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Influence of Aggregate Size on Self Compacting Concrete using Nafores 801 Liquid as Plasticizer

*Olatoyan Oladele John[1], Ajayi Oluwarotimi Wale[2], Olusami Joel Olusoji[3]
Omajali Deborah Ihotu[4]

[1,3,4]Department of Civil Engineering, Federal Polytechnic, Ede, Osun State, Nigeria
[2]Department of Civil Engineering, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria

Abstract: *Self-Compacting Concrete (SCC) is highly useful in congested reinforced structures where vibration or compaction prove difficult. It's a concrete that can flow, consolidate under its own weight and completely fill the formwork without further vibration. In this research, laboratory investigation of SCC mix prepared from three different recipe set of aggregates (20mm, 12.5mm, and 10mm) down size and mix designed for 1: $1^1/_2$: 3 mixing proportion with w/b ratio of 0.56 and Sulphonated Naphthalene Formaldehyde dosage (1.2% by weight of cement) was affirmed based on field trial. The SNF acting as Super plasticizer (Water Reducing Agent) and influence of the admixture was examined via the workability tests. However, it was examined by using the slump flow test, V – flow, and L – box test. The designed mix achieved consistency and self compatibility under its own weight without any external vibration or compaction. 150mm x150mm x 150mm cube specimen cast was done and thereafter cured for twenty eight (28) days. The strength development for each of the specimen at 3, 7, and 28 days for the respective mix was examined and the results showed that increase in the compressive strength with respect to the curing age, enhancement in workability, reduction in shrinkage, and bleeding of the concrete mix of SCC holds to the inclusion of Super Plasticizer in the mix. The significance of this research work lies in its attempt to provide information on the performance of Self Compacting Concrete made from different recipe sets of aggregate and its major advantage in salvaging time and labour.*

Keywords: *Aggregate, Curing, Self-Compacting Concrete (SCC), Sulphonated Naphthalene Formaldehyde, Plasticizer, Strength, and Workability.*

I. Introduction

Self Compacting Concrete (SCC) also known as Self-consolidating concrete is an intuitive innovative concrete that acknowledges the addition of plasticizer and stabilizer to the concrete mix to significantly increase the ease and rate of flow. Plasticizers are additives that alter the plasticity or fluidity of a material, they are introduced in other to increase or improve concrete's workability as well as its strength. By its very nature, SCC does not require vibration for placing and compaction. It achieves compaction into every part of the mould or formwork simply by means of its own self weight without any segregation of the coarse aggregate. Self compacted concrete is highly flowable concrete which can spread at all narrow space of congested area (especially in highly reinforced area) under its own weight without need of external vibration. It is characterized by its fresh properties such as filling ability, passing ability, and resistance to segregation.

However, the hardened concrete is dense, homogeneous and has the same mechanical properties and durability as traditional vibrated concrete. Its popularity usage in concrete construction is increased in many countries, since SCC is effectively applied for improving durability of structures while reducing the need of skilled workers at the construction site. The health and safety benefits, and the improved construction and performances results make it a very attractive solution. Self-compacting concrete (SCC) offers various advantages in the construction process due to its improved quality, and productivity. It also has higher powder content to a lower coarse aggregate volume ratio as compared to normally vibrated concrete (NVC) in order to ensure its fresh properties mentioned earlier. If only cement is used in SCC, then it become uneconomical, susceptible to be attacked and produces much thermal crack. It is therefore necessary to replace some of the cement by addition of filler to achieve an economical and durable concrete.

This study concerns the durability of self-compacting concrete (SCC). Since its earlier usage in Japan at the end of the century, SCC has been increasingly used in ready-mixed concrete and in the precast industry to improve several aspects of construction. it is also expected to replace vibrated concrete (VC) in many applications in the long term because of its various advantages; reduction of the harmful effects of sound in urban environments, possibility of pouring in strongly reinforced places or with complex geometry, and reduction in the industrial process costs [1]. The fresh properties and rheological characteristics of SCC are different than that of normal concrete, but both SCC and normal concrete may exhibit comparable mechanical properties if designed for similar strength grades. Yet, due to the difference in mixture design, placement and consolidation techniques, the durability of SCC may be different to that of normal concrete, and thus needs thorough investigation [2, 3]. On the basis of the above studies, this work is aimed at investigating the influence of recipe sets of aggregate nature (size and shape) on self consolidating concrete's compressive strength and workability using sulphonated naphthalene formaldehyde as plasticizer to ascertain the intuitive nature and acceptability of SCC and its usage in construction industry.

