The Effect of Steel and Polypropylene Fibers on Hardened and Fresh Concrete Properties

Shiren Osman Ahmed
Department of Civil Engineering, Delta Higher Institute for Engineering& Technology, Mansoura, Egypt

Abstract: A plain concrete has low tensile strength and brittle failure. In order to overcome this problem many investigations have been carried out. The current research investigates the effect of the addition of steel and polypropylene fibers on hardened and fresh concrete properties. Straight steel fibers (St) with a 63mm length and 0.9 mm diameter, and polypropylene fibers (PP) with a 12-mm length and 0.018 mm diameter were used. plain concrete mixes were prepared, control mix was prepared for comparison purposes. The first and second mixture were produced with steel fibers and polypropylene fibers separately and three mixtures were produced with the combination of steel and polypropylene fibers at (0.2% St +0.6PP), (0. 4% St +0. 4 PP) and (0.6% St +0.2 PP) by volume of concrete. Specimens were cured in water for 7 and 28 days. Compressive strength test, splitting tensile strength test, flexural strength test and the rate of water absorption test were performed at different ages of curing. The slump test was carried out on the fresh concrete to measure its workability. Test results have reflected that the compressive strength, tensile strength and flexural strength achieved maximum increase with mix M5 (0.6% St +0.2 PP). Compressive strength increased by 33.3 % of compressive strength for control mix at age of 28 days. Flexural strength of mix M5 had maximum increase; it increased by 48% of flexural strength for control mix. Rate of water absorption increased for all mixes of PP and St fibers compared to rate of water absorption for control mix. There is significant development in mechanical properties compared to control mix.

Keywords: Compressive strength, Flexural strength, Rate of water absorption, Splitting tensile strength, Slump test, Steel Fibers, Polypropylene Fibers.

1 INTRODUCTION

The construction industry has shown great interest in the use of fiber reinforced concrete due to the improvements in structural performance that can be produced compared to conventional concrete. The fibers improve ductility and durability of the concrete, it also reduces the expansion of cracking resulting from shrinkage of concrete, especially resulting from plastic shrinkage and redistribution it, as well as reduce the creep of concrete but with ratio less than that for shrinkage [1]. Increasing fiber length and dosage had much stronger effect than increasing fiber diameter on enhancing permeability due to greater enhancement on percolation of fiber tunnels. It was found that permeability of ultra-high-performance concrete (UHPC) is positively correlated with both the aspect ratio and dosage of polypropylene (PP) fibers. However, at low fiber aspect ratio, increased fiber dosage does not increase the permeability of UHPC. Similarly, at low fiber dosage, solely increasing fiber aspect ratio does not contribute much to increasing permeability of UHPC. The proposed model thus provides insight for PP fiber selection and optimization to prevent explosive spalling of concrete [2]. The concrete samples were made with different fibers amounts from 0 to 2 kg m-3. Also, the samples fabricated with coral aggregate and siliceous aggregate were examined and compared. The samples with added polypropylene fibers of 1.5 kg m-3 showed better results in comparison with the others. Coral aggregate concrete showed less electric resistivity and less compressive strength in comparison with samples fabricated of siliceous aggregates. It is concluded that the coral aggregates are not suitable for making concrete [3]. Three different types of fibers, including polypropylene fiber, polyolefin fibers, and steel fiber were used. The maximum drying shrinkage strength was highly dependent on fibers' module of elasticity. The average length cracking and its pattern in fiber reinforced concretes were different than control concrete. The physical properties of fibers have direct effects on reducing the cracking width [4]. The addition of 10% of Silica Fume (SF) increased compressive strength, shrinkage and cracking, permeability and carbonation depth. But, the combination of 10% SF and 0.07% Polypropylene short fibers (PPF) volumetric fraction mitigated early age cracking and significantly reduced water permeability and carbonation depth. The use of PPF in natural Pozzolans blended cement concrete combined with SF can be recommended to reduce long-term impact of early age cracking, and enhance durability. However, cement should not be reduced when SF is added to mixtures without PPF, because lower Cao reserves may affect final pH, leading to concretes more sensible to carbonation [5]. The addition of waste fiber fabric in to concrete can improve the compression performance of concrete. It is a technology that can be constantly improved, considering changes in both technical and environmental conditions [6]. Effect of hybrid polypropylene (PP) and steel fibers on explosive spalling prevention of ultra-high-performance concrete (UHPC) at elevated temperature was investigated. The use of hybrid PP and steel fibers completely prevented explosive spalling even at low fiber dosage of both fibers due to significant increase of permeability. Microstructural analysis revealed that such synergistic effect on increased permeability of hybrid PP and steel fiber-reinforced UHPC was attributed to enhanced connectivity of empty PP fiber tunnels by multiple microcracks generated from the thermal expansion of both fibers [7]. Addition of polypropylene fiber both water and gas permeability coefficient were increased. The fiber reinforced concrete would work better for plastic shrinkage susceptible structural elements (flat elements such as slab); however, it requires careful judgement while applying to a water retaining structures [8]. Results of steel fiber reinforced concrete with that of normal concrete showed the significant improvements in the results of compressive strength and flexural strength of concrete with different types of steel fiber with various constant volume fractions and different aspect ratio [9]. The effect of the addition of fly ash particles with different weight ratios of 15%, 20%, and 25% as well as the addition steel fibers with different volume fractions of 0.25%, 0.75%, and 1.25% on the mechanical properties of concrete was studied. the addition of fly ash particles had little effect on the mechanical properties of normal concrete, while the steel fibers had the greatest effect. The highest increase in compressive strength and flexural strength compared with reference concrete was 61.60% and 78.84%, respectively in the volume fractions 1.25% of steel fiber [10].

