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Fresh and hardened properties of rubberized concrete using fine rubber and silpozz

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Abstract. This work investigates the mechanical properties of conventional concrete (CC) and self compacting concrete (SCC) using fine rubber and silpozz were accompanied by a comparative study between conventional rubberized concrete (CRC) and self compacting rubberized concrete (SCRC). Fine rubber (FR) from scrap tires has replaced the fine aggregate (FA) and Silpozz has been used as a replacement of cement at the proportions of 5, 10 and 15%. Silpozz as a partial replacement of cement in addition of superplasticiser (SP) increases the strength of concrete. Fresh concrete properties such as slump test, compaction factor test for CRC, whereas for SCRC slump flow, T_{500}, V-funnel, L-box, U-box, J-ring tests were conducted along with the hardened properties tests like compressive, split tensile and flexural strength test at 7, 28 and 90 days of curing. The durability and microstructural behavior for both CRC and SCRC were investigated. FR used in the present study is 4.75 mm passing with fineness modulus 4.74. M30 grade concrete is used with a mix proportion of 1:1.44:2.91 and w/c ratio as 0.43. The results indicate that as FR quantity increases, workability of both CRC and SCRC decreases. The results also show that the replacement of natural fine aggregate (NFA) with FR particles decreases the compressive strength with the increase of flexural strength observed upto 5% replacement of FR. Also replacement of cement with silpozz resulted enhancement of strength in SCRC.

Keywords: conventional rubberized concrete (CRC); self compacting rubberized concrete (SCRC); fine rubber (FR); super plasticizer (SP); scanning electron microscope (SEM)

1. Introduction

The objective of recycling is to produce reusable materials by utilizing the waste materials in an effective manner which preserves the natural resourses. Wastes are being fully utilized technically in each field now a day. Rubber has played an important role in our life due to the grooming of transportation industry globally. For greener alternatives waste tyres should not be stock pilled or burnt. Rubber from discarded tyres is generally use in spot surfaces, automobile industry, construction work, geotechnical/asphalt applications, adhesives, shock absorption and safety products, in sound barriers to absorb the heavy sound, in rail roads for fixing of rails to the ground, agricultural purposes as fences and poles, where vibration damping is required, where

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resistance to impact or explosion is require. SCC is an innovative concrete which makes compaction easier with high compressive strength and durability with comparison to CC. SCRC combines the behavior of SCC (high early strength, faster construction times, ease of flow, low w/c ratio) with the tough behavior of rubber (high impact and plastic energy) gives a high performance building material.

