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Impact and Performance of Linen Fiber Reinforced Concrete in Slender Columns

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ABSTRACT: *This study was consisted of two phases, revealed the behavior of Self-Compacting Concrete (SCC) specimens of small-diameter slender column to achieve high quality concrete properties without using concrete vibrator. The first phase investigated the effect of linen fiber on the rheological properties of SCC using two mixes types: type I mix: without lime powder, and type II mix: with 20% lime as a replacement of cement content. The linen fiber was contented of 0, 2, and 4 Kg/m³. In the second phase, the type II mix was used to cast three columns; one with plain SCC and the other two with 2 and 4 Kg/m³ fiber contents. These columns were cured and cut in a certain manner to obtain 7 cylinders 150 × 300 mm and 8 slices 20 mm thickness. The cylinders were used to measure the distribution of unit weight, compressive strength, and ultrasonic pulse velocity (UPV) along the column height. The rheological properties of SCC were reduced with the additives of fibers to the mix constituents, but the properties of Fiber reinforced Self-Compacted Concrete (FSCC) were tested at 4 Kg/m³ fiber content. The distribution of unit weight, compressive strength, and UPV provided good compaction of concrete. Also, the distribution of coarse aggregate at bottom, middle and top sections of columns were uniformly distributed.*

Keywords: *SCC; Lime; Linen fiber; Slender column; Properties concrete tests.*

I. INTRODUCTION

Self-Compacting Concrete (SCC) is the type of concrete which does not require vibration at the time of placing and compaction. SCC also has the capacity to flow in congested reinforcement under it's own weight **[1]**. SCC is a highly flowable concrete; which does not segregate and can spread into place, fill the formwork with heavily congested reinforcement, and encapsulate the reinforcement without any mechanical vibration. Furthermore, SCC holds well in areas of difficult accessibility and complicated structural forms, while maintaining the homogeneity of the mixture. Segregation resistance combined with high fluidity resulted in consolidation entirely due to the concrete's own weight [**2**].

The use of SCC represents major technological advances, which leads to a better-quality concrete and an efficient construction process. It allows the construction of more slender building elements and more complicated and interesting shapes. The SCC also allows pumping of concrete to a great height and flows through congested reinforcing bars without the use of compaction other than the concrete self-weight. As a result, the use of SCC can lead to a reduction in construction time, labor cost, and noise level at the construction site.

The main difference between SCC and ordinary concrete is the existence of filler material in the SCC mixture. Previous researchers studied the effects of filler materials on the properties of SCC **[3, 4, 5]**. According to the results of some of these studies, the benefit of filler material usage in SCC can improve the workability with reduced cement content. By this way, low hydration heat and less cracking can be obtained. Moreover, since cement is the most expensive component of concrete, reducing cement content can be a good economical solution **[3]**.

The cost of SCC is remarkably increased with the use of high content of Portland cement and chemical admixtures. In some cases, savings in labor cost might offset the increase in material cost. However, the use of mineral admixtures, including fly ash, blast furnace slag, and/or limestone filler reduces the material cost and improves the

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quality of concrete properties of the SCCs **[6]**. To achieve high fluidity of SCC and prevent the segregation and bleeding during transportation and placing, the formulators have employed a high Portland cement content and used superplasticizer as well as viscosity modifying additives.

A number of studies have been reported in the literature concerning the use of mineral admixtures to enhance the self-compatibility and durability characteristics of SCCs. Sonebi **[7]** reported that the incorporation of pulverized fuel ash and limestone powder lessened the requirement of superplasticizer necessary to obtain the desired slump of SCC. The use of these materials also improve the rheological properties and reduce the risk of concrete cracking due to the hydration heat, results in more durable concrete. Ghazel and Khayat **[8]** found that the replacement of a large volume of cement by limestone powder decreases the cement content needed to achieve a given slump flow, viscosity, and compressive strength at early ages. Furthermore, the pores between aggregates were fulfilled which produced impermeable concrete. Therefore, the durability of concrete was also improved.

