



Effect of Nanomaterial on the Properties of Ultra High Performance Concrete

Nada Mahdi Fawzi Aljalawi

Civil Engineering Department, College of Engineering, University of Baghdad – Iraq

Article information

Article history:

Received: September, 10, 2021

Accepted: October, 12, 2021

Available online: October, 20, 2021

Keywords:

Ultra High-Performance Concrete,
Sustainable material,
Ordinary Portland cement,
Silica fume

*Corresponding Author:

Nada Mahdi Fawzi Aljalawi

nada.aljalawi@coeng.uobaghdad.edu.iq

DOI:

<https://doi.org/10.53523/ijoirVol8I2ID76>

Abstract

In recent years, there is a great interest in many countries to use the limestone powder in produce concrete by the replacing it as a proportion of cement weight able to improving the properties of the concrete as well as this type of powder lead to the reducing concrete cost and the CO₂ emissions through the process of cement industry. This study examined of the effect of the limestone powder indifferent proportion (5, 10, 15, and 20) % replaced by the weight of cement on the properties of Ultra High Performance Concrete). Where it included five tests consisted of workability of fresh concrete (slump test method), compressive strength, tensile strength, water absorption, and density. The Results show the possibility of replacing 15% of the cement weight with limestone powder lead to improving of concrete strength but negative effects on the properties observed as the amount of limestone powder exceeds this ratio.

1. Introduction

Ultra-high-performance concrete (UHPC) is an engineered cementations material which exhibits remarkable mechanical properties and excellent durability. With the consolidation of an addition degree about steel fibers (minimum of 3% by vol.), strain solidifying (SH) ultra-high-performance fiber strengthened solid (UHPC) can be produced which show reasonable tensile strengths and strain hardening (compressive strength > 150 MPa, tensile strength > 8 MPa with 1.5 strain hardening). UHPFRC offers the possibility from claiming outlining inventive structures and to new a considerable length of time it need been exhibited that UHPFRC can be used as a rehabilitation material for present structures [1]. Limestone has been utilized within concrete settling on to the most recent 25 years, not just those fundamental purposes for bringing down those overheads What's more natural load about bond production, in any case Also to increment those cement durability, further recently limestone is likewise utilized Likewise a filler material should expansion that workability Also soundness about new cement What's more to An secondary stream capable concrete, for example, self-compacting cement. [2]. Previously, late years, there is a produced vitality in the use of pounded sand gotten starting with limestone quarries On a few nations the place waterway sand will be not generally accessible. Also, the interest for aggregates to process cement is still secondary same time typical intends decline. An expansive amount about material in the measure from claiming filler will be handled through those span about pulverizing those powerless limestone, over specific, which might great a chance to be utilized concerning illustration an aggravator. The application of these resources is helpful to improving the concrete so as to reduction air voids [3].

The commercial importance of limestone's today lies chiefly in their reservoir properties since many of the world's major petroleum reserves are limited within carbonate rock [4] Limestone are public and common rocks and many significant as a source of lime to make cement component of all concrete, brick, stone buildings and other structures, such as bridges and dams. Limestone layers are common finished much of the stratigraphic record and include some very characteristic rock units, such as the Late Cretaceous Chalk, a relatively soft limestone that is found in many parts of the world [5]. The aim of this research is using a sustainable material to produce a new material with better properties and lower cost.

2. Experimental Procedure

2.1 Materials

Cement

Ordinary Portland cement (Type I) used in this study It conformed to the Iraqi Specification IQS No. 5/2019 type [15].

Aggregate

AL-Ukhaider Natural sand as a fine aggregate was used for concrete mixes of this work. The chemical and physical properties within the limit specified by Iraqi standard IQS No.45/1984, [16].

Mixing Water

The water used in this research within Iraqi to spes.No.1703/1992, [17].

Limestone Powder

The limestone powder was used within Limits of Iraqi Spec. No.807/ 2004, [18], It has been used as a mineral admixture added to the mixture in this research by replacement (5,10,15,20) % of cement weight The chemical composition and physical properties of limestone in Table (1 & 2).

Table (1). Chemical composition of limestone powder.

compound composition	Test Result	Limits of Iraqi spec. No.807
CaO	52.2	min45%
SiO ₂	35.7	min25%
F ₂ O ₃	27	min25%
Al ₂ O ₃	33	min25%
MgO	3.4	max5%

Table (2). Physical properties of limestone powder.