Rubberized concrete is considered as an ideal material in the field of engineering where high strength is not the primary factor such as in drive ways or in road construction. Concrete with rubberized concrete has higher set of deformation than non-rubberized concrete (Topcu 1995; Segre and Joekes 2000). In general for ordinary concrete the compressive strength obtained from cube test is found more than the cylinder test. But (Topcu 1995) gives the reverse result. The flexural strength was found to reduce two times than the compressive strength. Specimens with rubber as aggregate have higher toughness as compared to controlled specimen (Toutanji 1996). Washed tyres show better results than unwashed tyre. By treating powdered rubber with NaOH saturated aqueous solution for 20 minutes improve the toughness and porocity of the specimen. Waste tyres should be used in the form of fibers than chips. NaOH treatment does not work for waste tire chips (Fattuhi and Clark 1996; Segre and Joekes 2000; Li *et al*. 2004). The usage of rubberized concrete is more in the places like road foundations and bridge barriers where deformability or toughness is the key factor than strength. Rubberized concrete can also be used as a material having damping and elasticity properties to neutralize the structural vibration under impact effects (Siddique and Naik 2004). Eldin and Senouci (1993) used a different size of rubber aggregate containing steel wires. Large displacements and deformations were observed without sudden cracking. It is because of rubberized concrete has the potential to withstand large deformations like springs delayed the widening period. Khatib and Bayomy (1999) observed the impact of mixing two different kinds of rubber like crumb and chipped rubber. They categorized it in three groups. In Group A, crumb rubber was used as a replacement of fine aggregate. In Group B, chipped rubber was used as a replacement of coarse aggregate. In Group C, both the kind of tyres was mixed in equal volumes. Each group had eight different rubber contents within the range 5% to 100%. A decrease in slump was observed with the increase in rubber content. Mixtures with fine crumb rubber were found to be more workable than those with coarse tyre chips or a combination of tyre chips and crumb rubber. Thomas *et al.* (2014) observed that discarded tyre rubber may be utilized for the partial replacement of natural fine aggregates upto 7.5% without enough reduction in its desired strength. Guneyisi *et al*. (2014) investigated the durability properties of rubberized concrete using two types of waste scrap tyre rubber such as fine and coarse aggregate. The transport properties of the rubberized concretes were investigated through water absorption, gas permeability and water permeability tests. The corrosion behavior of reinforcing bars embedded in plain and silica fume based rubberized concrete was investigated by linear polarization resistance test. The results indicated that the utilization of SF in the rubberized concrete production enhanced the corrosion behavior and decreased corrosion current density values. Thomas and Gupta (2015a) observed that the values of compressive strength, flexural tensile strength, pull-off strength and sulphate attack of rubberized concrete were lower than that of control mix; but upto a certain percentage, they give better resistance to water absorption, and carbonation. Thomas *et al.* (2015b) observed macrocell corrosion and half cell potential measurements showed that there was no presence of corrosion. Thomas *et al.* (2015c) concluded that the high strength rubberized concrete is highly resistant to the aggressive environment. Emiroglu *et al*. (2015) experimentally evaluated the dynamic modulus of elasticity of self-consolidating rubberized concrete by using result of ultrasonic pulse velocity and resonance frequency tests. The results indicated that dynamic modulus of elasticity values obtained by non-destructive measurements techniques are well agreed with those given in the literatures. Thomas and Gupta (2016a) presented in a rivew paper that rubberized concrete shows high resistance to freeze-thaw, acid attack and chloride ion penetration. Use of silica fume in rubberized concrete enables to achieve high strength and high resistance to sulfate, acid and chloride environments. Thomas and Gupta (2016b) presented the compressive strength, flexural tensile strength, pull-off strength and depth of water penetration of the rubberized concrete were less than that of the control mix, while the abrasion resistance and water absorption (upto 10% substitution) exhibited better results than that of the control mix concrete. Thomas and Gupta (2016c) concluded that the rubberized concrete is highly resistant to the aggressive environments and can be implemented in the areas where there are chances of acid attack.

Limitation of rubber aggregate substitution to 30% gives better influence on mechanical performance of the composite. Rubberized concrete produces a lower flexural load bearing capacity, low elastic modulus, high straining and tensile capacity for deformation before microcrack formation. Higher free shrinkage is measured with the presence of rubber aggregate and not suitable for the places where high strength is the priority. When the rubberized mortar in fiber reinforced reduces the shrinkage cracking with improved durability of the structure (Turatsinze *et al*. 2006, 2007). Rubberized concrete alter concrete blocks more flexible and thus render softness to the surface and also performed well in both skid and abrasion test with high toughness and are able to absorb large quantities of energy after the peak load and prior to final failure (Sukontasukkul and Chaikaew 2006). Rubberized concrete is found to be an ideal material at harbors for wharf protectors where high durability is not required. Compressive strength of rubberized concrete was decreased in sea water due to presence of Mg and SO_4 ions which could react with hydrated cement components. Topcu and Demir (2007) concluded that in the regions where environmental conditions are not harsh, the use of concrete produced with 10% rubber aggregate was considered to be economical. Rubberized mortar should be used in places free from high temperature effect and where durability is important rather than strength. More expensive light weight aggregate could be substituted by waste tire rubber. Rubber aggregate provides sustainability, lower cost, lower impermeability and lack of porosity with a disadvantage of lower performance with fire (Merino *et al*. 2007). Batayneh *et al*. (2008) used crumb rubber with in size varying from 4.75 mm to 0.15 mm with a substitution of FA (sand) at various percentages of 20, 40, 60, 80 and 100%. It was found that with the increase in rubber content the slump and unit weight of the mixture decreased despite of that it could produce a good workable mix compared to the control mix. The strength of rubberized concrete fulfills the requirements of light weight concrete. Test specimens of rubberized concrete possess a strong bond and remained intact after failure compared to CC. Sukontasukkul (2009) found that crumb rubber concrete can be a better insulator with low density. All rubberized concrete have a lower heat transfer rate and superior heat resistivity and sound properties than plain concrete. Mishra and Panda (2015) investigated both fresh and hardened properties of CC and SCC and gave a comparative study between CRC and SCRC. They found that reduction of strength in CRC was more than SCRC. In both CRC and SCRC replacement of 5% rubber chips with coarse aggregate give more strength than other replacements. With increased amount of rubber chips the flow, filling and passing ability increases with in a less time period. At early age the addition of SP in SCC was giving more strength. Topcu (2009) investigated the usage of rubber in SCC by using fly ash as filler material. He concluded that with the increased amount of rubber and workability, T_{500} time decreased. V-funnel time was lying between 4.37 to 15.25 sec. SCC was having higher compressive strength and very compact microstructure but the failure of SCC was still brittle. SCRC is having tight microstructure. To reach self compacting properties, the requirement of SP in SCRC is more than SCC at constant w/c ratio. SCRC appear to be very attractive for the production of noise reducing pavements (Bignozzi and Sandrolini, 2006). RSCC is a kind of SCC manufactured from the waste tyres with partial replacement of aggregates by rubber particles. The research work is limited upto certain extent because of addition of rubber aggregate in concrete mixture causes a loss in strength. Rubberized concrete undergo ductile and plastic failure and a good absorbent of large amount of plastic energy under tensile and compressive load (Rahman *et al*. 2012). Panda *et al*. (2012) investigated on the influence of the rubber on fresh and mechanical properties of rubberized concrete starting from 0% to 12% rubber content in the M20 grade concrete. With the coarse aggregate was replaced by 3%, 6%, 9% and 12% of rubber, the compressive strength was found to decrease with the increase in percentage of replacement, but rubber in 3% replacement concrete acquired slightly higher compressive strength than those of concrete free from rubber. In this study, waste tyre rubber in the form of FR was used as a partial replacement for NFA in CC and SCC. The fresh concrete properties of CC are evaluated by slump and compaction factor test and SCC are evaluated by slump flow, T_{500}, V-funnel, L-box, U-box, J-ring tests. The hardened concrete properties are evaluated through compressive, split tensile and flexural strength test at 7, 28 and 90 days of curing. The micro structural study is also carried out for CRC and SCRC.