To increase the workability and reduce segregation of SCC, chemical admixtures are essential. The content of coarse aggregate and the water to binder ratio in SCC are lower than those of normal concrete. Therefore, SCC consists of large amounts of fine particles (blast-furnace slag, fly ash, and lime powder) to avoid gravity segregation of larger particles in the fresh mix. In this method, the coarse and fine aggregate contents are kept constant to easily achieve self-compatibility by adjusting the water/powder ratio and superplasticizer dosage only. Due to its intrinsic low porosity and permeability [**9, 10**], SCC usually has high performance of mechanical behavior and durability properties. These properties could even be improved if polymer fibers are incorporated, thus obtaining polymer fiber reinforced self-compacting concrete (PFR-SCC).

Rheological studies on fresh SCC have shown that an adequate combination of shear stress and plastic viscosity achieves self-compacting characteristics. If the viscosity is too low, an increase of shear stress is recommended to avoid segregation. On the other hand, if the viscosity is too high, a low shear stress would be necessary. Thus, an adequate balance of the fundamental rheological parameters, such as shear stress and plastic viscosity govern the behavior SCC.

Material concrete properties' observation at meso-structural level suggest that the composite material (concrete) can be formed by a mortar matrix, the aggregate fraction larger than 5 mm, the interfacial transition zone, and fibers if dealing with Fibre Reinforced Concrete (FRC). With regard to Performance Fibre Reinforced Concrete (PFRC), recent works reported the importance of a homogeneous distribution of the fibers **[11]** and its effects under uni-axial and flexural tension **[12, 13]**. The concrete homogeneity positively influences the mechanical and durability-associated transport properties **[9, 10]**. However, this acquires a major significance in the case of SCC, where the correct filling and compactness in the hardened state will specifically depend on the rheological properties of the material in the fresh state.

Since the high flowability of concrete is the distinctive characteristics of SCC, understanding the governing factors of the SCC behavior that are determined by appropriate mixture design methods is essential **[14 ,15]**. Therefore, the lack of researches on the comparison of the SCC with different lime powder additives and linen fiber for smaller diameter column, that provides rationale to this study. Hence, the objective of this study was to: **1)** analyze the meso-structural homogeneity of plain and FR-SCC for use in slender elements of considerable height, such as foundation and retaining walls, columns, and building panels, **2)** examine the segregation in SCC as a suspension of coarse aggregate in a mortar matrix, and **3)** study the distribution of the coarse aggregate along the height of the application-oriented slender elements. Therefore, this study shed the light on the problems occurred in the small diameter slender column using SCC technique. Using lime powder additives in concrete provides high quality (great homogenous and nonporous) concrete properties without vibrated concrete. The ratio of these additives used at the lab scale study can be implemented in a larger scale projects.

II. EXPERIMENTAL PROGRAM

A total of 3 circular SCC specimens' slender column of 150 mm diameter and 2500 mm height with tubes were cast and tested at the concrete technology laboratory at the University of Sirte, Libya. The physical and mechanical properties and the segregation of concrete constituents were measured along the column height. Also, the rheological properties of SCC of the three mixes used in casting columns were measured and analyzed. The rheological properties of SCC were measured in terms of slump flow diameter and slump flow time when the concrete reaches 50 cm diameter, passing of concrete through J-ring and the flow time through V-funnel.

The experimental work of this project is divided into two groups. The first group consists of 3 mixes; in which the cement content density was kept constant at 450 Kg/m³, and the lime was not used (i.e., zero lime powder). The 0% fibers mix represents the plain (or reference SCC mix). A high range water reducer (HRWR), RHEOBUILD 1100, was used at a constant content of 13.5 Kg/m³ (3% of the cement content) to satisfy the required workability, Table 1.

In mixes of group 2, the lime was used as a partial replacement of cement content Table 1. The total powder content was kept constant at 500 Kg/m³ and the lime content was 20% of the cement content. So to maintain the required total powder content of 500 Kg/m³, the cement content was 400 Kg/m³ and the lime content was 100 Kg/m³.

Three round columns with 150 mm diameter and 2500 mm height were cast using plain and linen fibers of two concentrations (2 and 4 Kg/m³). Three plastic tubes with the required diameter and length were opened from one side and supported vertically using the wooden form shown in Fig 1. Steel wires were used as clamps at short spaces to provide additional restrictions to open the plastic tubes. Placing of concrete columns was performed in a continuous manner without any type of compaction.

Table 1. Constituents of the two types of mixes used in this study.