II. Materials And Research Methodology

Conventional concrete tends to have a difficulty regarding the adequate placing and consolidation in thin sections and areas with congested reinforcement, which leads to large volume of entrapped air voids (formation of honey comb) thereby, compromises the strength and durability of such concrete. Using self compacting concrete (SCC) can eliminate the problem to the minimal, since it is designed to consolidate under its own self weight. Therefore, it is important to verify the mechanical properties of SCC before using it for practical applications. This research section was conducted to find out whether self compacting concrete would show an improvement in compressive strength as well as workability and yield a better bonding between aggregate and cement paste, in order to be used as a replacement for conventional concrete in highly reinforced areas in the construction industry.

2.1 Materials used and their Properties

2.1.1 Portland Cement

ASTM type I Portland cement is general-purpose cement suitable for all uses where the special properties of other types are not demanded. Its uses in concrete work include pavements, floors, reinforced concrete buildings, bridges etc. and it has the physical properties presented in TABLE 1 below accrue to itself. However, this work incorporated the use of commercially available ordinary portland cement (OPC) of 42.5R grade manufactured by Dangote Cement Plc.

Table 1: Physical Properties of Cement

Properties	Results obtained	Standard Requirement EN 197-1 BS 12-1996
Fineness	9	9 - 11
Consistency (%)	27.5	26 - 33
Initial setting Time, (min.)	150	30 minimum
Final setting Time, (hrs)	4.50	10 maximum
Specific gravity	3.15	-

Source: [4].

2.1.2 Aggregates

The fine aggregate (natural sand passing through 4.75mm IS sieve) used in casting the concrete cube was very clean and has the maximum size of 2mm. It was sourced within Ogbomoso community in south west part of Nigeria, which has quite big deposits of different types of sand. The bulk densities (for loose and compacted density) as well as specific gravity test were determined as per [5] and the results obtained were 1600.133 kg/m^3, 1718.063 kg/m^3, and 2.65 respectively. Also, the coarse aggregate used in the concrete mixtures was crushed stone (granite) available at quarry site along Ogbomoso – Oyo Express Way, Ogbomoso and having the maximum sizes; 20mm, 12.5mm, and 10mm down size. Their properties are presented in TABLE 2 below.

2.1.3 Water

The water used in the mix design was potable water obtained from the water-supply network system within Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria; it was free from suspended solids particles and organic materials which might have affected the properties of the fresh and hardened concrete.

Table 2: Properties of Coarse Aggregate

S/N	Attributes	Size of Coarse Aggregate (mm)		
		20	**12.5**	**10**
1	Passing through IS Sieve	20	12.5	10
2	Retained on IS Sieve	16	10	4.75
3	Loose Density (kg/m^3)	2.766	2.841	2.822
4	Compacted Density (kg/m^3)	1363	1437	1452
5	Fineness Modulus	7	6	5
6	Water absorption (%)	0.42	0.46	0.50

2.1.4 Chemical Admixtures

Chemical admixtures represent those ingredients which can be added to the concrete mixture immediately before or during mixing. The use of chemical admixtures such as water reducers, retarders, high-range water reducers or super plasticizers (SP), and viscosity-modifying admixtures is necessary in order to improve some fundamental characteristics of fresh and hardened concrete. They make more efficient use of the large amount of cementitious material in high strength and self-compacting concretes and help to obtain the lowest practical water to cementing materials ratio. The chemical admixture used to ascertain the intuitive nature of SCC in this research was Sulphonated Naphthalene Formaldehyde (SNF) based super plasticizer complying with ASTM C - 494 type F which was obtained from Structural Laboratory, Department of Civil Engineering LAUTECH, Ogbomoso, Nigeria. The properties of the admixture, as provided by their manufacturers (Mena Chemicals Industries Co. Ltd), are given in TABLE 3.