2. Experimental study

2.1 Used materials and properties

In the present investigation, Ordinary Portland Cement (OPC), 43 grade used was of specific gravity 3.15 along with initial and final setting time as 165 minutes and 360 minutes respectively. Natural river sand of zone III was taken as per IS: 383-1970 with specific gravity 2.67, fineness

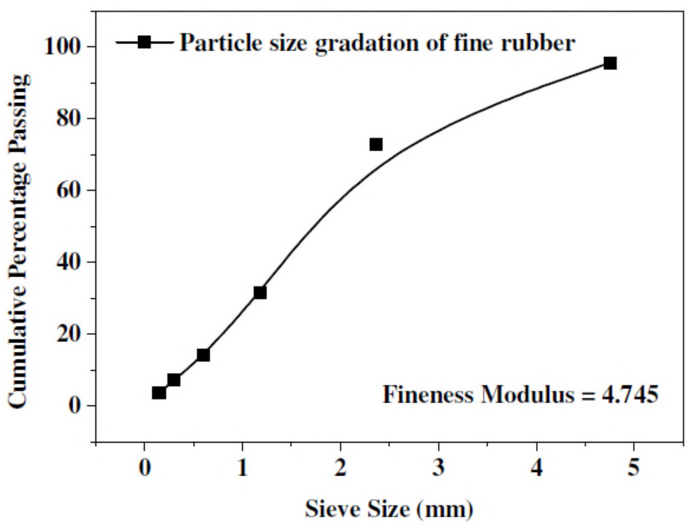

Fig. 1 Particle size gradation curve of fine rubber

Fig. 2 Residues of rubber passing through different sieves

modulus 3.03, water absorption 0.40% and bulk density 1568 kg/m^3. Natural coarse aggregate consist of rock fragments, 20 mm passing confirming to IS: 383-1970 (specific gravity 2.86, abrasion value 34.78%, impact value 24.00%, crushing value 23.30%, water absorption 0.20%, fineness modulus 7.00). Waste tyre rubber (passing through 4.75 mm sieve and fineness modulus 4.745). Silpozz is used as a substitute of silica fumes or micro silica. In the present study, silopzz (bulk density 0.23 gm/cc, LOI < 6.0%, physical state - solid nonhazardous, appearance – powder, colour – grey, specific gravity 2.3, mean particle size < 25 microns, surface area 17.1 m^2/gm) used as a filler material in SCRC mix (Panda and Prusty 2015). High end superpalsticiser (CERA HYPERPLAST XR-W40) was used for the production of SCC. The rubber was replaced with fine aggregate from 0% to 15% in both CC and SCC (SCR and SCRS) mix along with an additional replacement of cement with silpozz at 10% in SCRS. SP used to make good workability condition of the mix. SP is generally used for high early strength, excellent durability, high water reduction,