2 WORK OBJECTIVE

The main objective is to study effect of steel and polypropylene fibers on hardened and fresh concrete properties.

3 EXPERIMENTAL WORK

3.1 Materials

The different materials used in this investigation are: -

Cement: Ordinary Portland (CEM-I) cement with grade 42.5 N confirmed Egyptian Standard Specifications (ESS) requirements (4756-1/2007).

Fine Aggregate: Medium well-graded sand of fineness modulus 2.85 was used for concrete complies an Egyptian Standard Specifications (ESS) requirement (ECP.1109/2002).

Coarse aggregate: Crushed dolomite was used as coarse aggregate. Maximum nominal size of coarse aggregate was 20 mm.

Water: Fresh tap water was used for both mixing and curing purposes.

Chemical additives: Sikament-163 is used as a highly effective water-reducing agent and superplasticizer for the production of high-quality concrete in hot climates. The dual action of Sikament-163 promotes accelerated hardening with high early and ultimate strengths. It complies with ASTM C-494 Type A&F and B.S. 5075 Part 3.

TABLE 1 The Physical Properties of Polypropylene fibers

Shape of fiber	straight
Length	12mm
Diameter	.018mm
Aspect Ratio	666.66
Density	910 kg/mm^3

TABLE 2 THE PHYSICAL PROPERTIES OF STEEL FIBERS

Shape of fiber	straight
Length	63mm
Diameter	0.9mm
Aspect Ratio	70
Density	7800 kg/mm^3

3.2 Concrete Mixes

The concrete mixture was weighed and mixed in mechanical mixer for 2 min. The concrete mixture was cast in steel molds for different tests and compacted. Test specimens were demolded after 24 hours and were cured in water for 7, 28 days. A plain concrete mix (reference mix) was prepared for comparison purposes. The first and second mixture were produced with 0.6% steel fibers and 0.6% Polypropylene fibers separately and three mixtures were produced with the combination of steel and polypropylene fibers at (0.2% St +0.6PP), (0. 4% St +0. 4 PP) and (0.6% St +0.2 PP) by volume of concrete. w/c ratio of 40%. The used dosage of Sikament-163was 1% by weight of cement. Materials required per cubic meter of concrete are shown in TABLE 3.

TABLE 3 Mix Design (kg/m^3)

Mix	W/C	Water	Cement	Coarse aggregate	Fine aggregate	Plasticizer Sika Sikament-163	Polypropylene fibers	Steel fibers
Control	0.4	160	400	1188	660	4	0	0
M1 (0.6%PP)							5.5	0
M2 (0.6%St)							0	46.8
M3 (0.2% St +0.6PP)							5.5	15.6
M4 (0.4% St +0.4 PP)							3.46	31.2
M5 (0.6% St +0.2 PP)							1.82	46.8

3.3 Testing

3.3.1 Fresh Concrete

3.3.1.1 Slump Test

Slump test is to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. Concrete slump test is carried out from batch to batch to check the uniform quality of concrete during construction. The slump test is the simplest workability test for concrete, involves low cost and provides immediate results. The slump is carried out as per procedures mentioned in ASTM C143.