Table: 3: Typical Properties of Nafores 801 Liquid

Appearance	**Clear Brown Liquid**
Specific gravity @ 25^{o}C	1.19 - 1.24
PH @ 25^{0}	7 – 9
Solid Content (% by mass)	43 ± 1
Dilution in water	In any ratio (dilutes rapidly in hard or soft water)
Sodium Sulfate Content (% by Mass)	3 – 4
Chlorides (PPM)	250 max
Miscibility with water.	Miscible in all proportions
Shelf Life @ 25^{0}C	6 months minimum

Source: Mena Chemicals Industries Co. Ltd.

2.1.4.1 Super Plasticizer Dosage

Addition of adequate Super Plasticizer (SP) dosage can improve the flowability, self compacting ability and segregation resistance of fresh SCC for meeting the design requirements. Water content of the SP can be regarded as part of the mixing water [6]. However, in the present work, SNF condensate (SP 430) was used as a water reducing agent (Super Plasticizer). The dosage was obtained base on trial and error to suit the European Federation of National Associations Representing for Concrete (EFNARC) requirements. The SP dosage ranging from 1.0 to 1.5% by weight of cement was used.

(a): Cement **(b): Fine Aggregate**

(c): Coarse Aggregate **(d): Super Plasticizer**

Figure 1: Materials used

2.2 Research Methodology

2.2.1 Concrete Mix Design Batch

In this study, the material quantities required for 1m^3 of SCC Mix designed for 1 : $1^1/_2$: 3 mixing proportion with w/b ratio of 0.56 were estimated in Kilogram (kg) using the Absolute Volume Method (TABLE 4). Concrete batch was based on the respective recipe sets of grit sizes (20mm, 12.5mm, and 10mm) down, after the concrete had been manually prepared with 70 per cent volume of the estimated water, the required chemical

(Nafores 801L) dosage was thereafter mixed with the remaining volume of water and added to the concrete mix and thoroughly re-mixed together for few minutes before casting was done.

Table 4: Material Quantities for 1m^3 of SCC

Mixture ID	Raw Material used for designed concrete	Dosage (%)	Needs for 1m^3 of Concrete (kg)	Spec. Density (kg/l)	Yields Litre For 1m^3
SCC20	Cement	-	394.52	3.15	125.24
	Supper Plasticizer	1.2	4.73	1.19	3.98 (incl. in water)
	Water (w/b = 0.46)	-	181.48	1.00	181.48
	Total volume in litres without coarse and Fine aggregate				**306.72**
	Fine Aggregate	-	657.53	2.65	248.12
	Coarse Aggregate	-	1232.88	2.766	445.73
	Total Concrete		***2466.41***	***2.466***	***1000***
SCC12.5	Cement	-	398.89	3.15	126.63
	Supper Plasticizer	1.2	4.79	1.19	4.02 (incl. in water)
	Water (w/b = 0.46)	-	183.49	1.00	183.49
	Total volume in litres without coarse and Fine aggregate				**310.12**
	Fine Aggregate	-	664.82	2.65	250.88
	Coarse Aggregate	-	1246.54	2.841	438.77
	Total Concrete		***2493.74***	***2.492***	***1000***
SCC10	Cement		397.79	3.15	126.28
	Supper Plasticizer	1.2	4.77	1.19	4.01(incl. in water)
	Water (w/b = 0.46)		182.98	1.00	182.98
	Total volume in litres without coarse and Fine aggregate				**309.26**
	Fine Aggregate		662.98	2.65	250.18
	Coarse Aggregate		1243.09	2.822	440.50
	Total Concrete		***2486.84***	***2.487***	***1000***

2.2.2 Tests on Fresh Concrete

2.2.2.1 Slump Flow Test and T_{500mm}Test

The workability test herein was conducted in reference with [7]. The slump flow was used majorly to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan as earlier mentioned for use in assessment of underwater concrete. The diameter (i.e. spread) of the concrete circle is a measure of the filling ability of concrete [6]. Slump flow is definitely one of the most commonly used SCC tests at present. It involves the use of slump cone with conventional concretes as described in ASTM C143 (Standard Test Method for Slump of Hydraulic-Cement Concrete). The main difference between slump flow test and ASTM C143 (Standard Test Method for Slump of Hydraulic - Cement Concrete) is that the slump flow test measures the spread or flow of concrete sample, once the cone is lifted lieu of the traditional slump (drop in height) of the concrete sample. The T_{50cm} test was also determined during the slump flow test. T_{50cm} is simply the amount of time that the concrete takes to flow to a diameter of 500 millimeter.

