CAPILLARY SUCTION, ULTRASONIC PULSE VELOCITY AND CHLORIDE PENETRATION STUDIES ON BASALT REINFORCED SELF-COMPACTING RECYCLED AGGREGATE CONCRETE

S Rupali[1] , R Arun Raj[1]

1. Dr. B R Ambedkar National Institute of Technology Jalandhar, India

ABSTRACT. The growth of Self Compacting Concrete (SCC) is revolutionary landmark in the history of construction industry resulting in predominant usage of SCC worldwide nowadays. In the recent years the demand for construction materials has grown tremendously, so has the amount of construction and demolition waste, putting huge pressure on the environment. This has encouraged the use of recycled aggregate in concrete which not only allows for a more efficient life cycle of natural resources but also contributes to environmental protection leading to sustainable development. Recycled Coarse aggregate (RCA) concrete construction technique can be called as ‘green concrete’, as it minimizes the environmental hazard of the concrete waste disposal. Incorporation of fibers further enhances its properties specially related to post crack behaviour of SCC. Hence the aim of the present work is to study capillary suction, ultrasonic pulse velocity and chloride penetration of self-compacting recycled aggregate concrete reinforced with basalt fibre. The study comprises development of SCC mix design of M25 grade and later Basalt Fibers are added to the SCC mixes and their fresh, hardened and durability properties are determined and compared with conventional mix. The study presents considerable improvements in pulse velocity performance of self-compacting concrete by adding basalt fibers of different volume fractions (0, 2, 4 kg/m^3) and recycled coarse aggregates and there is no considerable enhancement of durability properties. The present study concludes that in terms of overall performances, optimum dosage of Basalt fiber (2 kg/m^3) and recycled aggregates (50%) is the best option in improving overall mechanical properties of self-compacting concrete.

Keywords: Self-compacting, Durability, Recycled coarse aggregate, Basalt fiber

S Rupali is a Asst.Professor of Civil Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India. Her research interest includes numerical modelling, slope stability, contaminant transport and geo-enviornment.
Telephone with Country Code: +91-8265999739 Email Id: satavalekarr@nitj.ac.in

R Arun Raj is a Post graduate student of Civil Engineering at Dr.B R Ambedkar National Institute Of Technology Jalandhar, India. His M.Tech dissertation is on studying the mechanical and durability properties of self compacting concrete.
Telephone with Country Code: +91 8289902292 Email.id: arunr1432@gmail.com

INTRODUCTION

The present scenario observes an increased use of sustainable materials. As sustainability helps in maintaining harmony with the nature. Concrete is the second most consumed material after water and uses significant amount of aggregates, sand and cement. Natural aggregates are produced from rocks which are non-renewable in nature and over consumption of aggregates is exhausting the limited availability of the material. The best way to overcome this predicament is to replace natural aggregate by recycled aggregate. Recycled aggregates are construction wastes which constitutes a large portion of waste in India and is affecting the environment significantly. In the last few decades experimental work to investigate the material properties and durability of recycled aggregates has been carried out [1-8]. Zoran et al. [1] studied, the key property of a recycled aggregate is higher water absorption in comparison to the natural which is a result of residual cement powder. Prashant and Vinod et al. [2] observed that the percent increase in water absorption with increasing RCA were recorded as 4.53%, 12.62%, 14.00%, 20.11% and 26.82% respectively compared to mix containing no recycled aggregate. Exteberria et al. [3] suggested that the method of producing RCA and the type of crusher that is used in this process is influential in the shape of RCA produced and the shape of the aggregate pieces is influential on the workability of the concrete. Qureshi et al. [4] studied that tensile strength test results show decreasing trend of strength as the percentage of recycled coarse aggregates is increased and percentage of natural coarse aggregates is decreased. Panda and Bal et al. [5] obtained that the difference of flexural strength is also more in 90 days as compared with28 days strength. As replacement of RCA increases, flexural strength of SCC decreases. The flexural strength of SCC decreases with increase in RCA. The 28 days' flexural strength of SCC obtained from experimental is less than the theoretical flexural strength in all the replacement ratio of RCA. Limbachiya et al. [6] concluded that the more recycled aggregate added will decrease the value of characteristic Strength because recycled aggregate has different characteristic, such as the ability to water absorption. Recycled aggregate can absorb more water than natural aggregate because recycled aggregate has many pores to absorb the water and it will influence the characteristic Strength. Nayan et al. [7] studied the 28 days average compressive strength is maximum when 2% basalt fibers were used. About 83% & 92% increase in compressive strength than the design strength, when the basalt fibers are introduced in concrete. One should take care of basalt fiber during mixing with concrete. It should be not allowed to mix more than 1.5 minute, otherwise it will segregate. Kou and Poon [8] observes that the 28-day compressive strength of the concrete mixtures decreased with an increase in the recycled aggregate content. In addition to that, few studies dealt with the influence of RCA on the mechanical properties of concrete [Katrina and Kang [9], Murat et al. [10], Mehmet et al. [11], Kaijian and Jianzhuang [12] and Puja et al. [13]]. From the detailed literature survey, it is clear that there are only few studies conducted for analysing durability of fiber reinforced recycled concrete aggregate. However, the influence of basalt fiber along with recycled concrete aggregate on self compacting concrete was found limited. Also the durability studies such as capillary suction and chloride penetration tests are not performed heretofore to understand the permeability and absorption capacity of fiber reinforced concrete. Hence, present investigation is focused to study the mechanical and durability properties of self-compacting fibre reinforced recycled aggregate concrete. Also, to obtain the optimum replacement of normal coarse aggregate (NCA) with the Recycled coarse aggregate (RCA) in the design of basalt fibrous self-compacting concrete. In last, the objective is to obtain the effective dosage of basalt fibre by conducting the durability test and mechanical test.

