Monitoring workability properties of self-compacting concrete (SCC) using Internet of Things (IoT)

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Abstract. Workability, determines whether the concrete is suitable to cast in-situ for specified job. In practice it is determine by multiple test methods to find the workability properties by following EFNARC guidelines. To evaluate these properties in single test Ultrasonic sensors (hc-sr04) and Ultrasonic pulse velocity (UPV) test are used. The float glass box of dimensions 300×300×400 mm with reinforcement inside 16mm dia with spacing 46mm and clear cover 40mm is used for simulation. The hc-sr04 sensors are placed at the corners of the glass column for determining the concrete filled into the box and monitor through Arduino.ide software. The filling ability is determined by the time taken to fill the column and classified into FA1, FA2 & FA3 classes. The passing ability is determined by the difference of concrete height at inside the reinforcement and at the corners after filling and classified into PA1, PA2 & PA3. Ultrasonic velocity measurements are taken by direct mode and based on the variations at different locations segregation resistance is classified into SR1, SR2 & SR3. The aim of this simulation was to establish the relation between experimental tests and simulation IoT test results. Comparison between empirical tests and stimulation model shows that this model can used to check the workability at in-situ to meet the job specification.
Key Words: SCC, Workability Properties, Ultrasonic sensor (hc sr04),Ultrasonic Pulse Velocity test and IoT

1 Introduction

Workability of concrete plays a key role in SCC Mix as it is design to meet the specific job requirements. SCC has ability to flow under its own weight, it has higher fluidity than ordinary concrete and can pass through heavy reinforcing bars without using vibrator. As SCC Mix design is a trial & error process multiple tests are done in determining the properties for finalizing mix proportions. According to EFNARC (European Federation of National Associations Representing for Concrete) guidelines used Slump flow, T_{50} cm Slump flow and V funnel for determining filling ability, L Box, U Box and J Ring for determining Passing ability and V-funnel at T_5 min for finding Segregation resistance. The percentage of cementitious material, water cement ratio, grading of aggregates and quality of the materials etc., effects the workability of concrete and further effects on strength and durability of a

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structure. The heavy reinforcement structures need high flowability and high stability are required for achieving quality and strength therefore, it is important to recheck the workability properties at in-situ conditions. The variations in laboratory test conditions and in-situ conditions may differ due to concrete reactions with the environmental changes. The evaluation of workability properties at in-situ conditions can help to known the weather workability meets the job specification before application to ensure the quality control of structure.

1.1 Ultrasonic Sensors

These sensors works by emitting and receiving sound waves at a frequency of 40kHz which are too high for humans to hear. The HC-SR04 Ultrasonic sensor comes with four pins namely (a)trig pin emits a high-frequency sound (40kHz) (b)echo pin receives the reflected sound (c) VCC (Voltage Common Collector) supply power (d) Ground pin (Gnd) as shown in figure 1. The time taken by sound waves transmitted in air medium and received back multipled with speed of sound in air divided with two for calculating the distance between object and sensor. The distance between the sensor and poured level gives the height of filling.

Fig. 1. Ultrasonic sensor (hc-sr04 module)

1.2 Ultrasonic Pulse Velocity Test

A non destructive test to check the strength and quality of concrete by measuring velocity of an Ultrasonic Pulse Velocity (UPV) waves passing through a concrete structure. Unlike conventional testing methods, the ultrasonic waves do not significantly affect the microstructure and disturb the structure. The variations in UP waves are used to derive indices that reflect stability of concrete and interpret the material homogeneity.

1.3 Internet of Things (IoT)

IoT is a network of inter connected devices that can communicate with one another and stay connected via the Internet or other wired or wireless protocols. The Arduino.ide software helps to maintain connection between the sensors (i.e. hardware) and flow of information (i.e. software) and easy to develop projects. The Arduino Uno board has a microcontroller board based on the ATmega328P with 14 digital I/O pins suitable for connecting multiple hc-Sr04 sensors. The Arduino.ide serial monitor can be used to check the output without internet or wifi.