2.2.2.1.1 Slump Flow Apparatus

The mould used is in the shape of a truncated cone with internal dimensions 200mm diameter at the base, 100mm diameter at the top and a height of 300mm. The base plate is of a stiff non - absorbing material of at least 700mm square, marked with center location for the slump cone, and further concentric circle of 500mm diameter. The other apparatus required are trowel, scoop, ruler, and a stop watch.

2.2.2.1.2 Procedure

About 6 liter of concrete is needed to perform the test. The base plate and the inside of the slump cone were moistened. The base plate was placed on level stable ground and the slump cone was centrally placed on the base plate and firmly held down. The concrete was filled into the cone with the scoop without tamping. The excess material on the top of slump cone was scraped off and leveled with a trowel. The surplus concrete around the base of the cone was also removed. The slump cone was raised vertically upwards allowing the concrete to flow out freely. The time taken for concrete to reach the 500mm spread circle was noted and recorded by using the stopwatch. This is the T_{500} time. After the flow of concrete was stopped, the final diameter of concrete in two perpendicular directions was measured. The average of the two measured diameters is known as slump flow in mm. Ranging between 650 – 800 mm is the acceptable range for SCC [8]. The slump flow test is evidence as captured in Fig. 2 shown below.

Figure 2: T_{50cm} Slump Flow Test

In addition to the slump flow test, L-Box and V - Funnel test were also carried out to assess the flowability, passing ability and stability of the SCC. The L-Box ratio (h_2/h_1) was found to be in the range of 0.80 - 1.0. The V - funnel was filled completely with concrete and the bottom outlet was opened, allowing the concrete to flow. The V - funnel flow time is the elapsed time in seconds between the opening of the bottom outlet and the time when the light becomes visible from the bottom, when observed from the top. Good flowable and stable concrete would consume short time to flow out. Khayat and Guizani [9] and venkateswara et al. [10] reported a close proximity flow time range (6-11sec.) that is recommended for a concrete qualify as a SCC according to EFNARC specification.

(a): V – Funnel Test

(b): L – Box Test

Figure 3: V – Funnel and L – Box Workability Test

2.2.3 Cube casting

The concrete (SCC) cube was cast using 150mm x 150mm x150mm mould. The inside of the mould was oil coated purposely to facilitate easy removal of the specimens. While other materials (cement, sand, and chemical admixture) used for the same mix proportion of M30 grade were held constant, the maximum aggregate varied in sizes (20mm, 12.5mm and 10mm) down as described in sub-section 2.2 above were used in the cast. Thirty cube specimens were cast altogether for the experiment as captured in Fig. 4 below.

Figure 4: Cast SCC Cube Specimens

2.2.4 Cube Curing

The composite cube specimens were removed from the moulds after 24 hours of casting, and submerged immediately in portable water at room temperature. The specimens were cured for the required age of 3, 7, and 28 days respectively. The fresh water in the tank was emptied and refilled at a stretch of ten days interval (i.e. twice) prior to the last crushing age. All the specimens under immersion were always kept overwhelmed with at least 20cm of water above the specimen's top as shown in Fig. 5.

Figure 5: Self Consolidating Concrete under Water Immersion for Curing

2.2.5 Compressive Strength

Compressive strength plays a vital role in controlling and confirming the quality and reliability of concrete. However, Parupalli et al. [8] defines compressive strength of a material as the value of uniaxial compressive stress reached when the material fails completely. In this investigation, the cube specimens' sizes 150mm x 150mm x 150mm were tested in conformation with [11]. The test was performed on a compression testing machine. The machine built with the facility to control the rate of loading with a control valve and it has been calibrated to the required standards with a certified proof ring. The plates were cleaned and kept ready in all respect for use.