CHARACTERIZATION OF MATERIALS

This chapter describes the test methods applied in this research work for characterization of materials used in manufacturing of concrete and evaluation of the effect of basalt fibre on properties of concrete.

Cement

Ordinary Portland cement grade 43 conforming to BIS: 8112-1989 [14] was used in this study. Consistency and setting times of cement were determined as per BIS: 4031-1988 [15].

Fine Aggregate

Natural river sands from Punjab, India has used in this research work. Sand was then sieved through 4.75 mm sieve to remove the particles coarser than 4.75 mm before use in concrete. specific gravity and water absorption of river sand was determined as per procedure given in BIS: 2386 (Part I and II)-1963 [16].

Coarse Aggregate

Crushed stone coarse aggregate was taken from quarry located near Pathankot, Punjab, India. Maximum size of coarse aggregate was 10 mm. Specific gravity and water absorption of coarse aggregate were determined as per procedure laid in BIS: 2386 Part III- 1963 [16]. RCA were collected from crushed concrete cubes and beams from structural engineering laboratory (aged about zero to one-year-old) and was a mixture of concrete with different design characteristic strength (ranging from 25 MPa to 30 MPa) and all of them were undergone a loading (direct compression or combined shear-bending) up to failure. The exposure condition of the source may be considered as normal. Collected cubes and beams were hammered to fragment pieces and sieved to obtain desired size. Specific gravity and water absorption were also found out as above mentioned for coarse aggregate.

Basalt Fibre

Basalt materials have been used as a reinforcing composite material for the construction industry, specifically as a less expensive alternative to carbon fiber. When the fiber in contact with other chemicals they produce no chemical reactions that may damage health or the environment. Basalt base composites can replace steel (1 kg of basalt reinforces equals 9.6 kg of steel, **Shafiq et al. [17]**) as light weight concrete can be get from basalt fiber. Basalt rock is melted at high temperature and rapidly drawn into a continuous fiber. The tensile strength and Elastic modulus of basalt fiber was 2600 and 90 MPa respectively, Wei et al. [18].

Mix Design

Calculation for M30 grade of SCC was done following EFNARC code 2005 [19]. Fly ash was used as a partial replacement for OPC 43 cement. Super plasticizer admixture was used to reduce the water content and improve workability as per the requirement for SCC and Basalt fibre was added according to the designed proportion. To determine the fresh properties of the mix prepared conforming to SCC, different fresh tests like slump flow, V-Funnel were performed. The experimental work was conducted at Structural Engineering lab of Civil Engineering Department of NIT, Jalandhar. The work involved mixing, casting and testing of standard specimens. Six type of mix were used here including the control mix. Mix consists of 0 and 50% replacement of normal coarse aggregate and addition of 0, 2 and 4 kg/m^3 of Basalt fibre. R0B0 is the control mix having no basalt and recycled aggregate, see Tables 1 and 2.