Physical properties	Test Result	Limits of Iraqi spec.No.807
The retain on sieve 0.85	0.15	max 5%
Initial setting time	2.5	min 2 hr.
Final setting time	34	max 48 hr.

Micro steel fibers (msf)

In this study used micro steel fibers (msf) show Figure (1) fiber its properties in Table (3).



Figure (1). Micro steel fiber (msf).

Table (3). Micro steel fiber propriety.

Length	13 mm
Diameter	200 um
Specific gravity	1.3
Tensile strength	2300 MPa

HRWRA

The workability was adjusted by using high range water reducing admixture (super plasticizer) commercially known as Sika *Viscocrete*-5930 produced by sika Company. The recommended dosage by the manufacture was in the range (0.8- 2) % liters /100kg of the cement. This type of admixture within the limit specified ASTM C494 type, G, [19].

Nano Silica fume (NSF) Silica fume has been used as a mineral admixture added to the mixes of this study. The percentages used were 23%, as partial replacement of cement weight chemical composition and physical properties of SF are shown in Table (4). SF used in this work with in the requirements of ASTM C1240-16, [20].

Table (4). Chemical and physical properties of Silica fume.*

Oxide composition	Oxide content	ASTM C1240-16
SiO ₂	89.2	Min 85%
Al ₂ O ₃	1.3	-
Fe ₂ O ₃	1.8	-
MgO	2.3	-
LOI	2.5	Max.6%
CaO	2.5	-
Physical properties		
Specific gravity	2.016	
particle size	40 nm	
Physical form	powder	

*Manufacture properties.

Concrete Mixes

The ACI 237R-07 [21], process followed to design the mixes of UHPC to achieve characteristic compressive strength of 155 MPa at 28 days, and provides a guideline for proportioning mixtures, the batches were prepared as trials mixes, and then the optimum proportions regulate to follow the fresh and hardened properties of the standard specifications. water to cement ratio (w/c) equal to 0.18 The proportions of mixes in this study lime stone powder changed as a replacement by cement weight in changed percentages (5,10,15,20) %, the mix proportion are given in Table (5).

Table (5). Mix proportion of lime stone powder and cement.

Mix	Details	CEMENT Kg /m ³	Fine aggregate Kg /m ³	Lime stone powder (LP)kg/m ³ as partial replacement of cement	Nano silica Kg /m ³ As partial replacement of cement	Weight Water kg/m ³	Micro steel fiber% by volume	Dosage of HRWR Liter/100kg of cement	w/p
MR	0%LP	800	983	0	186.5	144	1	0.8	0.14
M1	5%LP	760	983	40	186.5	144	1	0.8	0.14
M2	10%LP	720	983	80	186.5	144	1	0.8	0.14
M3	15%LP	680	983	120	186.5	144	1	0.8	0.14

Concrete Preparation

The mixing procedure is done according to ASTM C192 [22]. Firstly, the Cement, silica fume, and sand were charge together in planetary high speed mixed for 2 minutes. Then Half of the full quantity of super plasticizer was mixed with water and the mixture and it was added gradually to the dry mixture for 8 to 10 minute after that superplastizer was added slowly and mixing was continuous for about another 5 minutes then, the steel fibers were added to the mixture slowly, then the fibers charged completely in, the mixing was continued for a more period of 3 minutes to verify that the fibers good distributed in mixture of UHPC.

Casting and Curing

mixture casted with in first 20 minutes of mixing to get specimens for the test compress strength and the mixture into molds kept on a vibrating table and then vibrating the table for about 30 seconds later filling to consolidate the mixture covered the sample for 24 hours in the laboratory then submerged in water tank for 28-day curing before testing for compressive strength.

2.2 Testing

Flow Test

Workability Determination of the Concrete Mixtures The flow ability was tested by the flow table test in accordance with ASTM C-1437, [23]. The flow is the resulting increase in average base diameter of the mortar mass, expressed as a percentage of the original base diameter of Flow table cone (100 mm), where flow value = $(d1+d2)/2$.

Compressive Strength Test

The Compressive strength test determine with British slandered Bs.1981: part 116 (1983), [24] by normal cubes samples of (100) mm side length, were cubes, and the average of three samples were used for each mix. Each concrete cube was placed in the compression device on one of its sides after cleaning the faces of the cube) so that the compressive load was applied perpendicularly to the direction of concrete placement in the molds at constant amount the cubes were tested at the age of 7, 28, 90 days.