Mix constituent / **Mix Type**		**Lime powder (kg)**	**CA (kg)**	**FA (Kg)**	**W/C**	**Water content (kg)**	**Sp (%)**	**Sp (kg)**	**Fiber content (kg)**
I	Without fibers	0	800	900	0.5	225	3	13.5	0
	With 2Kg/m³ fibers	0	800	900	0.5	225	3	13.5	2
	With 4Kg/m³ fibers	0	800	900	0.5	225	3	13.5	4
II	Without fibers	100	800	900	0.57	285	2.5	12.5	0
	With 2Kg/m³ fibers	100	800	900	0.57	285	2.5	12.5	2
	With 4Kg/m³ fibers	100	800	900	0.57	285	2.5	12.5	4

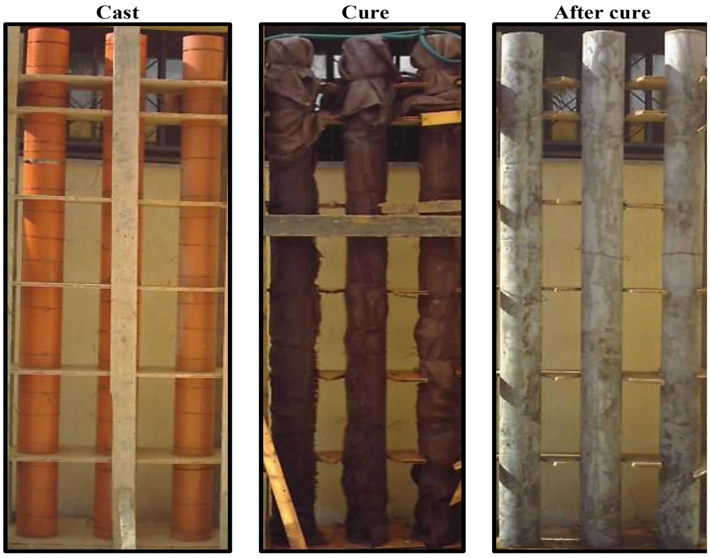

Fig. 1 Slender Column of specimens for (casting, curing, & after curing).

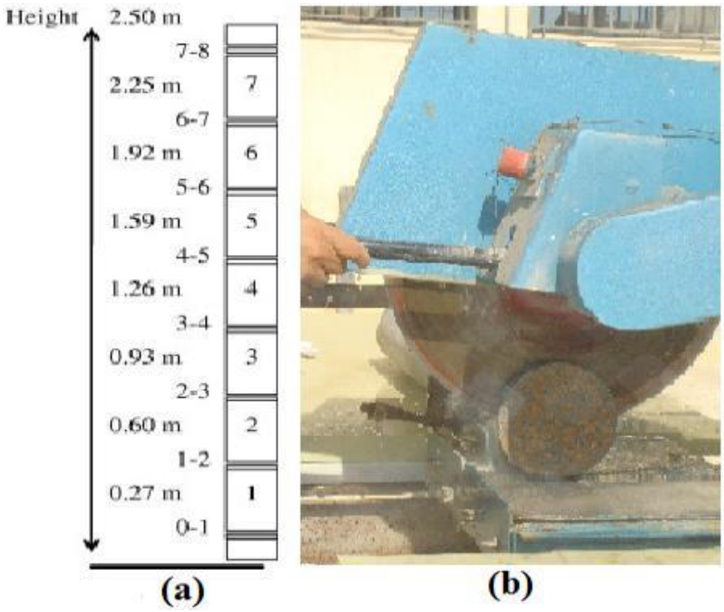

Fig. 2 Sawing sketch and samples.

III. TEST METHODS

3.1. Fresh Properties of Self-Compacting Concrete

Testing of self-compacting concrete in fresh state was carried out using three types of tests namely; slump flow, J-ring and, V-funnel as shown in Fig 3.

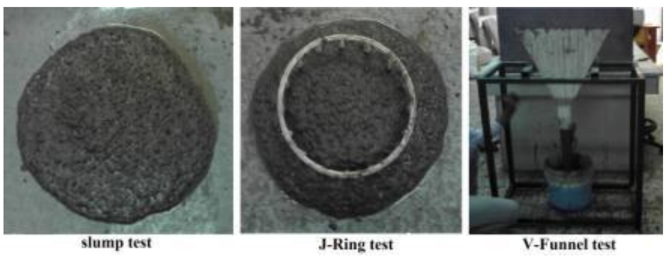

Fig. 3 Test specimen of SSC; “Slump test, J-Ring test, & V-Funnel test”.