Table 1 Description of Mixes

NO	MIX DESIGNATION	DESCRIPTION
1	R0B0	RCA0% Basalt 0 kg/m^3
2	R0B2	RCA0% Basalt 2 kg/m^3
3	R0B4	RCA0% Basalt 4 kg/m^3
4	R50B0	RCA50% Basalt 0 kg/m^3
5	R50B2	RCA50% Basalt 2 kg/m^3
6	R50B4	RCA50% Basalt 4 kg/m^3

Table 2 Adopted Mix Proportions of SCC

INGREDIENTS	MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6
Cement (Kg)	420	420	420	420	420	420
Fly Ash (Kg)	180	180	180	180	180	180
Water (w/c=0.41) (Kg)	246	246	246	246	246	246
Sand (Kg)	890	890	890	890	890	890
10mm NA (Kg)	124.5	124.5	124.5	62.29	62.29	62.29
6.3mm NA (Kg)	373.7	373.7	373.7	186.8	186.8	186.8
4.75 mm NA(Kg)	124.5	124.5	124.5	62.29	62.29	62.29
10 mm RCA (Kg)	0	0	0	58.6	58.6	58.6
6.3mm RCA (Kg)	0	0	0	175.8	175.8	175.8
4.75mm RCA (Kg)	0	0	0	58.6	58.6	58.6
SP (Kg/m^3)	15	15	15	15	15	15
BF (Kg)	0	2	4	0	2	4

EXPERIMENTAL INVESTIGATIONS

The first stage of investigations was carried out to develop SCC mix of a minimum strength M25 grade using basalt fiber. For developing SCC of strength M25 grade, the mix was designed based on EFNARC 2005 code using basalt fiber. Finally, SCC mixes which yielded satisfactory fresh properties and required compressive strength, were selected and taken for further investigation. In the second stage of investigation SCC with different fiber contents with different volume fraction were mixed and the mix proportions are shown in Table 2. A number of trial mixes had been conducted in the laboratory and satisfying the requirements for the fresh state given by EFNARC 2005 code. To maintain the basic characteristics of self-compacting concrete a water-cement ratio of 0.41 was adopted and a percentage dosage of super-plasticizer were fixed for all mixes. As per the condition, to maintain the workability, slight variation of dosage of superplasticizer was adopted for each mix. The cubes (100×100×100) mm and cylinders (100×200) mm, were casted and investigations were conducted to study the durability properties of basalt fiber reinforced self-compacting recycled aggregate concrete. After casting was done the cubes were kept in room temp. For 24 hours then the moulds were removed and taken to the curing tank containing fresh potable water to cure the specimen for 7 days, 28 days and 56 days. Further, the tests Ultrasonic Pulse Velocity (UPV), Capillary Suction Test (CST) and Rapid Chloride Penetration Test (RCPT) were carried out as per the codal procedures.

RESULTS AND DISCUSSION ON FRESH CONCRETE

Slump Flow

The slump flow decreases with increase in fiber percentage, see Table 3. The decrease in flow value is observed maximum when 100% recycled aggregate and 4kg/m^3 basalt fiber used. The slump flow diameter for R100B4 has got 2.2% less than that for control mix. When 50% recycled aggregate and 4kg/m^3 basalt fiber is used, the slump flow has got a diameter 1.9% less than that of control mix. When 0% recycled aggregate and 2 kg/m^3 basalt fiber is used only 1% decreased has found on slump flow diameter. This is because basalt fibers absorbed more water from the mix as the fibers are little porous in nature. But all mixes have satisfied the norms of self-compacting concrete.

T50 Flow

The T50 flow, which was measured in terms of time (seconds) increases as the slump flow value decreases, **s**ee Table 3. The decrease in slump value is due to the increase in the percentage of fiber which was explained in previous section. The maximum time taken to flow was observed when 100% recycled aggregate and 4 kg/m^3 basalt fiber was used and minimum was observed in control mix having normal coarse aggregate without basalt fiber.