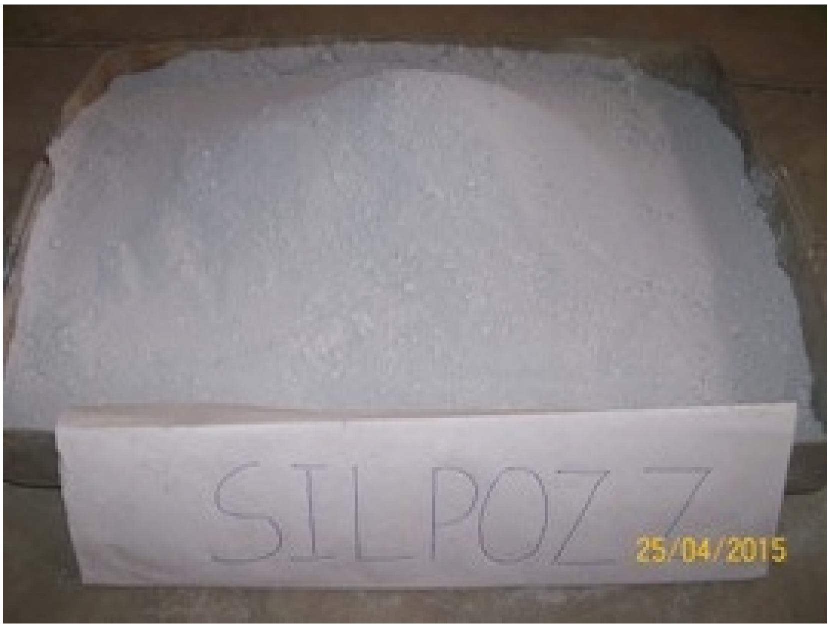

Fig. 3 Sample of silpozz

Table 1 Details of concrete mix (CR, SCR and SCRS) along with specific identification

Concrete mix proportions	SP (%)	Mix Identity
Conventional Concrete (CC)		
CC mix with Cement (100%) + NFA (100%) + NCA (100%) + FR (0%)	-	CR0
CC mix with Cement (100%) + NFA (95%) + NCA (100%) + FR (5%)	-	CR5
CC mix with Cement (100%) + NFA (90%) + NCA (100%) + FR (10%)	-	CR10
CC mix with Cement (100%) + NFA (85%) + NCA (100%) + FR (15%)	-	CR15
Self Compacting Concrete (SCC)		
SCC mix with Cement (100%) + NFA (100%) + NCA (100%) + FR (0%)	0.35	SCR0
SCC mix with Cement (100%) + NFA (95%) + NCA (100%) + FR (5%)	0.40	SCR5
SCC mix with Cement (100%) + NFA (90%) + NCA (100%) + FR (10%)	0.45	SCR10
SCC mix with Cement (100%) + NFA (85%) + NCA (100%) + FR (15%)	0.50	SCR15
SCC mix with Cement (90%) + NFA (95%) + NCA (100%) + FR (5%) + Silpozz (10%)	0.48	SCR5S10
SCC mix with Cement (90%) + NFA (90%) + NCA (100%) + FR (10%) + Silpozz (10%)	0.50	SCR10S10
SCC mix with Cement (90%) + NFA (80%) + NCA (100%) + FR (15%) + Silpozz (10%)	0.60	SCR15S10

high flowing, filling and passing ability of concrete. The particle size gradation curve of fine rubber is shown in Fig. 1.

The residues obtained from different rubber particles passing through different sieves are shown in Fig. 2. Sample of silpozz is shown in Fig. 3.

Table 2 Details of mix (CR, SCR and SCRS) quantity per m^3 of concrete

Mix Identity	Mix quantity with different constituents in m^3 of concrete						
	Cement (Kg)	NFA (Kg)	NCA (Kg)	Silpozz (Kg)	Rubber (Kg)	SP (Kg)	Water (Kg)
CR0	434.32	624.77	1264.97	_	0	_	186.76
CR5	434.32	593.53	1264.97	_	31.24	_	186.76
CR10	434.32	562,30	1264.97	_	62.47	_	186.76
CR15	434.32	531.05	1264.97	_	93.72	_	186.76
SCR0	434.32	843.43	822.23	0	0	1.52	186.76
SCR5	434.32	801.26	822.23	0	42.17	1.73	186.76
SCR10	434.32	759.08	822.23	0	84.35	1.95	186.76
SCR15	434.32	716.92	822.23	0	126.51	2.71	186.76
SCR5S10	390.88	801.26	822.23	43.43	42.17	2.08	186.76
SCR10S10	390.88	759.08	822.23	43.43	84.35	2.17	186.76
SCR15S10	390.88	716.92	822.23	43.43	126.51	2.60	186.76