The acceptance criteria for testing SCC using the above-mentioned tests are giving in Table 2.

Table 2. Acceptance criteria for testing SCC.

Test method	Unit	Typical range of values		Test Results	
		Minimum	Maximum		
Slump flow	mm	650	800	573	735
T50cm Slump flow	sec	2	5	0.94	4.8
J-ring	mm	0	10	2.3	13.8
V-funnel	sec	6	12	1.84	8.7

IV. RESULTS: HARDENED PROPERTIES

4.1. Compressive strength

The compressive strength of self-compacting concrete depends mainly on its rheological properties, while in traditional vibrated concrete. The first main factor controlling compressive strength is the vibration or compaction. The results of compressive strength vs percentage of linen fibers are given in Fig. 4. As shown in figure 4, the compressive strength of SCC was increased at 2 kg/m3 fiber content, then decreased at 4 kg/m3 fiber content. The compressive strength of type I mixes (without lime powder) was 33, 42.8 and 40.8 MPa at zero, 2 and 4 kg/m3 fiber contents, respectively. The corresponding values in mix type II (20% lime) were 30.6, 31.2 and 27.8 seconds, respectively.

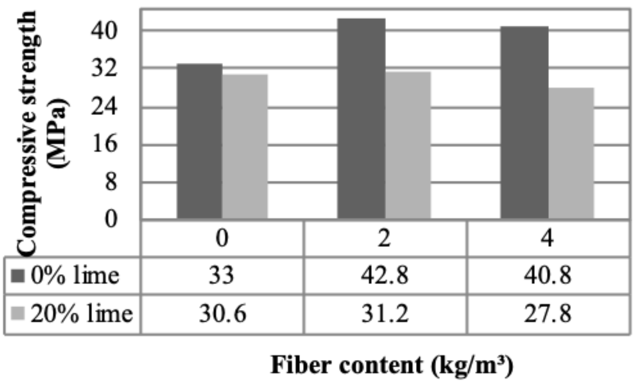

Fig. 4 Compressive strength vs linen fiber content.

4.2. Splitting strength

A cylindrical test specimen is subjected to a compressive force applied along its longitudinal axis. The resultant tensile force splits the test specimen into two parts. The results of splitting strength of mixes without fibers vs fiber content is shown in Fig. 5. The results have the same trend of the compressive strength results, i.e., the splitting strength was increased at 2 kg/m^3 fiber content, then decreased at 4 kg/m^3 fiber content. The splitting strength was 3.4, 4 and 3.8 MPa at 0, 2 and 4 kg/m^3.

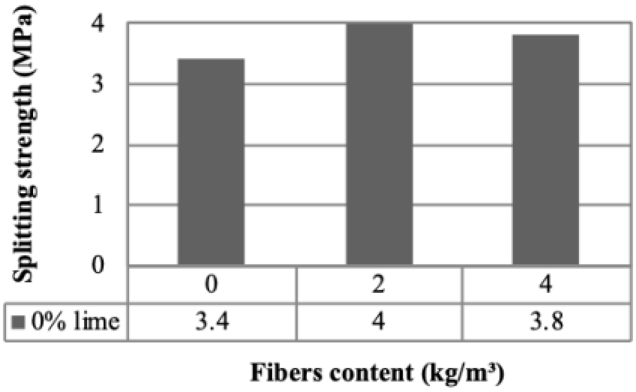

Fig. 5 Splitting strength vs linen fiber content.

4.3. Hardened Properties of Standard Cylinders

For the purpose of comparison, standard cylindrical specimens 150 × 300 mm were cast, cured, and tested to measure their unit weight, compressive strength, and ultrasonic pulse velocity (UPV). Results of these properties were used as a reference for those obtained for cylinders cut from the columns. Figs. 6 to 8 show the unit weight, compressive strength and UPV of mix type II (20% lime) with different fiber contents. The unit weight was 2214, 2229, and 2198; the compressive strength was 30.6, 31.2, and 27.8 and the UPV was 4.05, 4.03, and 4.07 at 0, 2 and 4 kg/m^3 fiber contents, respectively.