V-Funnel Test

V-Funnel test, which was measured in terms of time (seconds) increases as the slump flow value decreases, see Table 3. As the percentage fibre content increases, the mixes have found to be little harsher. So J-Ring test has performed to meet the workability criteria as per EFNARC code 2005. In V-Funnel test the mix having 100%recycled aggregate and 4kg/m^3 took more time to come out from V-Funnel than the control mix. It was observed that all the mixes have satisfied the SCC workability norms as per EFNARC 2005.

Table 3 Results of the fresh properties of mixes

MIX DESIGNATION	SLUMP FLOW		V-FUNNEL (S)
	T500 mm (s)	D (mm)	
R0B0	2.4	695	6.4
R0B2	2.8	688	6.8
R0B4	3.1	685	7.1
R50B0	2.6	690	6.8
R50B2	2.9	685	7.2
R50B4	3.3	682	7.6

RESULTS AND DISCUSSION ON HARDENED CONCRETE

Ultrasonic Pulse Velocity

The UPV meter acts on principle of wave propagation hence higher the density and soundness, higher the velocity of wave in it. The addition of basalt fiber, having micro grains acts like filler and improve density, whereas super-plasticizer facilitates the uniform distribution of all particles including fiber and impart cohesiveness to the mixes. These factors improve density and homogeneity of mixes in short overall soundness of concrete improves. From Fig. 1(a) and (b), it has found that, up to 2 kg/m^3 addition of basalt fiber, velocity is increasing. The addition of 2kg/m^3 basalt fiber in 0% recycled aggregate results in an increase in velocity of 0.5% compared to the control mix R0B0. The addition of basalt fiber 4kg/m^3 results in decrease in velocity of 0.28% compared to control mix R0B0 in the 28th days. This might be due to the lumping of long fibres during mixing, at high fibre dosage. On 56th day addition of 2kg/m^3 results in an increase in velocity of 0.7% and observed a decrease in velocity of 0.3% beyond 2kg/m^3. It was observed from Fig. 1(b) that maximum velocity has obtained for the mix having 50 % recycled aggregate and 2 kg/m^3 basalt fiber. When 50% recycled aggregate has replaced on 28th day, 2kg/m^3 addition results in 0.43% increase and beyond that a decrease in velocity of 0.43% has been noted. On 90th day up to 2 kg/m^^{3} basalt fiber addition results in an increase in velocity of 0.25% and beyond that addition results in 0.3% decrease in velocity. The pulse velocity through concrete increased with increase in curing period. The pulse velocity values increased at a faster rate from 28th day to 56th day of curing period. It was observed that, an addition of 2kg/m^3 results in an increase of 0.5% and comparatively large decrease of 1.71% up to 4kg/m^3.