Splitting tensile strength test

It was conducted on the samples with a (ASTM) C496/C496M, [25]. Splitting tensile strength tested with. Cylindrical specimens of (150×300) mm was used determine the splitting tensile strength according to ASTM C 496 using the compressive device. In this test way, a diametric compressive force applied along the side of a

concrete cylindrical sample until tensile failure occurs. Steel plate of the compressive machine is used to distribute uniformly the load applied along the length of the cylinder. The cylinders are tested at the age of 7, 28. Cylinders was taken as shown in the following equation

$$\tau = 2P / \pi LD$$

where: T: Splitting tensile strength (MPa), P: Max. Applied load (NL), L: Length (mm), D: Diameter (mm).

Total Water Absorption Test

The absorption tested according to ASTM C642 [26]. A 100 mm cubic sample used throughout this test.

$$\text{Absorption\%} = ((Ba-Aa)/Aa) *100$$

where: Aa = oven dry weight (gm.), Ba = saturated surface dry weight (gm.), This test was at 28 days.

Density

The density test of concrete is determined by used (100*100*100) mm concrete cubes in dry air by calculating the dimensions and weight of specimens using the measurement feet (vernier) and the electrical scale. The test is done according to ASTM C642.

3. Results and Discussion

3.1 Workability

The flow ability results for mixes changed with the several proportion of lime powder show the slump reduced with increase of replacement proportions of limestone powder due to the nature, surface feature and accuracy of the size of the powder granules and the fine of limestone particles (finer than cement) is related to the relatively high water absorption capability which is attributed chiefly to the great specific surface of limestone powder where Slump reduction 25% of mix 5 compared with reference mix show Table (6) and Figure (2).

Table (6). The effect of limestone powder on the slump.

Mix/ no	Limestone powder %	w/c %	Sp%	Slump (mm)
MR	0	0.18	0.8	210
M1	5	0.172	1.1	208
M2	10	0.165	1.2	204
M3	15	0.162	1.3	185
M4	20	0.153	1.4	180

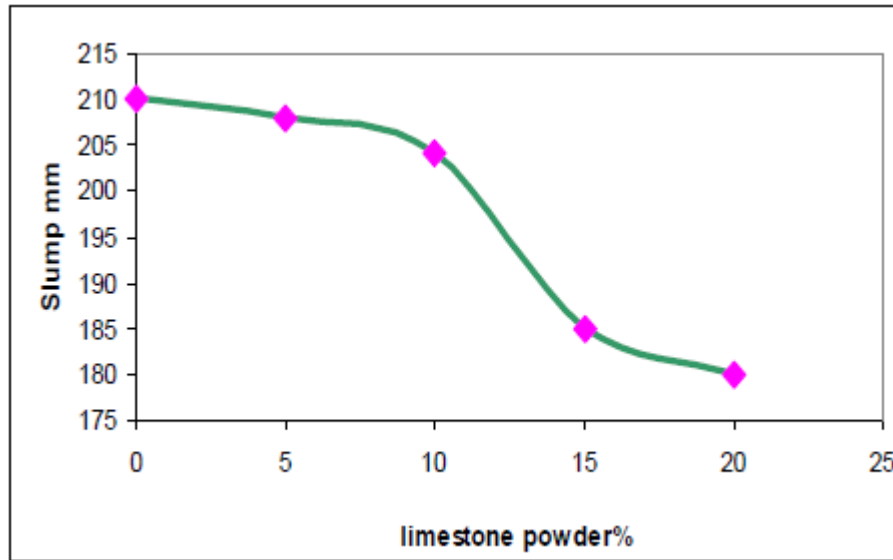


Figure (2). The effect of limestone powder on the slump.

3.2 Compressive Strength

Figure (3) displays the changed of compressive strength with different % of LP, it can be seen that a 15 % LP causes increase in the compressive strength about 15 %, 7.7%, 9% compared with the reference mix at the age (7,28,90) day respectively and 20% additional of limestone powder which reduced about 11 %, 2% and 3 % of the compressive strength at age 7, 28 and 90 day, where its presence by 15% led to an improved in resistance with a more regular distribution of lesser C-S-H minerals, finer pore structure, accelerated cement hydration. Moreover, the bond between cement paste and the good result providing by the fine particle but the increases in amount of fines so much led to make the cement paste is not able to coat all fine and coarse particles, so drop in the reactive clinker component results in significant physical modifications of the material. This phenomenon declining the cement-to aggregate bond and leads to a damage in compressive strength for upper filler quantities than the optimal value of LP addition that in this study was limited by (15%) limestone shows Table (7) and Figure (3).