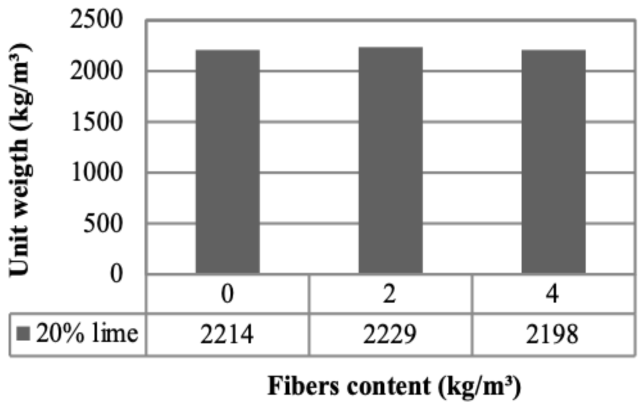

Fig. 6 Unit weight vs linen fiber content.

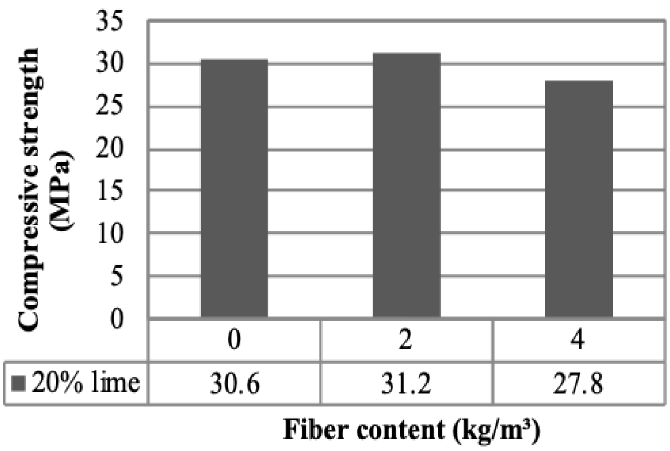

Fig. 7 Compressive strength vs linen fiber content.

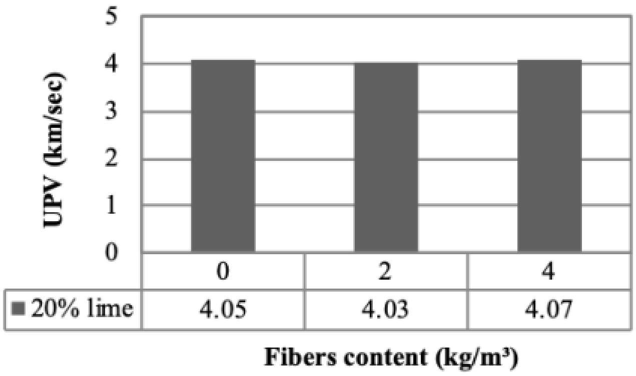

Fig. 8 UPV vs linen fiber content.

4.4. Columns Results

Fig. 9 shows the surface finish of cylinders cut from the three columns cast. The surface finish of all specimens was satisfactory and strictly homogeneous irrespective of the specimen location; from bottom, middle or top (Fig. 9). Interestingly, while all sides of the tubes were practically free of defects, air bubbles weren't observed on the all sides.

Fig. 9 The final stage of cylinders cut showing the surfaces from the three columns cast. These pictures evidence non-porous cylinder columns.

To study the variation of the physical and mechanical properties of the SCCs along the column, Figs. 10 to 12 present the variation in height of the unit weight, concrete compressive strength (f_c) and ultrasonic pulse velocity (UPV), respectively. These properties were measured on the 150 × 300 mm cylinders cut along the height of the columns.