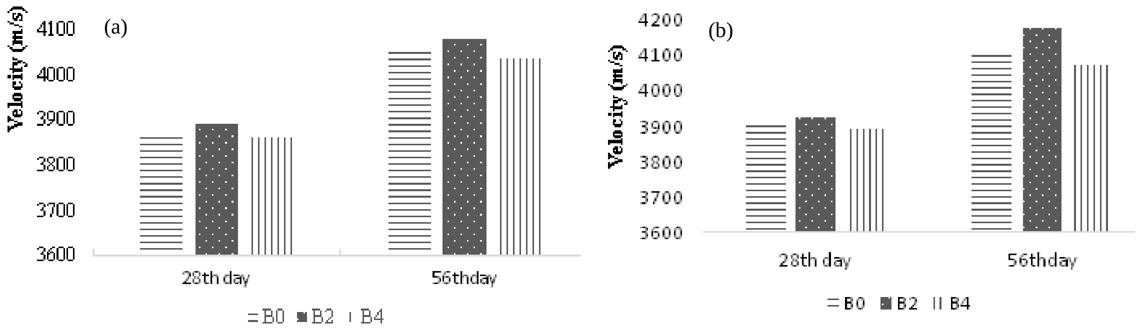

Figure 1 Behaviour of mixes with basalt fibre along with (a) 0 and (b) 50 % RCA

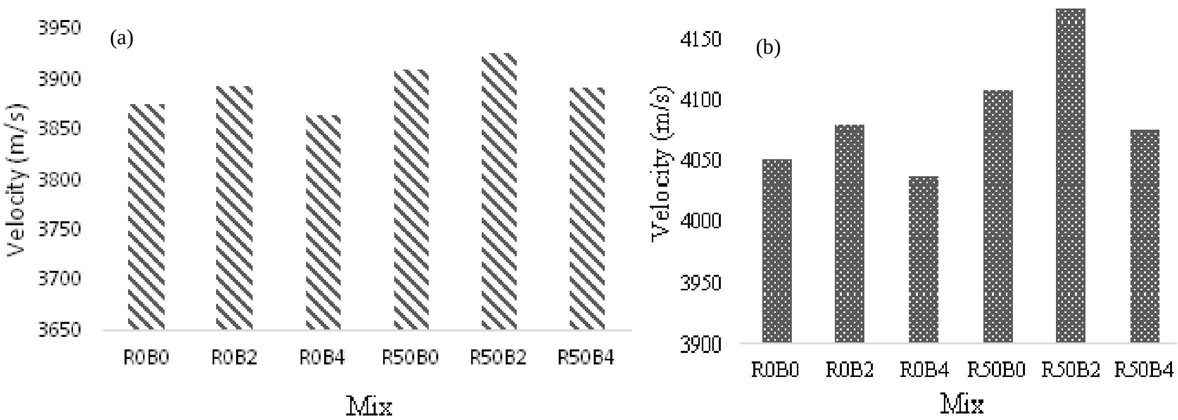

Figure 2 Behaviour mixes with basalt fibre and RCA after (a) 28th and (b) 56th days

Rapid Chloride Penetration Test

Resistance to chloride ion penetration depends largely on the volume and size of interconnected capillary voids present in the concrete and microcracks present in the paste and at the aggregate-paste interface. Rapid chloride penetration test results of concrete mixtures are presented in Fig.4.21. Total charge in coulombs (C) passed over a period of 6 hrs duration through concrete was measured at 28, 56 and 90 days of curing age**.** As per ASTM C 1202-10, the chloride permeability of all SCC mixes, R0B2, R0B4, R50B0, R50B2, R50B4, as well as control mix (R0B0) at 28 days of curing age was moderate. Fig 3 shows that, with increase in basalt fiber, chloride permeability was observed to be increased. After 56 days of curing, with 0% recycled aggregate, the percentage increase of chloride permeability for R0B2 and R0B4 are 1.45% and 5.71% respectively. It was observed that, with the same dosage of basalt fiber, the chloride penetration of SCC mixes has increased with increase in the percentage of recycled aggregates in the mixes. When SCC mix prepared without basalt fiber, the percentage increase for R50B0 after 28 days of curing are 5.2%. This might be attributed due to, the large amount of voids present in the recycled aggregate, since the resistance to chloride ion penetration depends largely on the volume and size of interconnected capillary voids present in the concrete, and hence results in the poor performance in chloride ion penetration.

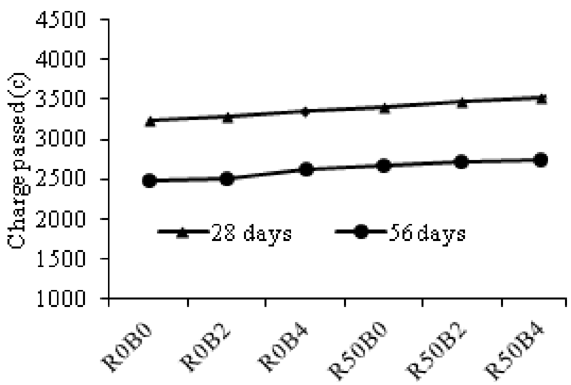

Fig 3 Chloride penetration of SCC mixes at 28 and 56 days

Capillary Suction Test

The capillary water absorption of selected specimens are tested on 28 and 56 days of curing and presented in this section graphically. The slope of curves is decreasing in nature with time. This might be attributed due to the denser concrete formed by cumulative absorption of water which will further resists the water absorption of these specimens. It is observed that, with the increase in dosage of basalt fiber the capillary suction has found to be increased. From Fig 4 it can be seen that, after 28^{th} days of curing, the SCC mix without recycled aggregate, R0B2 and R0B4 has got a percentage increase of absorption about 27.8% and 53.47% respectively in 6 hours compared to the control mix R0B0. Similarly, for the SCC mix with 50% recycled aggregate, R50B2 and R50B4 has got a percentage increase of absorption about 54.01% and 97.38% respectively in 6 hours compared to the control mix R0B0. This tremendous increase in absorption might be due to the hydrated cement paste stick on the surface of recycled aggregates.