At the respective required age of curing, the specimens were removed from the curing tank and cleaned to wipe off water around its surface. The specimens with its smooth surfaces placed on the bearing surface of the machine such that compressive load was centrally applied at the core of the specimen as shown in Fig. 6. The maximum crushing load to failure at which the specimen breaks was noted. The compressive strength test has been conducted on SCC (made from three different coarse aggregate sizes) at 3, 7, and 28 days respectively. Three specimens from each SCC were subjected to loading for the respective curing ages, and the maximum crushing values was averaged and taken as the mean strength.

Figure 6: Cube Specimen under Compressive Loading

III. Results

3.1 Tests Results of Fresh SCC

In this research section, the experimental results of self consolidating mixes for different recipe of aggregate sizes considered on compressive strength and workability were discussed. However, the workability test of the reference mix performed for quality control performance were slump flow, T_{50cm}, V – funnel, and L - box test which found to satisfies all the requirement as per standards specified by EFNARC guidelines. The overall outcomes of the fresh SCC properties of the reference mix are reported as shown in TABLE 5.

Table 5: Fresh Properties of Self Consolidating Concrete

Mix ID	Size of C.A (mm)	Slump Flow 650-850 (mm)	T_{50cm} Slump (2-5 sec.)	V - Funnel (6-12 sec.)	L - Box Ratio 0.8 - 1.0
SCC20	20	670	5	12	0.84
`SCC12.5	12.5	715	3.6	11	0.90
SCC10	10	730	3.1	9.9	0.92

3.2 Mechanical Properties of SCC with different Aggregate Sizes
3.2.1 Compressive Strength

The results output of the mechanical properties obtained based on the specimens tested as per Indian standard test procedures (as per IS: 516) are elucidated. The details of the compressive strengths of M30 grade of SCC for the reference dosage (1.2% by weight of cement used) of chemical admixture (Sulphonated Naphthalene Formaldehyde) are presented in TABLE 6.

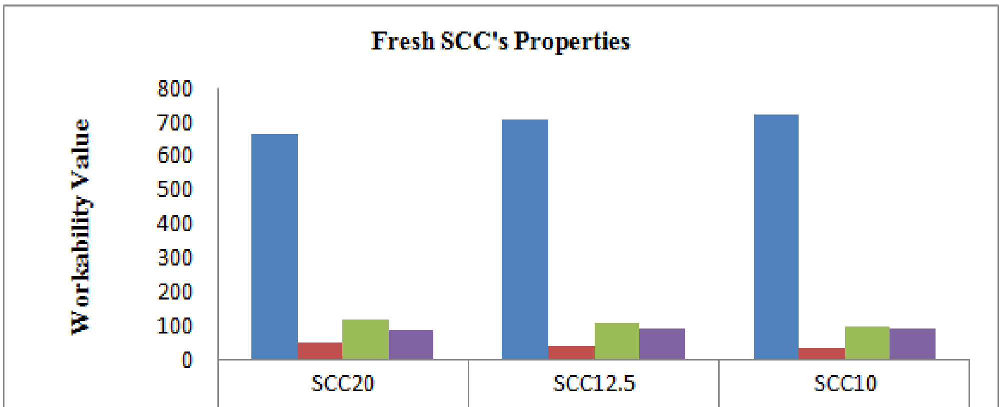
Table 6: Compressive Strength of M30 Grade of SCC

Mixture ID	Age of Curing (days)		
	3rd	7th	28th
SCC20	15.90	23.15	37.00
SCC12.5	18.10	24.50	38.55
SCC10	19.17	26.83	39.65

IV. Discusion

The details properties of the fresh SCC (for M30 grade of concrete) presented in Table 5 above, based on these fresh properties for different sizes of aggregates considered, it can be noted that M30 grade of concrete with all the different maximum aggregate sizes satisfies the spelt out requirements of EFNARC specifications [12]. The fresh properties improvement holds to the presence of chemical admixture content in the mix. However, best fits for the plot of workability test vs. aggregate sizes (Fig. 7) justifies that there is significant increase in workability as the size of aggregate falls. Also, aggregate on the lower side yielded better results in M30 grade of concrete.