3.3.2 Hardened Concrete

3.3.2.1 Compressive Strength Test

The compression test was conducted of the prepared concrete. The cube specimens with dimensions of 15*15*15 cm were cast. All specimens were provided with sufficient time for hardening (24 hours) and cured for 7 and 28 days. For each age, three (3) specimens were prepared. After the specified period all the specimens were tested for its maximum load in the compression testing machine. The cubes were tested on hydraulic machine 1500 kN capacity [11].

3.3.2.2 Flexural Strength Test

Flexural strength test was carried out on prisms with dimensions 10*10*50 cm on flexure testing machine under four points loading. For each age, three (3) specimens were prepared and cured with two cases of curing methods in water and air. The strength was analyzed for 7 and 28 days. The flexural strength is calculated from the formula as given below [12, 13]: -

Flexural strength $=PL/d1d_2^2$

Where, P the maximum applied load to the specimen (N), d1 the width of the specimen (mm), d2 the depth of specimen (mm).

3.3.2.3 Splitting Tensile Strength

The cylinder specimens with dimensions of 15*30 cm were tested on compression testing machine of capacity 1500KN. The bearing surface of machine was cleaned and other sand or other materials were removed from the surface of the specimen. For each age, three (3) specimens were prepared. The strength was analyzed for 7 and 28 days. The load applied was increased continuously. The tensile strength is calculated from the formula as given below [14]: -

Tensile strength $=2P/\pi DL$

Where, P the maximum applied load to the specimen (N), D diameter of cylinder, L length of cylinder.

3.3.2.4 The Rate of Water Absorption

The cube specimens with dimensions of 10*10*10 cm were cured at age of 7 and 28 days then concrete samples were dried in an oven at a temperature of 100 to 110 °C for not less than 24 hours. After removing each specimen from the oven, samples were cooled in dry air and the mass were determined. Samples were immersed in water at approximately 21°C for not less than 48 hours after final drying, cooling and determination of mass. Samples were removed from water and excess water was toweled and then weighed .The rate of water absorption is calculated from the formula as given below [15]: -

Absorption after immersion% $= [(B-A)/A] *100$

Where
A The mass of oven-dried sample in air
B The mass of surface-dry sample in air after immersion

3.3.2.5 Density

Density (ρ) is the mass of a unit volume of hardened concrete expressed in kilograms per cubic meter. The cube specimens with dimensions of 15*15*15 cm were cured at age of 28 days. Density is calculated from the formula as given blow [16].

$\rho=m/V$

m = the mass of the as-received specimen in air (in kg)
V= the volume of the specimen calculated from its dimensions (in m^3)

4 RESULTS & DISCUSSION

4.1 Fresh Concrete

4.1.1 Slump Test

Slump test was done to evaluate workability for different mixes. The results are shown in Fig. 1. It was noticed that slump value reached to 50 mm at control mix. The slump value decreased for other mixes compared to control mix. The decreasing on slump value were 20%, 10%, 40%, 32%, 26% for M1, M2, M3, M4 and M5 of slump value for control mix. The minimum slump value was in mix M3 of (0.2%St,0.6%PP). This is may be due to the large creation of frictional resistance between polypropylene, steel fibers and the concrete particles.

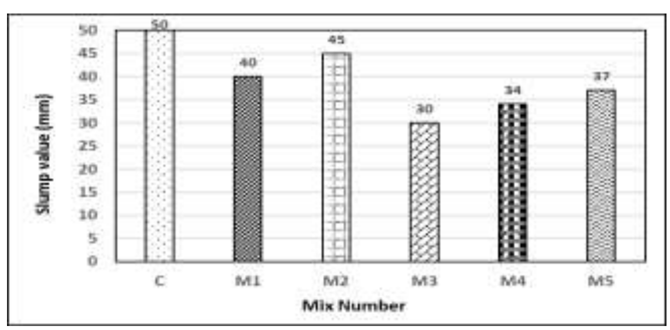

Fig. 1. Slump flow test for different mixes

4.2 Hardened Concrete
4.2.1 Compressive Strength Test

The results of the compressive strength are represented in TABLE 4 and the graphical representation in Fig. 2. At age of 7 and 28 days, Compressive strength increased for all mixes of PP and St fibers except mix M1 of 0.6% PP. The maximum compressive strength reached in the mix M5 of (0.6% St +0.2 PP). It increased by 33.3 % of compressive strength for control mix at age of 28 days. This is may be due to the high elastic modulus of steel fiber and the low elastic modulus of polypropylene fibers. The minimum compressive strength reached in the mix M1 of PP fibers. This is may be due to larger specific surface area of PP fibers increased the air content in concrete which can reduce the compressive strength.