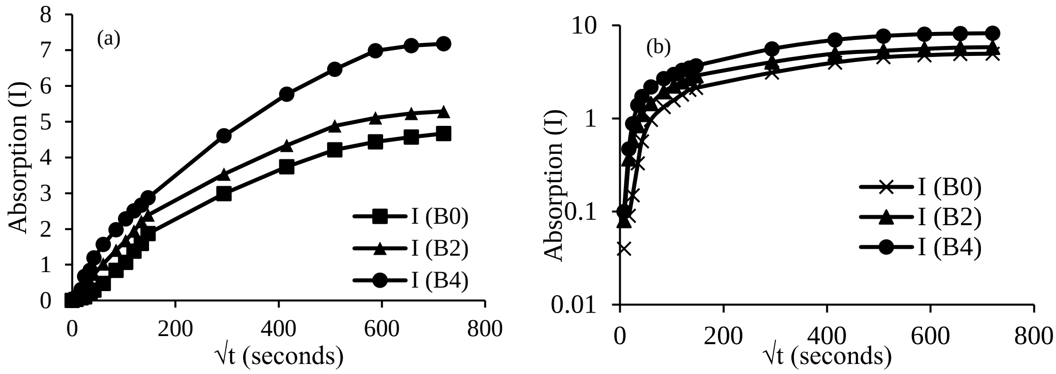

Figure 4 Absorption of SCC mixes (a) without recycled aggregates (b) with 50% recycled aggregates at 28 days

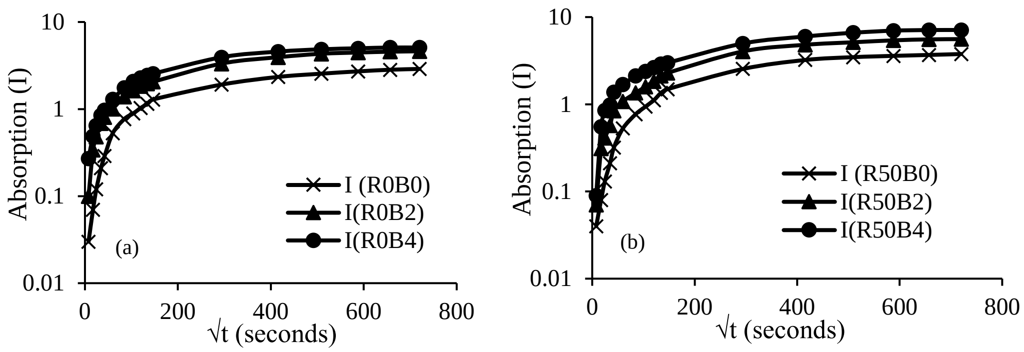

Figure 5 Absorption of SCC mixes (a) without recycled aggregates (b) with 50% recycled aggregates at 56 days

From Fig 5 it can be seen that, after 56^{th} days of curing, the SCC mix without recycled aggregate, R0B2 and R0B4 has got a percentage increase of absorption about 59% and 76% respectively in 6 hours compared to the control mix R0B0. From Fig 5, it was observed that with the increase in dosage of recycled aggregate the capillary suction has found to be increasing. The reason may be due to the additional water absorbed by the old mortar adhered to RCA.

Initial rate of absorption (IRA) up to 6hr has represented graphically in Fig 6. It is evident that, as the time progress the capillary suction rate is decreasing. Absorption is more for that mix which is having more dosage of basalt fiber with the same dosage of recycled aggregate. This might be attributed due to the pores present in the basalt fiber results in considerable suction of water. From Fig 6(b), it is evident that, after 56 days of curing, the SCC mix without Basalt fiber, R50B0 has got a percentage increase of absorption significantly in 6 days compared to the control mix R0B0, which again shows that recycled aggregate significantly enhancing the capillary suction.