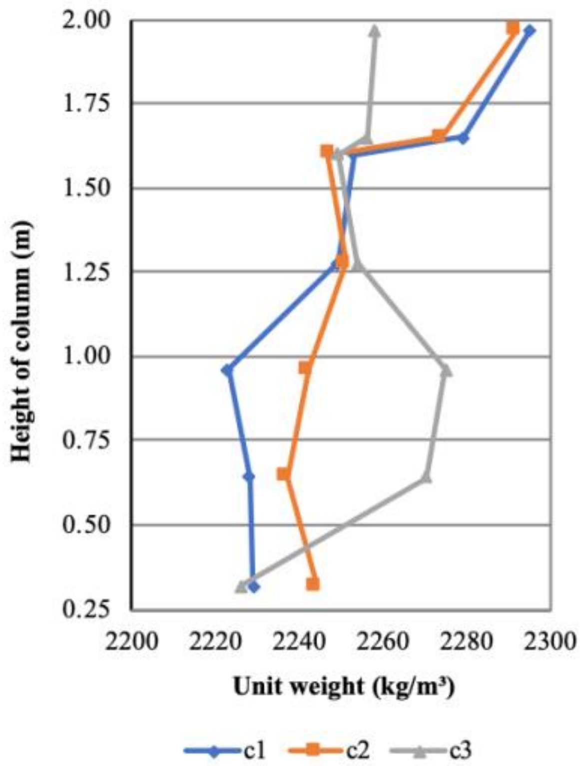

Fig. 10 Variation of unit weight along the columns.

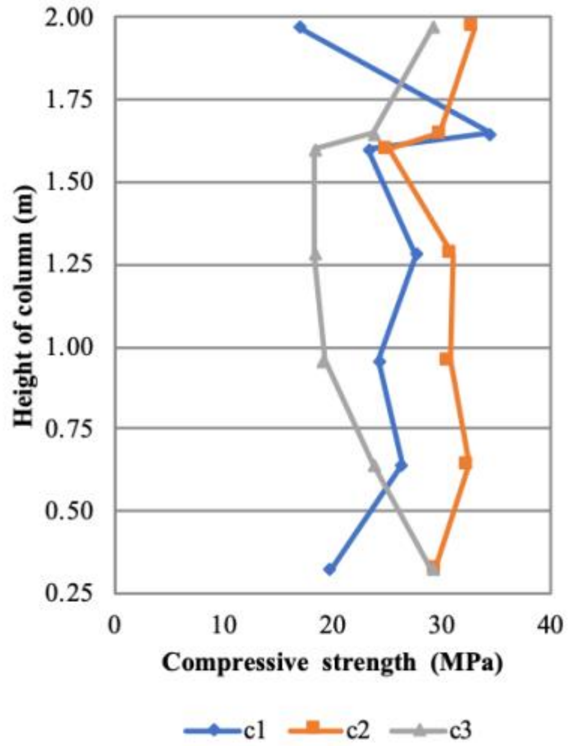

Fig. 11 Variation of compressive strength along the columns.

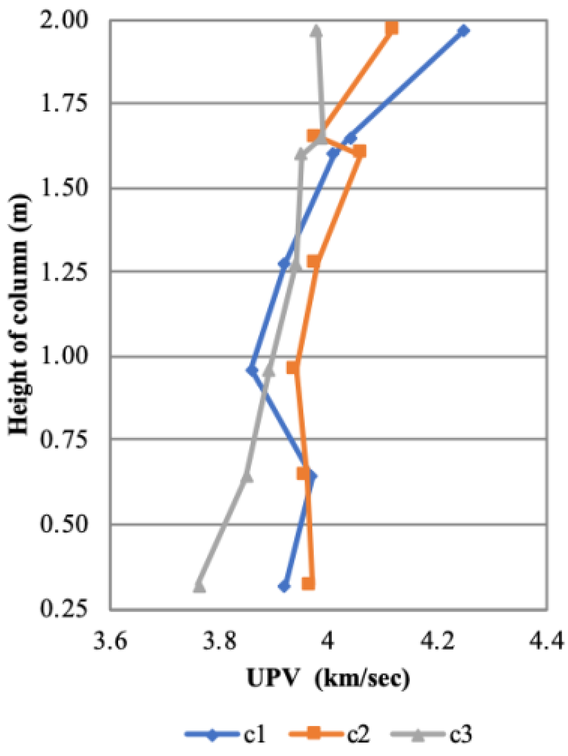

Fig. 12 Variation of UPV along the columns.

Figs. 10 to 12 show the followings:

A) The variation of unit weight along the column height was very low in case of SCC incorporated 2 kg/m3, indicating good compaction of concrete along the column height.