2.2 Mixture proportion

The grade of concrete M30 was designed according to standard specification IS: 10262-2009. The mix proportion of 1:1.44:2.91 were taken for this experiment with w/c ratio of 0.43. Four different mixes of concrete mixtures were made by replacing 0%, 5%, 10% and 15% of sand with fine rubber for CC. Seven concrete mixtures were made for SCC with same w/c ratio of 0.43; first (SCR) by replacing 0%, 5%, 10% and 15% of sand with fine rubber, second (SCRS) was by replacing cement with silpozz at 10% and sand by fine rubber at 5, 10 and 15% with 0.35%, 0.4%, 0.45%, 0.5%, 0.48%, 0.5%, 0.6% of SP to achieve the EFNARC (2005) Guidelines. The mix design was prepared in trial basis. Several trial mixes were prepared. In final trial, the amount of fine aggregate was increased by 35% with a decrease in 35% of coarse aggregate followed by required amount of superplasticiser to satisfy the EFNARC (2005). The details of concrete mix along with their mix identity are described and presented in Table 1. The details mix quantity per m^3 of concrete is presented in Table 2.

3. Test program

3.1 Fresh concrete test

Fresh concrete is that phase of concrete from time of mixing till the time of being transferred, placed and compacted in its final location in the structure. It consists of operations like batching, mixing, transporting, placing, compacting and surface finishing. This is also called as “Green Concrete”. The fresh concrete tests are conducted to know the workability and consistency of CR. In this study, slump test and compaction factor test was conducted for each proportion of mixing.

To study the workability of SCR, with various combinations of fine rubber and silpozz, tests on fresh concrete were conducted. For SCR and SCRS, there are six experiments were conducted in the laboratory for each mix to know the fresh concrete properties such as slump flow test, T_{500} test, J-ring test, V-funnel test, L-box test and U-box test which follow EFNARC (2005) guidelines. The slump flow test, T_{500} test and J-ring test are presented in Figs. 4 a, b, c. The L-box test, V-funnel

Fig. 4 (a) Slump flow test (b) T_{500} test (c) J-ring test

Fig. 5 (a) L-box test (b) V-funnel test (c) U-box test

test and U-box test are presented in Figs. 5 a, b, c.

The slump flow as given in Fig. 4(a) is used to appraise the flowability of SCC without any obstructions which results in fulfillment of filling ability of SCC. The test procedure is so quick that as soon as the mix prepared the test conducted within 5 sec. The horizontal free flow of SCC is evaluated from T_{500} test without any obstruction as shown in Fig. 4(b). The T_{500} test was conducted for each proportion of mixing. It is the usual test, and gives a good knowledge of filling ability. The J-ring test is used for evaluation of the passing ability of the concrete. The J-ring test determines three factors like flow spread, blocking step and flow time. The J-Ring flow spread indicates the delimited deformability of SCC due to the obstruction of reinforcement bars and blocking step qualifies the blocking effect. The flow time represents the rate of deformation within a particular flow distance. The J-ring used in this test is shown in Fig. 4c.

The L-box test measures the filling and passing ability of SCC. The test evaluates the flow of the concrete along with the degree to which it is subjected to blocking by reinforcement. The principle of L-box test is shown in Fig. 5a. V-funnel is a type of test which is used to determine the filling ability of the concrete with aggregate of maximum size 20 mm. The setup of V-funnel test in laboratory is shown in Fig. 5b**.** The U-box is used to enumerate the confined flow ability and capacity of SCC to flow under circumscribed spaces. The setup of U-box test in the laboratory is shown in Fig. 5c.