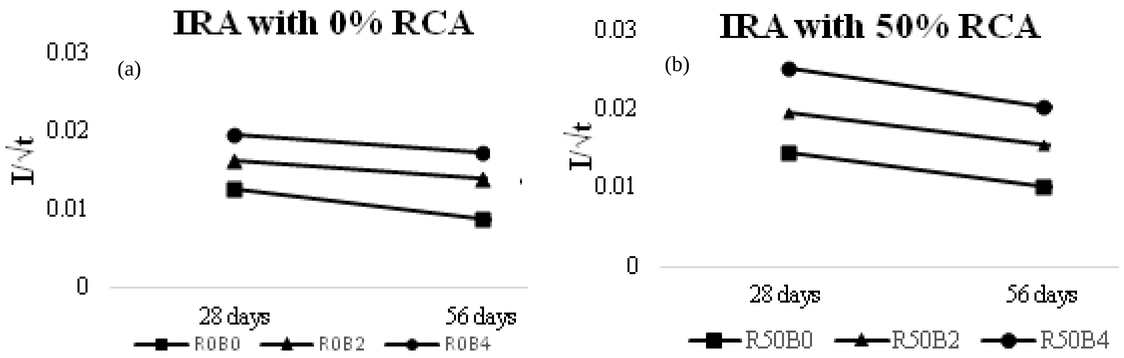

Figure 6. IRA of SCC mixes with (a) 0 and (b) 50 % RCA

The secondary rate of absorption (SRA) up to 6hr has represented graphically in Fig 7. It is evident that, as the time progress the capillary suction rate is decreasing. The SCC mix with 50% recycled aggregate and 4kg/m^3 basalt fiber dosage was found the maximum rate of initial and secondary absorption on 28 and 56 days. The control mix R0B0 has got the least rate of capillary absorption. So now it is clear that as a percentage of recycled aggregate and basalt fiber significantly affects the capillary absorption. Adhered mortar on recycled aggregate plays a lead role in water absorption. So while using RCA for practical purpose, thorough cleaning of RCA would arrest the suction for some extend. So together with a dosage of basalt fiber and recycled aggregate results in poor performance in capillary suction due to the pores present in fiber and adhered mortar stick to the recycled aggregates.

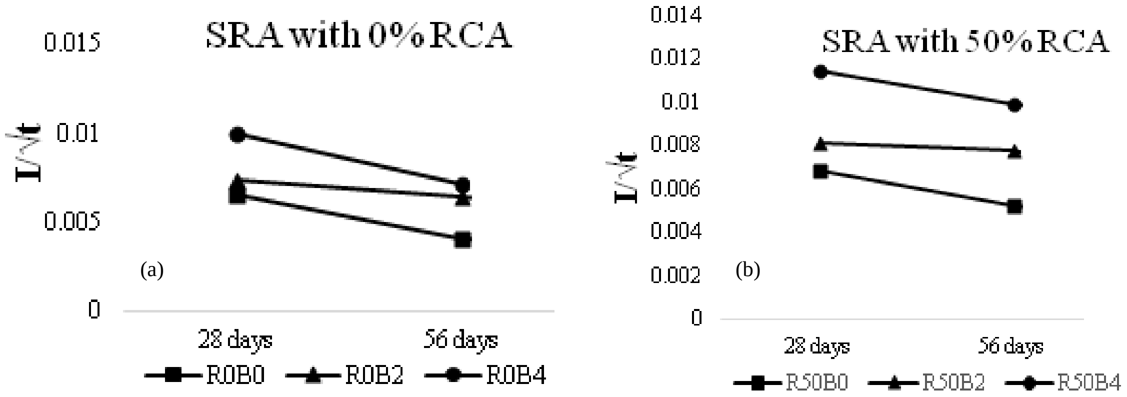

Figure 7 SRA of SCC mixes with (a) 0 and (b) 50 % RCA

CONCLUSION

The present work is focused to study the influence of recycled aggregate and basalt fiber on self-compacting concrete through durability and non-destructive tests. Mechanical properties of concrete was evaluated by ultrasonic pulse velocity test and durability properties were evaluated through capillary suction test and rapid chloride penetration tests. Based on the detailed experimentation, the following conclusions are drawn;

- The tests on fresh concrete concludes that with the addition of basalt fiber, the workability found to be reduced. The reason for this phenomenon is that a large in number of porous and lesser in flow ability due to the distributed fiber in the concrete, which restrains mixture from segregation and flow.
- In the UPV, the UPV values of SCC mix has found to be increased with the supply of Basalt fibre. Optimum dosage has found to be 2kg/m^3.