Table (7). Compressive strength value.

Mix type	Limestone powder%	SP %	w/c %	Water Kg/m ³	Compressive strength (MPa)		
					7day	28 day	90day
MR	0	0.8	0.18	144	110	133	160
Max1	5%	1.1	0.172	144	113.5	157	175
Max 2	10%	1.2	0.165	144	124	167	182
Max 3	15%	1.3	0.162	144	126	170.5	185.5
Max 4	20%	1.4	0.153	144	112	135	165

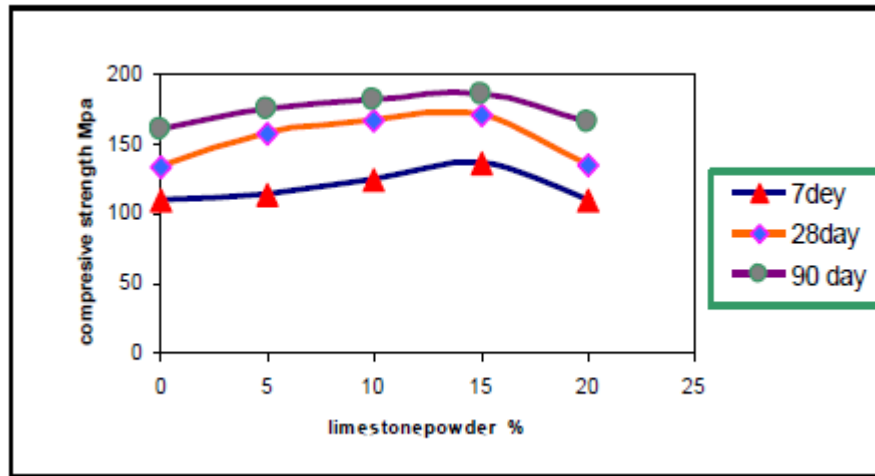


Figure (3). Compressive strength with replacement of LP.

3.3 Splitting Tensile Strength Test

The splitting tensile strength of concrete increasing with the increase limestone powder and reached to (23, 6, 19) % at (7, 28, 90) days, respectively with 15% replacement of limestone powder compared with reference mix. These results are due to the bond between cement paste and sand particles may be strengthened and provide a good effect by the fine particles and improving the quality of the interfacial zone, but the tensile strength reduce to (21, 7, 5) % at (7, 28, 90) day compared with 20% replacement of limestone powder due to of fines so greatly run to create the cement paste is not able to coat all fine and coarse particles, so drop in the reactive clinker component. And weakened the cement-to aggregate connection and leads to a loss in tensile strength show Table (8) and Figure (4).

Table (8). Splitting tensile strength of concrete mixtures.

No/Max	Lime stone addition %	Splitting tensile strength (MPa)		
		7 day	28day	90 day
Mix R	0	5.1	6	6.3
Mix 1	5	5.5	6.1	6.5
Mix 2	10	6	6.7	6.9
Mix 3	15	6.3	7	7.5
Mix 4	20	6.2	6.4	6.6

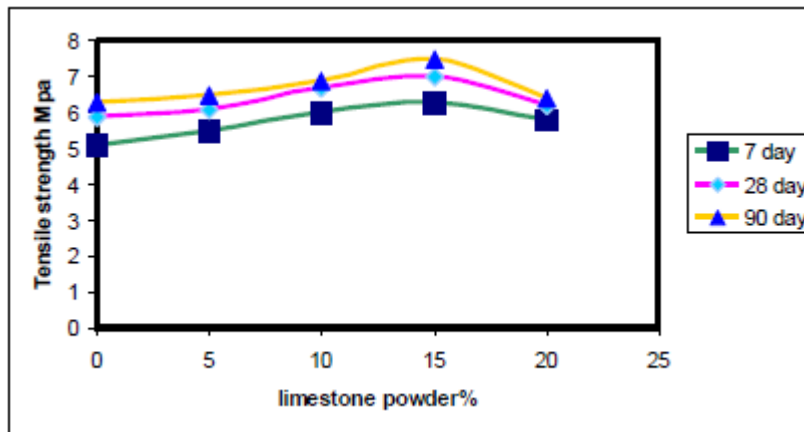


Figure (4). The Influence of the limestone powder on splitting tensile strength.