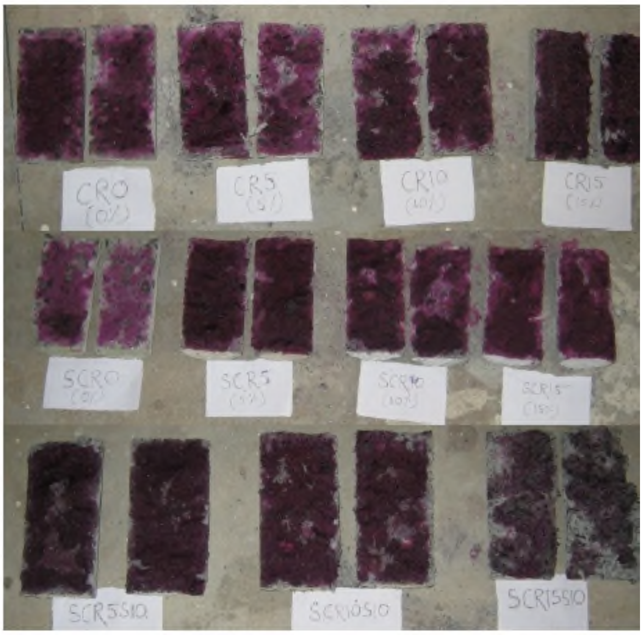

Fig. 6 Test specimens of CR, SCR and SCRS after carbonation

3.2 Hardened concrete test

The hardened concrete test conducted for CR and SCR at 7, 28 and 90 days of curing under water. After casting and proper curing, the concrete specimens such as cubes, cylinder and prism were tested to know the compressive, split tensile and flexural strength. The curing has been done properly to achieve the target strength.

3.3 Durability test

3.3.1 Carbonation test

Carbonation of concrete is associated with the corrosion of steel reinforcement and with shrinkage. After curing in water for 28 days, the concrete samples were dried in oven for 48 hours. Each specimen was divided in to two pieces from the longitudinal sides. Carbonation is the result of the dissolution of CO_2 in the porous concrete. The extension of carbonation was measured by sprinkling 1% phenolphthalein solution to the newly aerated concrete surface. The non carbonated areas were transformed to purple leaving the carbonated areas as uncolored as shown in Fig. 6.

3.3.2 Water absorption test

The cubes were fully submerged in clear water on account of 24 hours at constant room temperature. Then the blocks were taken away from water and dried for 1 minute in air. After liberating all the cubes were oven dried at 105˚C to 110˚C for 24 hours. The water absorption value is calculated as follows:

Water absorption percent = (A-B) / B × 100

Where, A = wet mass of unit in kg, B = dry mass of unit in kg

3.4 Microscopical study

According to Hall *et al.* (2012) microstructure of concrete matrix is one of the crucial factors in controlling the development of strength characteristics. The SEM analysis conducted to examine the bond characteristics of rubberized concrete. The SEM samples collected after the compressive strength tests. All samples chosen for the SEM analysis coated thin gold for electrical conduction.

4. Results and discussions

4.1 Fresh concrete test results

The fresh concrete test generally executed to find the workability of concrete. Slump test and compaction factor test is used to measure the workability of fresh CRC, which is done immediately after the mixing. Fine rubber decreases the workability, with increase in the replacement level. According to Bataynehe *et al.* (2008) rather than the declined value of measured slump, mixing and casting reflected that increased in rubber content in mix still produced a good workable mix in contrast to the control mix. The slump values for CR0, CR5, CR10, and CR15 are 45, 30, 15, and 10 with compaction factor as 0.86, 0.84, 0.82, and 0.81 respectively. In SCRC, for slump flow test the rubber particles in the mixture behaves like a binder preventing the flow which results in loss in workability far quicker than conventional SCC (Rahman *et al*., 2012). The fresh concrete test results of SCC for slump flow, T_{500} and J-ring are presented in Table 3. In SCC, the fresh concrete test results of SCR0, SCR5, SCR10, SCR15, SCR5S10, SCR10S10 and SCR15S10 are given as well as the standard value as per EFNARC (2005) guidelines. Slump flow test values of the mixes are 560, 660, 610, 625, 650, 640 and 660 mm respectively, so it belongs under slump flow classes SF1 and SF2. As per EFNARC (2005) guidelines, T_{500} results is classify into two classes such as VS1 and VS2. If the result is ≤ 2 sec, it is considered as VS1 class and if the result is > 2 sec, it is considered as VS2 class. The T_{500} values are 14, 13, 18, 14, 16, 17 and 15 sec, so it falls under VS2 class. From the result, it is observed that the T_{500} test results of SCR5 mix is less than SCR0 mix, indicate more flowable concrete as compared to control mix, whereas SCR10 mix is more than SCR0 mix, taking relatively more time to cover 500 mm circle, indicate less flowable concrete. The SP required for SCR5 mix is 0.4% whereas for SCR10 is 0.45%. It indicates as rubber content increases more quantity of SP required to satisfy the EFNARC guidelines and also to maintain the flow of concrete. In J-ring test, the step height results are 12, 8, 10, 9, 8, 10 and 10 mm, so it confirm the EFNARC (2002) criteria. If the step height is more, the passing ability of the concrete is less. SCR10 mix having 10 mm step height, indicate less passing ability as compared to SCR5 and SCR15. The fresh concrete test results of SCC for V-funnel, L-box and U-box are presented in Table 4. The V-funnel test values are 10, 7, 9, 8, 9, 10 and 8 sec, so it lies in between 7 and 27 secs as per EFNARC (2005) guidelines. As time increases the flowability decreases. The flow time for emptying of SCR10 mix is 9 sec, indicate less flowable as compared with SCR5 and SCR15. For L- box test the passing ability values are 0.76, 0.85, 0.83, 0.9, 0.86, 0.85 and 0.78, it is greater than 0.75 as per EFNARC (2005) guidelines. The U-box test values are 69, 50, 65, 60, 55, 64 and 45 mm, it is less than 80 mm as per EFNARC (2005) guidelines**.** The results indicate that upto 5% replacement of rubber achieving good passing and flow ability of SCC. As rubber content increases, the amount of SP

