers type SF1 with 0.75% of SF2 (H1), 0.5% SF2 (H2), and 0.5% polypropylene fiber (H3) increases the compressive strength at 28 day by about 2.9%, 14.9%, and 20.21% compared to the 1.5% SF1- (M2)
- The inclusion of fibers in (LWAMSC) significantly improves the splitting tensile strength for both single and hybrid fiber reinforced samples relative to the reference concrete. Hybrid fiber reinforced (LWAMSC) samples show significant increase in splitting tensile strength. The percentage of increase in splitting tensile strength for (LWAMSC) specimens prepared from H1, H2, and H3 mixes is about 6.85%, 20.25%, and 7.47%, respectively, attribute to the control mixture.
- The incorporation of fibers increases the flexural strength in single and hybrid fiber concrete compare to the reference concrete. The increase ratio of flexural strength for hybrid (LWAMSC) supplied of mixtures H1, H2, and H3 is 20.9%, 35.61%, and 12.02% respectively relative to the reference concrete.
- The resultant indicated that, the most efficient state addition proportion of hybrid fiber was 1.0% of (SF1) with 0.5% of (SF2) this ratio raised the strengths of compressive, flexural, and split tensile for 4.34%, 52.93%, and 297% successively, comparing to reference concrete.

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