3.4 Total Water Absorption

The results of the total absorption of several kinds of studied concrete mixes are showing in Table (9) and Figure (6). The effects usually show that all concrete mixes exhibit continuous reduction in the total absorption values with the use of limestone powder the ratio of absorption reached with 15% replacement of limestone powder (6.02). This performance for that is due to the surface area and particle size of limestone powder and ability of it to the bond among cement paste and sand particles and afford a good result by the fine particles and improving the quality of the interfacial zone, shown in Table (9) and Figure (5).

Table (9). Total water absorption result.

Max No	Lime stone addition (%)	Absorption% at 28 day
Mix R	0	6.6
Mix 1	5	6.3
Mix 2	10	6.2
Mix 3	15	6.02
Mix 4	20	6.06

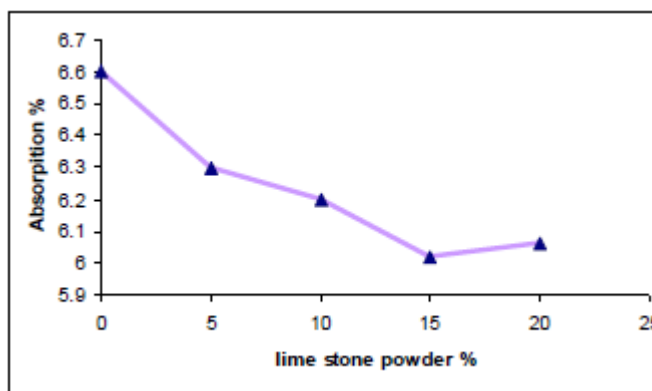


Figure (6). The influence of the limestone powder on the water absorption for concrete.

3.5 Density

Table (14) & Figure (7) shows the variation of concrete density with the percentage of LP as a partial replacement with cement, the density increases up to an optimal value at amount 15% compensating and then reduction for upper ratio. This is due to lime stone powder worked as filler powder first filling voids around sand grains, up to

the optimum. For maximum limestone powder quantities, those voids being completely filled, filler powder then occupies the place of sand grains, hence diminishing sand quantity, and consequently the mix density.

Table (10). Density test of mixes concrete.

NO/Max	Lime stone addition (%)	Density (Kg/m ³)
Mix R	0	2510
Mix1	5	2512
Mix 2	10	2514
Mix 3	15	2520
Mix 4	20	2512

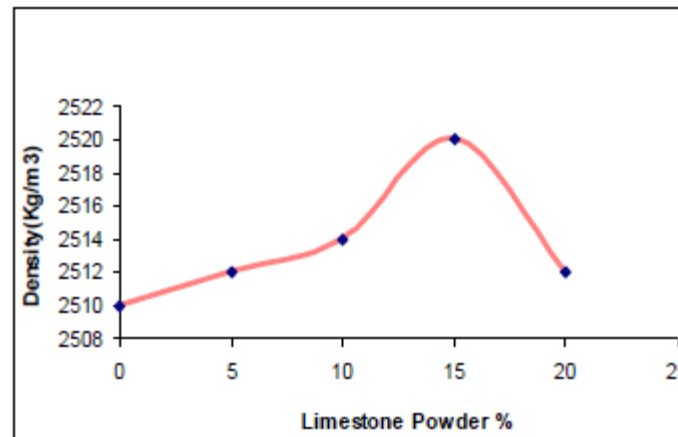


Figure (7). The influence of the limestone powder on the density of concrete.

4. Conclusions

1. Workability reduced with the increase of the proportion of replacement of limestone powder replaced in the mixtures.
2. The mix with 15% replacement of cement with limestone had significantly investigated higher compressive strength values around 15% at ages 28 days compared with reference mix.
3. Partial replacement of cement by limestone powder increase the splitting tensile strength, as the replacement ratio (15%) of limestone powder improved up 6% of tensile strength more than reference mix, but it decreased by the replacement rate to 20 % of limestone powder to (7%) compared with reference mix.
4. The addition of lime stone powder (LP) to mixture led to reducing in the total absorption values (38, 30, 20) % for using (5, 10, 15) % of LP at age 28 days.
5. The addition of lime stone powder (LP) to the mixture led to increase of density of concrete where 15%.
6. replacement of cement with limestone could significantly investigated higher density values about 10% higher from reference mix.