Table 3 Fresh concrete test results of slump flow, T_{500} and J-ring

Mix Identity	SP (%)	Slump flow		T_{500} Test		J-ring Test		
		Test Result (mm)	EFNARC (2005) Guidelines (mm)	Test Result (sec)	EFNARC (2005) Guidelines (sec)	Step height result (mm)	Total flow result (sec)	EFNARC (2002) guidelines (mm)
SCRO	0.35	560	550-650	14	>2	12	8	0 – 10
SCR5	0.40	660	650-750	13	>2	8	15	0 – 10
SCR10	0.45	610	550-650	18	>2	10	18	0 – 10
SCR15	0.50	625	550-650	14	>2	9	11	0 – 10
SCR5S10	0.48	650	550-650	16	>2	8	17	0 – 10
SCR10S10	0.50	640	550-650	17	>2	10	14	0 – 10
SCR15S10	0.60	660	650-750	15	>2	10	15	0 – 10

Table 4 Test results of V-funnel, L-box and U-box

Mix identity	V-funnel		L-Box			U-Box	
	Test result (sec)	EFNARC (2005) guidelines (sec)	Test result (H_2/H_1)	T_{400} (sec)	EFNARC (2005) guidelines (mm)	Test result (H_2/H_1)	EFNARC (2005) guidelines (mm)
SCRO	10	7-27	0.76	17	≥0.75	69	≤80
SCR5	7	7-27	0.85	15	≥0.75	50	≤80
SCR10	9	7-27	0.83	16	≥0.75	65	≤80
SCR15	8	7-27	0.90	9	≥0.75	60	≤80
SCR5S10	9	7-27	0.86	13	≥0.75	55	≤80
SCR10S10	10	7-27	0.85	18	≥0.75	64	≤80
SCR15S10	8	7-27	0.78	16	≥0.75	45	≤80