- It was observed through RCPT, the Basalt fibre doesn’t have any significant role in enhancing the performance of SCC mix. Control mix has got the better result. With the replacement of recycled aggregate, the performance of concrete has found to be poor. So the replacement of NVC with RCA is not recommended.
- In Capillary Suction Test (CST), Capillary suction has found to be increased as the dosage of basalt fiber increases. Introduction of fiber with RCA yielded much increase in capillary suction due to the high porosity of fiber and recycled aggregate. The orientation of basalt fiber doesn’t impart on capillary suction because of due to the high porous behaviour of fiber become dominant.

REFERENCES

1. ZORAN J G, GORDANA A, TOPLICIC-CURCIC IVA M D, AND NENAD S R., Properties of self-compacting concrete prepared with coarse recycled concrete aggregate, Volume 24, Issue 7, July 2010, pp 1129-1133.
2. PRASHANT M O, AND VINOD, M M., Self-compacting concrete with recycled aggregate: A solution for sustainable development, INTERNATIONAL JOURNAL OF CIVIL AND STRUCTURAL ENGINEERING Volume 4, No 3, 2014, pp430-440.
3. ETXEBERRIA M, VÁZQUEZ E, MARÍ A, AND BARRA M, Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete, Cement and Concrete Research 37, pp 735–742.
4. QURESHI L A, JAHANGEER M M, TAHIR MUBEEN AND RAJA TASADDIQ M., Effect of Using Recycled Concrete as Coarse Aggregate on Tensile and Flexural Strength of Concrete, Fourth International Conference on Sustainable Construction Materials and Technologies.
5. PANDA K C, AND BAL P K. Properties of self-compacting concrete using recycled coarse aggregate, Proceedia engineering Volume 51, 2013, pp 159-164.
6. LIMBACHIYA M C, LEELAWAT T AND DHIR R K., Utilization of recycled concrete aggregate in high-strength properties concrete. Journal of Materials and Structures, 2013, 33, pp574-580.
7. NAYAN R, MUKUND G, AND MALLIKARJUN P, Basalt Fiber Reinforced Concrete, International Journal of Science and Research, 2013, pp2319-7064.
8. KOU S C AND POON C S, Properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates, Cement & Concrete Composites, 2009, 31, pp 622–627.
9. KATRINA M. AND KANG T H K, Recycled Concrete Aggregates, International Journal of Concrete Structures and Materials, 2013, Vol.7, No.1, pp.61–69.
10. MURAT T, ALI M A, AND KAMBIZ R, Freeze–thaw resistance, mechanical and transport properties of self-consolidating concrete incorporating coarse recycled concrete aggregate, Materials and Design, 2013, 53, pp 983-991.
11. MEHMET G, ERHAN G, HATICE O, TAHA I AND MEHMET T Y. Failure characteristics of self-compacting concretes made with recycled Aggregates”, Construction and building material, 2015, 98, pp 334-344.
12. KAIJIAN, Z. AND JIANZHUANG X., Prediction model of carbonation depth for recycled aggregate concrete, Cement and Concrete Composites, 2018, 88, pp 86-99.
13. PUJA R, SARATH K P AND SANKET N, Sustainable self-compacting concrete from C&D waste by improving the microstructures of concrete ITZ, Construction and Building Materials, 2018, 163, pp 557-570.

14. BIS: 8112-1989, Indian Standard 43 Grade ordinary Portland cement – specification, Bureau of Indian Standards, New Delhi, India.
15. BIS: 4031-1988, Indian Standard Consistency of Standard Cement Paste, Bureau of Indian Standards, New Delhi, India.
16. BIS: 2386-1963, Methods of Test for Aggregates for Concrete, Bureau of Indian Standards, New Delhi, India.
17. SHAFIQ N, AYUB T AND KHAN S U, Investigating the performance of PVA and basalt fiber reinforced beams subjected to flexural action. Compo Struct, 2018, 153, pp30–41.
18. WEI B, CAO H AND SONG S, Environmental resistance and mechanical performance of basalt and glass fibers. Mat Sci Engg A, 2010, 527, pp4708–4715.
19. EFNARC, The European Guidelines for Self-Compacting Concrete- Specification, Production and Use, BIBM, CEMBUREAU, ERMCO, EFCA EFNARC, 2005, p. 68.