2 Review of Literature

This section provided a detailed overview of existing related work. Debajyoti Misra et al. (2020) proposed a smart building health monitoring system using piezoelectric sensors to generate lamb waves. The hardware system consists of sensors, filter and amplifier circuits, electronic timing device and a microcontroller. The UPV waves in concrete depends on its density and modulus of elasticity, used effectively for quality of concrete. Augusto M. Gil et al. (2019) have presented two approaches one based on an empirical approach to determine the self-compacting ability of mixtures of fixed mortar content and a second approach based on aggregate packing, with different mortar contents for different mixtures. The fixed motar content presented greater strength, greater ultrasound wave velocity. The high packing density of coarse aggregate results in greater UPV and greater SCC performance. Kodathala Sai Varun et al. (2018) proposed a system to automate water level in tank while monitoring the percentage of filled height with help of hc sr04 sensors by using Arduino board. Ashish Kumar and Gaurav Kumar (2018) came up with a blend design based on Bureau of Indian Standards methodology and appropriate adjustments were made according to the guidelines. The test mixtures maintained flowability, self-compression and ground clearance. The compressive strength and tensile strength after 28 days for grade M30 were achieved. Benaicha et al. (2015) proposed a UPV-based technique to assess the fillability of SCCs without segregation at young age. A vertical chanel introduced to a pair of transducers for propagating waves at four levels. Based on the variations in ultrasonic waves the concrete stability is predicted and introduced homogeneity coefficient. H.A. Mesbah (2011) evaluated the applicability of the conductive method to evaluate the stability of SCCs at an early age. A column channel with a height of 1005 mm and a cross section of 250 × 250 mm with a 4-zone multi-electrode probe in the channel is used. This method compares conductivity-based stability indices with the change in coarse aggregate and water content determined immediately after measurement on plastic concrete. EFNARC (2002) provides information on standards for the properties of SCCs in the plastic phase and testing in the hardened state and related constituent materials used in the manufacture of the SCC. The guidelines are written with an emphasis on ready-mix concrete and concrete in situ when there are requirements between supplier and user for specification of fresh concrete and hardened concrete. In addition, the guidelines include specific and important requirements for cement concrete users regarding site preparation and placement methods when different from traditional vibrating concrete. Nan Su et al. (2001) proposed a composite design based on the packing factor of the aggregate content ratio. The main consideration of the proposed method is to fill the paste of binders to the aggregate frame gaps with loosely stacked aggregates. Okamura and Osaka (1993) developed the empirical approach for mix design. The main idea is to do a mortar and slurry test first to check the properties and compatibility of the SP, cement, fine aggregate and pozzolanic material, and then the test mix of the SCC.

3 Experimental Work

3.1 Material

The mixtures studied were systematically quantified using OPC 53grade in combination with Class F fly ash and coarse aggregate with a maximum aggregate size of 12.5 mm was used. To check whether the mix proportion obtained according to the proposed Nan SU Mix design method meets the requirements of JSCE, the experiments performed for determining the material properties are shown in Table 1. These aggregates are used in combination with binary binders (cement and fly ash) to achieve different packing densities of the powder phase. Coarse aggregates have a specific gravity of 2.65 and a water absorption of

0.5%. Fine aggregate sand is used with a density of 2.31. High grade water reducing agent (HRWR) based on Poly carboxylic ether or SP with a specific gravity of 1.1.

Table 1. Properties of materials used

	Cement	Fly Ash	SP	FA	CA
SiO_2	20.49	55.5	-	-	-
$Al_2 O_3$	6.57	27.9	-	-	-
Fe_2O_3	3.27	6.3	-	-	-
CaO	62.40	6.27	-	-	-
MgO	1.91	1.6	-	-	-
Loss on ignition	1.57	5.01	-	-	-
Specific surface area (m^2/kg)	*305.4*	(86.95% <45 5 μm)	-	-	-
Specific gravity	3.01	2.19	1.10	2.63	2.61
Bulk density	-	-	-	1498	1450

3.2 Mix proportions

The main objective of the experimental program is to evaluate the workability properties using IoT with Ultrasonic sensors and UPV test and parallely by manual workability test are done to design M30 grade. The packing factors vartions are taken for designing the mix. The water-binder ratio of 0.4 with cement OPC 53 grade 284.89 kg/m^3 volume ratio of fine to coarse aggregate is 52/48 keeping constant in three trial mixes. Stability and flowability were adjusted by using different percentages of SP for 3 SCC sample mixtures. The mix proportions of three sample mix are presented in Table 2.

Table 2. Mix proportions

	Sample 1	Sample 2	Sample 3
Packing Factor	1.12	1.16	1.20
S/a ratio	0.52	0.52	0.52
Cement	284.89	284.89	284.89
Fly ash	174.23	147.98	121.73
Powder	459.12	432.87	406.62
Fine Aggregate	844.48	874.64	904.80
12.5mm Coarse Aggregate	805.32	834.09	862.85
SP dosage (1.2% of cement)	8.26	7.79	7.32
Water binder	178.69	168.47	158.26

3.3 Mixing and preparing sample mixes for testing

The mixing is kept constant to give homogeneity and uniformity in all sample mix. The quantified materials are mixed in following process firstly by mixing all of the aggregates and binder for a minute. Then potable water is added and mixed for another minute and at last SP is diluted and added the concrete is mixed for another three minutes. In the end of mixing, tests are immediately performed out on fresh concrete to assess the workability of SCC according to EFNARC standards.