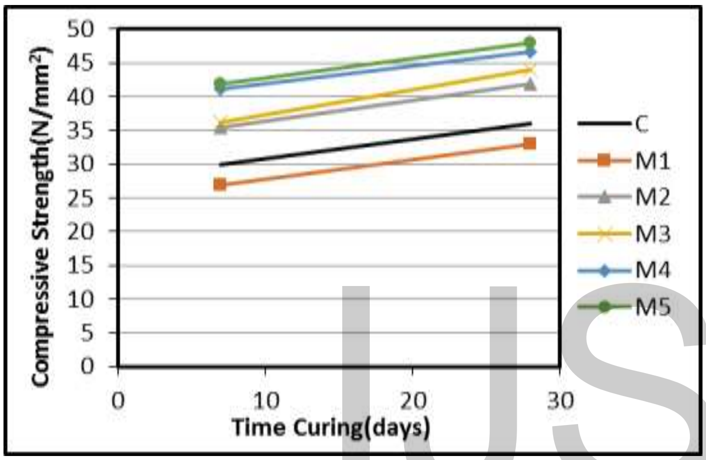

Fig. 2. Compressive strength for different mixes

TABLE 4 COMPRESSIVE STRENGTH (N/MM^2) FOR DIFFERENT MIXES

Mix	Compressive Strength (N/mm²)	
	Age(days)	
	7 days	28 days
C	30	36
M1	27	33
M2	35.5	42
M3	36.3	44
M4	41.1	46.5
M5	42	48

4.2.2 Flexural Strength Test

The results of the flexural strength are represented in TABLE 5 and the graphical representation is shown in Fig. 3. At age of 7 and 28 days, flexural strength increased for all mixes of PP and St fibers compared to flexural strength for control mix. At age of 28 days, flexural strength of mix M5(0.6% St +0.2 PP) had maximum increase; it increased by 48% of flexural strength for control mix. This is due to that prism under four points loading, cracks occur in concrete and fibers limit growth of cracks.

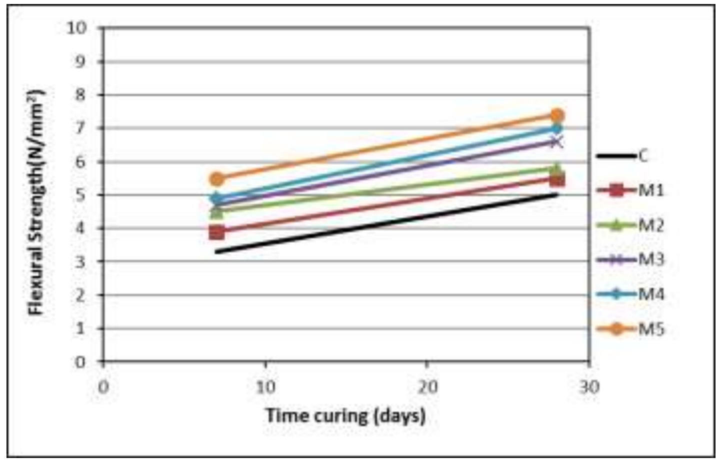

Fig. 3. Flexural strength for different mixes

TABLE 5 FLEXURAL STRENGTH (N/MM^2) FOR DIFFERENT MIXES

Mix	Flexural Strength (N/mm²)	
	Age(days)	
	7 days	28 days
C	3.3	5
M1	3.9	5.5
M2	4.5	5.8
M3	4.7	6.6
M4	4.9	7.0
M5	5.5	7.4

4.2.3 Splitting Tensile Strength Test

The behavior of polypropylene and steel fibers reinforced concrete in splitting tensile strength seems to be similar to that in flexural strength. The results of the tensile strength are represented in Table 6 and the graphical representation is shown in Figure 4. At age of 7 and 28 days, splitting tensile strength increased for all mixes of PP and St fibers compared to splitting tensile strength for control mix. At age of 28 days, splitting tensile strength of mix M5 (0.6% St +0.2 PP) had maximum increase; it increased by 66.7% of flexural strength for control mix. This is due to combination of polypropylene and steel fibers produced an improvement of the split tensile strength.