References

- [1] E. Brühwiler and E. Denarié, “Rehabilitation of concrete structures using Ultra-High Performance Fibre Reinforced Concrete”, The Second International Symposium on Ultra High Performance Concrete, March 05 - 07, 2008, Kassel, Germany, pp. 1–8, 2008.
- [2] O. Esping, “Effect of limestone filler BET (H₂O)-area on the fresh and hardened properties of self-compacting concrete”, *Cem. Concr. Res.*, vol. 38, p. 938–944, 2008.
- [3] Ilker Bekir Topcu and Ali Ugurlu, “Effect of the use of mineral filler on the properties of concrete”, *Cem. Concr. Res.*, vol.33, Issue7, p. 1071–1075, 2003.
- [4] G. Nichols, *Sedimentology and Stratigraphy*, second, A John Wiley & Sons, Ltd., 2009.
- [5] Y.Benachour, C.A.Davy, F.Skoczylas, and H.Houari, “Effect of a high calcite filler addition upon microstructural, mechanical, shrinkage and transport properties of a mortar” *Cem. Concr. Res.*, vol. 38, p. 727–736, 2008.

- [6] A.Yahiaa, M.Tanimura, and Y.Shimoyama, Rheological properties of highly flowable mortar containing limestone filler-effect of powder content and W/C ratio, *Cem. Concr. Res.*, vol. 35, Issue 3 -532–539, 2005.
- [7] R.B.A. Alshahwany, “Effect of Partial Replacement of Sand with Limestone Filler on Some Properties of Normal Concrete”, *Al-Rafidain Eng.*, vol.19, Issue 3, p. 37–48, 2011.
- [8] N.M.F. and Alwaan,” Effect of Steel Fiber on Properties of High Performance No-Fine Concrete” *Int. J. Eng. Technol.*, vol.7, p. 30–32, 2018.
- [9] W. Huang, H. Kazemi-Kamyab, and W. Sun, K. Scrivener, “Effect of cement substitution by limestone on the hydration and microstructural development of ultra-high performance concrete (UHPC)” *Cem. Concr. Res.*, vol. 77, p. 86–101, 2017.
- [10] H.M. Ahmed and R.N. Wadie, “Properties of Self Compacting Concrete Containing Limestone Powder as Replacement of Sand” *Journal of Engineering and Development.*, vol.15, p. 1813-7822, 2011.
- [11] Nada Mahdi Fawzi and A.S.T. Agha, “The Effect of Curing Types On Compressive Strength of High Performance Concrete”, *Journal of Engineering and Development*, vol.18, no 7, 2012.
- [12] J. F.Burroughs, JayShannon, T.S. Rushing, Y. Kevin, Q. B.Gutierrez, D. W.Harrelson, “Potential of finely ground limestone powder to benefit ultra-high performance concrete mixtures”, *Construction. Building Material*, vol.141, p. 335–342, 2017.
- [13] Nada Mahdi Fawzi and Aliaa F "Produce High performance concrete by use different types of local pozolans" *Journal of Engineering*, vol. 15, 2009
- [14] Nada Mahdi Fawzi Aljalawi, Effect of sustainable palm fiber on high strength concrete properties, *IOP Conference Series: Materials Science and Engineering*, vol. 518, Issue 2, 2019.
- [15] Iraqi Standard Specification, No 5/2019 “Portland Cement”.
- [16] Iraqi Standard Specification, No 45/1984 “Aggregate from Natural Sources for Concrete and Construction”.
- [17] Iraqi Standard Specification, no 1703/1993 “water used in concrete”.
- [18] Iraqi Standard Specification, no 807/1988 “Lime That Used in Building”.
- [19] ASTM C494/C494M-19.,” Standard Specification for Chemical Admixtures for Concrete
- [20] ASTM C1240-15,” Standard Specification for Silica Fume Used in Cementitious Mixtures”
- [21] A.C.I 237R Committee, “Self-Consolidating Concrete”, 2016
- [22] ASTM C192/C192M – 16a,” Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory”
- [23] ASTM C1437 – 15, “Standard test method for flow of hydraulic cement mortar”
- [24] British Standard: BS 1881-116, Testing Concrete: Part 116: “Method for determination of compressive strength of concrete cubes” (1983).
- [25] ASTM C496/C496M –11,” Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens”.
- [26] ASTM C642-13, “Standard Test Method for Density, Absorption, and Voids in Hardened Concrete”.