The glass column used for the workability assessment was made of a plexiglass mould with a height of 400 mm and a cross section of 300 × 300 mm. A diameter of 55m holes introduced with 25mm spacing from bottom for placing the ultrasonic transducers as shown in figure 2.

A thin plastic sheet is used for covering the holes to take UPV readings conveniently. The advantage of plastic sheets neglect the glass effect and with applied grease the minute gaps are removed. The hr sc04 sensors are placed at the corners of the glass column these recored the height of the concrete being poured. Two ultrasonic sensors are placed before the reinforcement to check the passing ability as the difference in corners and intermediate heights.

Fig. 2. The simulation model - with reinforcement and sensors connected

3.4 Performance of test

(a) Manual test

The 3 SCC sample mixes of M30 grade are tested for checking the workability properties based on the EFNARC test procedures. The slump flow diameter is checked for the flowabilty. The V-funnel test time readings are taken for testing the filling ability and at T_5 sec i.e. at 5 sec rest after filling trap door released, the segregation readings are taken. The flow in J Ring, L Box, U Box is tested to find the segregation resistance. According to The European Guidelines for Self Compacting Concrete classification is done to meet job specification at in-site as shown in Table 3.

Table 3. Classification based on European Guidelines for Self Compacting Concrete

	Class 1	**Class 2**	**Class 3**
Slump flow (SF)mm	550 to 650	660 to 750	760 to 850
T_{500} (VS)	2 ≥	2 <	-
Viscosity (VF)	8 ≥	9 to 25	-
Passing ability (PA)	≥ 0,80 with 2 rebars	≥ 0,80 with 3 rebars	-

(b) Simulation model

The sensors are connected to Arduino.ide. software for serial monitoring. The Arduino board is a micro-controller connecting sensors and software. The trig, echo, VCC and Ground pins are connected to digital pins and VCC and GND pins to the controller. The code is compiled and run. The channel column is filled by a standard V- funnel for same outflow environment for each mix. The volume of concrete taken is 24 liters. The V-funnel is placed exactly middle to the glass column as shown in figure 3. The ultrasonic sensors record the height while pouring and the millis() function in the code determine the seconds to fill the column. After filling the channel the final readings i.e. height at middle and corners, time taken to fill, passing ratio (difference of height), classification of PA and FA are displayed in serial monitor as shown in figure 4.

Fig. 3. Test performance while filling the glass column

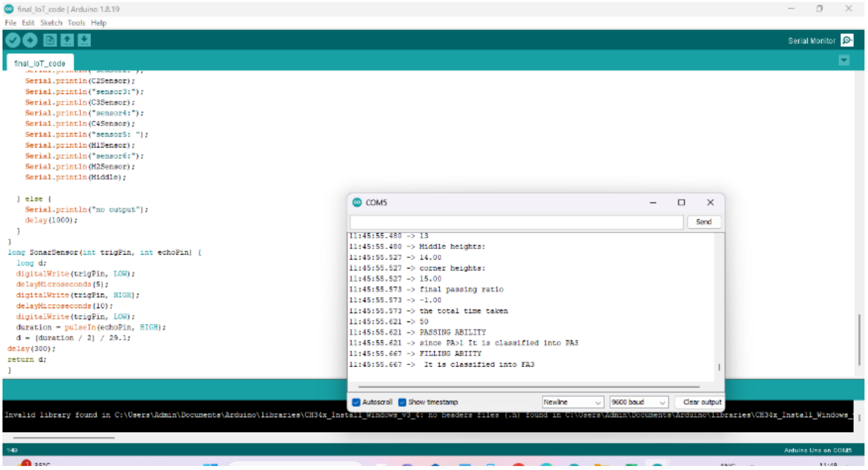

Fig. 4. Results displayed on Serial Monitor

The proposed simulation model classification is shown in Table 4. Filling ability (FA) describes the viscosity of concrete while filling in reinforcement in the channel. FA1 has good filling ability compared to FA3 for best surface finish with least time. The double of V funnel ranges are taken for classifying FA. FA1 is suitable for slabs, footing with congested reinforcement. FA2 for slabs, wall, beams and column with reinforcement. FA3 for ramps and other applications with very less reinforcement. Passing ability (PA) is classified based on the difference in height of concrete at corners and immediate before reinforcement in channel. The reinforcement vertical bar spacing 46mm and stirups spacing 150mm. PA1 has easy flow throught congested reinforcement than PA2 and PA3 has least passing ability i.e it has blocking before reinforcement. PA1 suitable for civil engineering structures, PA2 for housing, vertical structures. PA3 for least reinforcement. The UPV measurements are taken at 3 sections in the glass column as shown in figure 5. The 50 mm diameter transducer transmits frequency of 54 kHz travels distance in propagation time in the material. The speed of propagation of sound waves in a material determined as velocity equal to travelling distance by propagation time. Variations of UPV's at three heights gives the stability of concrete. The segregation resistance (SR) is done by determining the ratio of UPV at section 1 and section 3. Based on ratio SR is classified into SR1, SR2 and SR3 helps in finding the homogenity to achieve strength. SR1 is suitable for vertical applications with confinement less than 60 mm, SR2 for vertical applications with confinement greater than 60mm and SR3 for less confinement. This classification of properties helps to identify the suitable application of SCC while placing the concrete to meet the quality and durability of the structure.