B) The unit weights of all specimens taken from plain SCC and SCC with 4 kg/m3 were equal in the upper half of the columns, while a big difference was observed in the lower half.

C) The compressive strength of SCC was increased with the increase of fiber content to 2 kg/m3, then decreased with the extra increase of fiber content to 2 kg/m3.

D) The variation of compressive strength along the column height was low in the cases of concrete studied (i.e., SCC and FSCC), indicating good compaction of concrete along the column height.

E) The UPV of SCC and FSCC were very close to each other, indicating the good compaction of the two types of concrete, and

F) A low variation of UPV along the column height was observed.

Fig. 13 shows the distribution of coarse aggregate across the 20 mm thick slices after polishing one of the cut planes to photograph of the cross section. The slices shown were taken from bottom, middle and top of the columns. As shown, there was a well distribution of coarse aggregate along the column height, indicating good compaction without segregation in the lower part of the columns.

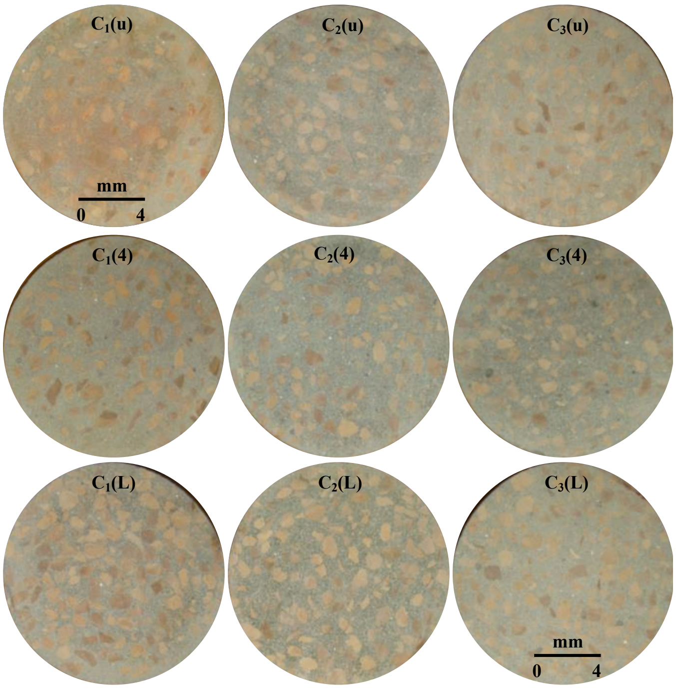

Fig. 13 Distribution of coarse aggregate along the column's height.

V. CONCLUSION

Within the scope of this work, the following main conclusions can be drawn:

1. Addition of linen fiber to SCC mix constituent reduced the flowability of SCC. In type I mix (without time) the slump flow diameter was reduced from 690 mm to 625 mm and then to 573 mm with the addition of 2 and 4 kg/m^3 fibers, respectively. The slump flow time (T500) was prolonged from 2 seconds to 2.7 and 4.8 seconds, respectively. Similar trend of results with different values were obtained in type II mix.
2. The difference in height of concrete between inside and outside of J-ring was increased with the increase in fiber content. The efflux time of concrete through the V-funnel was also increased with the increase in fiber content. This means that the presence of fiber in the SCC mix decreases the filling ability and passing of concrete through narrow spaces.
3. The variation of unit weight along the column height was very low in case of SCC incorporated 2 kg/m^3, indicating good compaction of concrete along the column height.
4. The unit weights of all specimens taken from plain SCC and SCC with 4 kg/m^3 were equal in the upper half of the columns, while a big difference was observed in the lower half.
5. The compressive strength of SCC was increased with the increase of fiber content to 2 kg/m^3. Then, it is decreased with fiber content more than 2 kg/m^3.
6. The variation of compressive strength along the column height was low in the cases of concrete studied (i.e., SCC and FSCC), indicating good compaction of concrete along the column height.
7. The UPV of SCC and FSCC were very close to each other, indicating the good compaction of the two types of concrete.
8. A low variation of UPV along the column height was observed.
9. The distribution of coarse aggregate across the column section was homogenous along the column height indicating good compaction without segregation in the lower part of the column.

VI. ACKNOWLEDGMENT

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