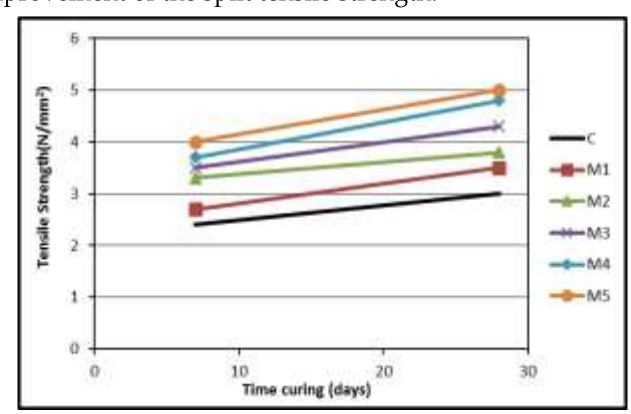

Fig. 4. Splitting tensile strength for different mixes

TABLE 6 SPLITTING TENSILE STRENGTH (N/mm^2) FOR DIFFERENT MIXES

Mix	Splitting tensile strength *(N/mm^2)*	
	Age(days)	
	7 days	*28 days*
C	2.4	3
M1	2.7	3.5
M2	3.3	3.8
M3	3.5	4.3
M4	3.7	4.8
M5	4	5

4.2.4 The Rate of Water Absorption Test

Rate of water absorption results for concrete after7 and 28 days of curing are presented in Fig. 5. At age of 7 and 28 days, rate of water absorption increased for all mixes of PP and St fibers compared to rate of water absorption for control mix. At age of 28 days, rate of water absorption of mix M5 (0.6% St +0.2 PP) had maximum increase; it is increased to 4.9% compared to control mix which its rate of water absorption was 3.9%. The reason is that with an increase of polypropylene and steel fibers in the concrete the degree of compaction of the mixes reduces as a result the volume of air voids in the concrete increase causing an increase in rate of water absorption.

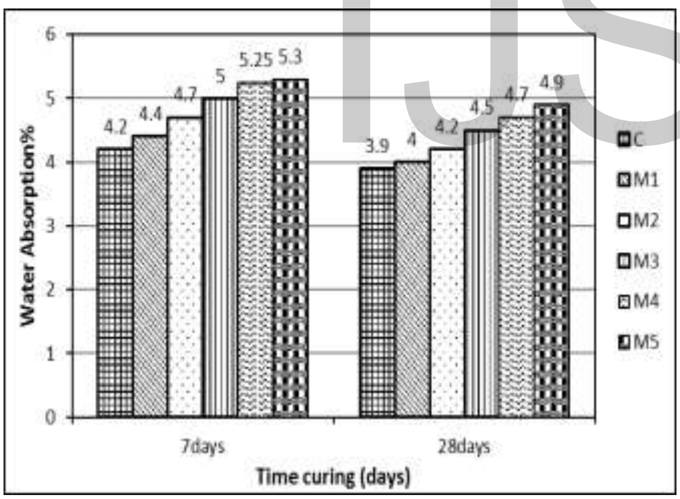

Fig. 5. The rate of water absorption for different mixes

4.2.5 Density Test

The density of the polypropylene and steel fibers concrete after 28 days of curing is summarized in Fig. 6. The density of mix M2 and M5 increased while density of other mixes decreased compared to density of control mix. This may be due to the high density of steel fibers and low density of polypropylene fibers.

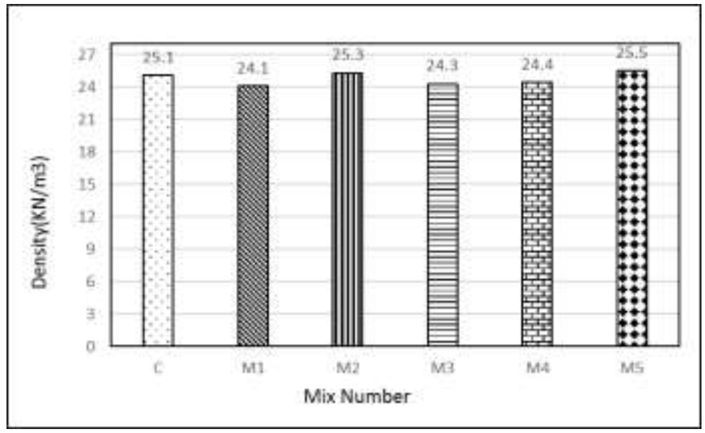

Fig. 6. The density for different mixes

5 CONCLUSIONS

From the experimental study it can be concluded that:

1. The slump value decreased for all mixes of PP and St fibers compared to control mix. The decreasing on slump value were 20%, 10%, 40%, 32%, 26% for M1, M2, M3, M4 and M5 of slump value for control mix.
2. Compressive strength increased for all mixes of PP and St fibers except mix M1 of 0.6% PP. The maximum compressive strength reached in the mix M5 of (0.6% St +0.2 PP). It increased by 33.3 % of compressive strength for control mix at age of 28 days.
3. Flexural strength increased for all mixes of PP and St fibers compared to flexural strength for control mix. At age of 28 days, flexural strength of mix M5 (0.6% St +0.2 PP) had maximum increase; it increased by 48% of flexural strength for control mix.
4. Splitting tensile strength take the same approach. It increased for all mixes of PP and St fibers compared to splitting tensile strength for control mix. At age of 28 days, splitting tensile strength of mix M5 (0.6% St +0.2 PP) had maximum increase; it increased by 66.7% of flexural strength for control mix.
5. At age of 7 and 28 days, rate of water absorption increased for all mixes of PP and St fibers compared to rate of water absorption for control mix. At age of 28 days, rate of water absorption of mix M5 (0.6% St +0.2 PP) had maximum increase; it is increased to 4.9% compared to control mix which its rate of water absorption was 3.9%.
6. The density of mix M2 and M5 increased while density of other mixes decreased compared to density of control mix.

REFERENCES

1. Al-Bayati ESN, "Flexural Behavior of Hybrid Polypropylene and Steel Fiber Reinforced Concrete T-beam", MSc. Thesis. Tikrit University; Tikrit, Iraq: 2012.
2. Li, Y., Zhang, Y., Yang, E., and Tan, K.H.," Effects of Geometry and Fraction of Polypropylene Fibers on Permeability of Ultra-High-Performance Concrete After Heat Exposure", Cement and Concrete Research, Vol. 116, pp. 168-178, 2019.
3. Kakooei, S., Akil, H.M., Jamshidi, M. and Rouhi, J.," The Effects of Polypropylene Fibers on The Properties of Reinforced Concrete Structures", Construction and Building Materials, Vol. 27, pp. 73-77, 2012.
4. Yousefieh, N., Joshaghani, A., Hajibandeh, E. and Shekarchi, M.," Influence of Fibers on Drying Shrinkage in Restrained Concrete", Construction and Building Materials, Vol. 148, pp. 833-845, 2017.
5. Medina, N.F., Barluenga, G. and Olivares,F.H. ," Combined Effect of Polypropylene Fibers and Silica Fume to Improve The Durability of Concrete with Natural Pozzolans Blended Cement", Construction and Building Materials, Vol. 96, pp. 556-566, 2015.
6. Qin, Y., Zhang, X., Chai, J., Xu, Z. and Li, Sh.," Experimental Study of Compressive Behavior of Polypropylene-Fiber-Reinforced and Polypropylene-Fiber-Fabric-Reinforced Concrete", Construction and Building K.H.,Materials, Vol. 194, pp. 216-225, 2019.
7. Li, Y., Tan, K.H., Yang, E.," Synergistic Effects of Hybrid Polypropylene and Steel Fibers on Explosive Spalling Prevention of Ultra-High-Performance Concrete at Elevated Temperature", Cement and Concrete Composites, Vol. 96, pp. 174-181, 2019.
8. Sadiqul Islam, G.M. and Gupta, S.D.," Evaluating Plastic Shrinkage and Permeability of Polypropylene Fiber Reinforced Concrete," International Journal of Sustainable Built Environment, Vol. 5, pp. 345-354, 2016.
9. Dahake, A.G. and Charkha, K.S.," Effect of Steel Fibers on Strength of Concrete", Journal of Engineering, Science & Management Education, Vol. 9, pp. 45-51, 2016.
10. Abdul-Rahman, M.B., Ali, A.A. and Younus, A.M.," Effecting of Steel Fibers and Fly Ash on the Properties of Concrete", Tikrit Journal of Engineering Sciences, Vol. 25, pp. 12-18, 2018.
11. ISO 4012 Concrete-Determination of Compressive Strength of Test Specimens.
12. ISO 1920 Concrete Tests-Dimensions, Tolerances and Applicability of Test Specimens.
13. ISO 4013 Determination of Flexural Strength of Test Specimens.
14. BS-1881 Testing Concrete, Part 117 Method of Determination of Tensile Splitting Strength
15. ASTM C642. Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. Philadelphia (PA): ASTM; 2001.
16. BS 1881. Part 114 Methods for determination of density of hardened concrete