Table 4. Classification of proposed stimulation model

Classes	**Measured value**	**Class 1**	**Class 2**	**Class 3**
Filling ability (FA)	Time (total sec)	16-24	8-16 & 24-30	<8 & 30<
Passing ability (PA)	Height difference (cm)	0	1	1<
Segregation resistance (SR)	Velocity (ratio)	0.99-1	0.95 - <0.99 & 0.99< - 1.05	<0.95 & >1.05

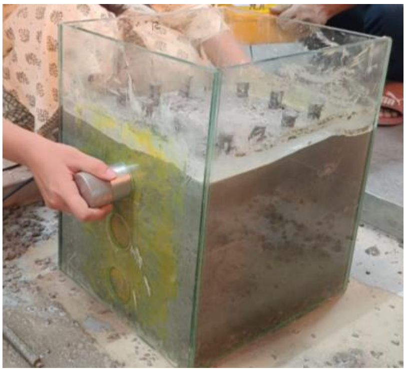

Fig. 5. UPV measurements at 3 sections

4 Test Results

The results of the manual test methods are shown in Table 5 and the classification according to The European Guidelines for Self Compacting Concrete are shown in Table 6.

Table 5. Manual Test methods results

Properties	**Range**	**Sample 1**	**Sample 2**	**Sample 3**
Slump flow	650-800mm	675	635	540
T50 cm	2-5sec	2.2	2.6	3.2
J-ring	0-10mm	5.7	6.5	7.3
V-funnel	8-12sec	10.4	12.3	15.2
V-funnel (5min)	+3 sec	12.6	16.5	20.1
L-Box	0.8-1.0	0.74	0.65	0.56

U-Box	0-30mm	18	21	25

Table 6. Classification of SCC Samples based on manual results

	Sample 1	**Sample 2**	**Sample 3**
Slump flow (SF)	SF2	SF1	SF1
T500(VS)	VS2	VS2	VS2
Viscosity (VF)	VF2	VF2	VF2
Passing ability (PA)	PA2	PA2	PA2

The simulation readings are taken for the same 3 SCC samples and are classified accordingly based on EFNARC guidelines. The serial monitored results are shown in Table 7.

Table 7. Stimulation model results

	Sample 1	**Sample 2**	**Sample 3**
Total time(sec)	24	26	30
FA classification	FA1	FA2	FA2
Corners height C1	15	14	15
Middle height M1	16	15	14
Passing ratio (C1 - M1)	1	1	1
PA classification	PA2	PA2	PA2
UPV @ 1-1 m/sec	264.67	263.7	257
UPV @ 2-2 m/sec	242.3	235.7	281
UPV @ 3-3 m/sec	268.2	249.1	261.4
Hc=UPV [(1-1)/(3-3)]	0.99	1.04	0.98
SR classification	SR1	SR2	SR2

5 Scope

This project can be extended by introducing piezoelectric sensors to the simulation model for determining the velocity propagation measurements. The piezoelectric (PZT) sensors generate lamb waves uses pitch catch technique may also be used for determining the homogeneity of SCC. The introduction of PZT's help to monitor automatically through IoT cloud. The PZT's are also cost effective and easy to stimulate the results.

6 Conclusion

The mix proportions are designed for 3 SCC Samples of M30 grade by Nan-Su mix design principals with packing factors 1.12,1.16 & 1.20. Manual workability tests are performed and results are classified based on European guidelines. The filling ability and passing ability is studied through hc sr04 sensors and segregation resistance with ultrasonic pulse velocity measurements and classified into FA, PA and SR.

1. In this study it is observed that ultrasonic sensors and UPV test can also be used in determining the workability properties.
2. It is observed that with the increase in packing factor the workability decreases.
3. It can be used to determine the suitable application before placing the concrete at in-situ conditions.
4. The wastage of concrete and performance time can be reduced as it can be performed in single test.

5. This test can be additionally used where the high quality and safety of the structure is given high priority.

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