The parameters involved in this investigation were the three maximum aggregate sizes (20mm, 12.5mm, and 10mm) down, three different ages of curing (3, 7, and 28 days), M30 grade of concrete, SP dosage and the type of concrete (SCC). As it were from the Figure representing different ages of curing with respect to the mechanical property (compressive strength), it will be observed that concrete strength increases with age. Fig. 8 however shows the strength trend of the three concrete cube specimens at different age in comparison with the 28 days strength. In the same vein, the details of the compressive strengths of M30 grades as presented above explicitly revealed the influence of grit size on the mechanical attributes of SCC with respect to the curing age (Table 6). The cement contents used were 394.52kg, 398.89kg, and 397.79kg respectively for the M30 grades. The three effective sizes of aggregate for the above mixes have been arrived and the same was adopted in the further study. The discussed below are the best fits of plots.



	SCC20	SCC12.5	SCC10
Slump Flow	670	715	730
T500 X10-1	50	36	31
V–Fun. X10-1	120	110	99
L - Box X10-2	84	90	92

Figure 7: Computation of Workability Test Results

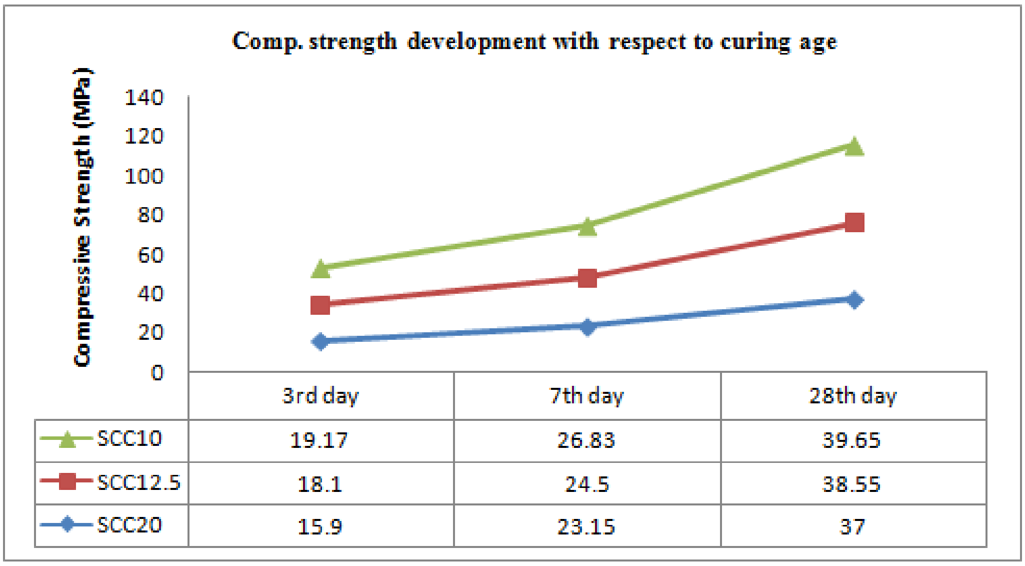


Figure 8: Compressive Strength vs. Curing Age

V. Conclusion

The present investigation conclusively account for the following; It has been verified by using the slump flow, V - funnel tests and other tests on fresh self consolidating concrete that self compacting concrete (SCC) achieved consistency and self - compatibility under its own weight without external vibration or compaction, fills the formwork, and also has the tendency to encapsulate reinforcements within a very short period of time only through the action of gravity and gives an excellent surface finish. However, its high flowable rate as captured in TABLE 5 shows an increase in workability of mix in terms of slump and L - box test. Also, in terms of time (T_{50cm}) and V – funnel test, SCC10 mix with lower aggregate size will tends to encapsulate the formwork in a very limited time frame compared to others mix with higher aggregate sizes as it is evidence from the chart (Fig. 7) above. This submission is found to be in close proximity with the reported result's range (6-11sec.) by [9] and [10] which falls within the recommended specification for a concrete qualify as a SCC according to EFNARC requirements.

It was also concluded from the above study that curing age has considerable effect on the mechanical properties of concrete such as compressive strength etc. and durability as revealed in Fig. 8 above; the upward linear trend which did not experience drop with respect to age of the respective series (SCC20, SCC12.5, and SCC10) is an evidence that prioritize the importance of intensive curing in concrete work. Also, from the outcomes of the data analyzed using Microsoft Office Excel 2007 (Fig. 8), it was inferred that the grade of scc concrete increases with decrease in the effective maximum size of aggregate due to proper interlocked and suffice flowable cement paste between the grain sizes. It should therefore be noted that this report does not account for the strength of SCC cast with aggregate size lower than 10mm.

Likewise, the shape and size of the aggregate has significant influence on the workability of SCC mixes. Conversely, [13] ascertain that the use of flaky and elongated aggregates reduces the strength thereby compromised the durability of SCC and normally vibrated concrete (NVC). However, the characteristics of self compacting concrete (higher early and ultimate compressive strength; by lowering water cement ratio up to 30%, improved workability by maintaining same water cement ratio, strong plasticizing effect without any tendency to segregation, and reduced cement) arrived at was all attributed to the incorporation of optimum Nafores 801 L dosage. In this context, the present investigation holds to the contribution which explicitly spelt out the influence of aggregate nature on the mechanical and fresh properties (such as flowability, passing ability, stability etc.) of self compacting concrete.

References

[1]. A. Stephan, E. Gilles, W. Vincent, Estimates of self-compacting concrete potential durability Construction and Building *Materials, Elsevier Science, 21(10),* 2007, 1909 – 1917.

[2]. Nehdi, M., Bassuoni, M.T, Benefits, limitations and research needs of self compacting concrete

[3]. technology in the Arabian Gulf: a holistic view. Paper presented at the annual concrete technology & corrosion protection conference, Dubai, UAE, Nov. 2004

[4]. W. Zhu, J. Bartos, Permeation properties of self compacting concrete. *Cement Concrete Res 33(6)*, 2003, 921 – 926.

[5]. P.W. Birkeland, and H.W. Birkeland, Connections in Precast Concrete Construction, *ACI Journal 63,(3),* 1966, 345-368.

[6]. Indian standard code of practice for, "Methods of test for aggregates for concrete", IS: 2386 (Part III): 1963, Bureau of Indian Standards, New Delhi.

[7]. R.S. Parupalli, R. Chandrashekar, K. Nagaraju, *Effect of Size of Aggregate on Self Compacting Concreting Concrete of M70 Grade,* Master dis., Gokaraju Rangaraju Institute of Engineering and Technology Bachupally, Hyderbad-72, M.A, 2008.
[8]. American Society for Testing and Materials (ASTM), C143/C143M – 15a: Standard Test Method for Slump of Hydraulic-Cement Concrete, 2009.
[9]. European Federation of National Associations Representing for Concrete (EFNARC), Specification and guidelines for self-compacting concrete, English edition. European Federation for Specialist Construction Chemicals and Concrete systems. Norfolk, UK, 2002.
[10]. K.H. Khayat, Z. Guizani,. Use of viscosity-modifying admixture to enhance stability of fluid concrete. *ACI Mater J, 94(4),* 1997, 332-41.
[11]. S.R. Venkateswara, M.V. Seshagiri, P.K. Rathish, Effect of Size of Aggregate and Fines on Standard and High Strength Self Compacting Concrete, *Journal of Applied Sciences Research, 6(5),* 2010, 433-442.
[12]. Indian standard code of practice for, "Methods of tests for strength of concrete", IS: 516. 1959, Bureau of Indian Standards, New Delhi
[13]. European Federation of National Associations Representing for Concrete (EFNARC), Specification and guidelines for self-compacting concrete, European Federation of Producers and Applicators of Specialist Products for Structures. UK, 2008.
[14]. S. Zhutovsky, K. Kovler, A. Bentur, Efficiency of lightweight aggregates for internal curing of high strength concrete to eliminate autogenous shrinkage, *Materials and Structures, 35(246),* 2002, 097-101.