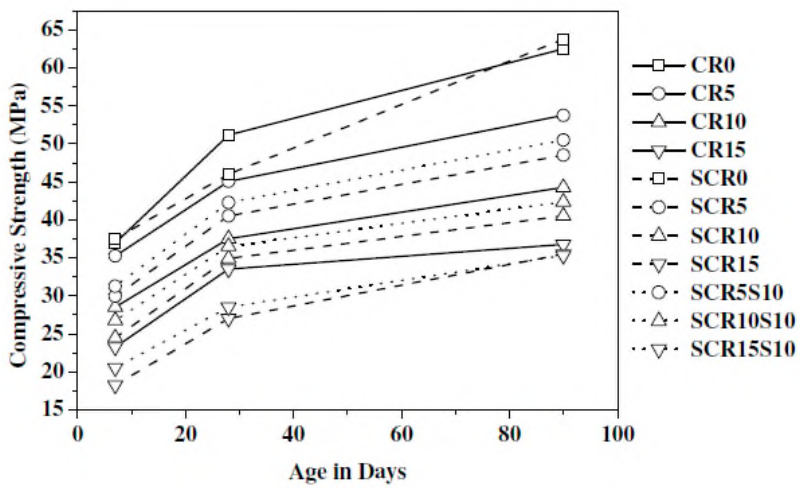

Fig. 7 Compressive strength of rubberized concrete versus age in days

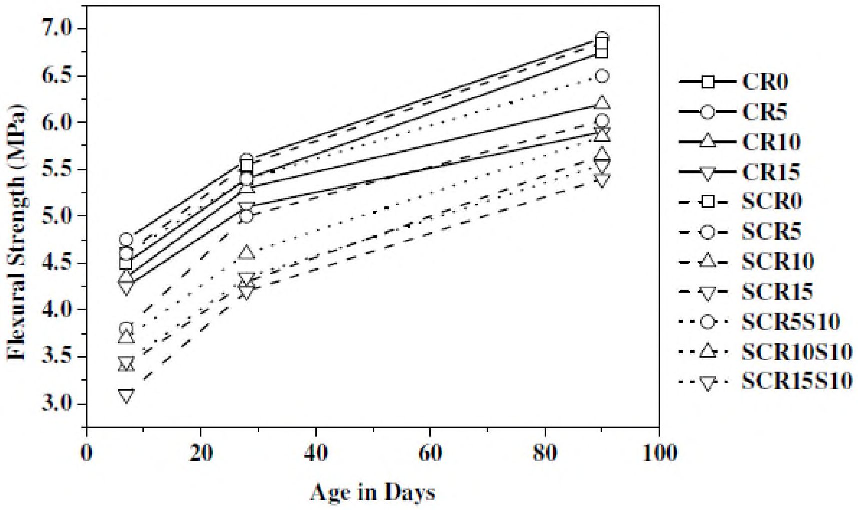

Fig. 8 Flexural strength of rubberized concrete versus age in days

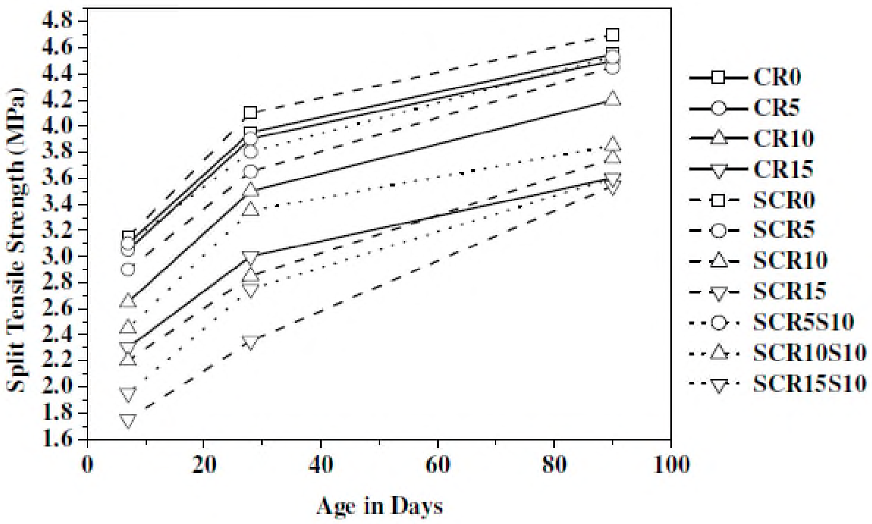

Fig. 9 Split tensile strength of rubberized concrete versus age in days

amount also increases to satisfy the EFNARC guidelines. When silpozz is added in rubberized SCC, the amount of SP required more as compared to rubberized SCC without silpozz. This indiacate silpozz decreases the workability.

4.2 Hardened concrete test results

The hardened concrete test results are obtained at time interval of 7, 28 and 90 days of curing. The compressive, flexural and split tensile strength verses age in days for CR and SCR (SCR and SCRS) are presented in Figs. 7-9. The compressive strength of CR0 at 7 days, 28 days and 90 days

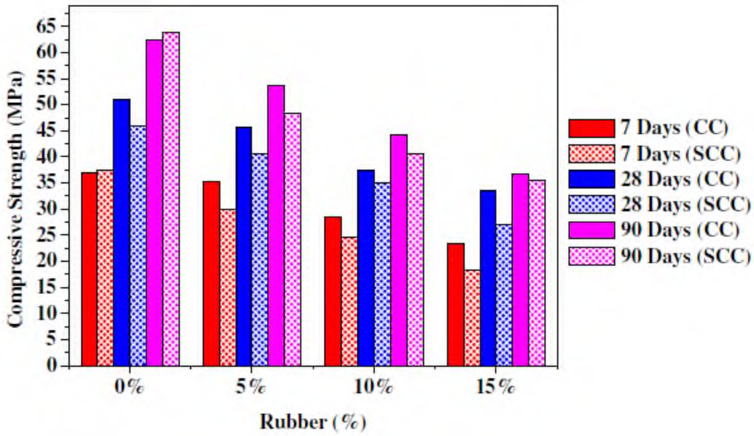

Fig. 10 Comparison of compressive strength for CC and SCC

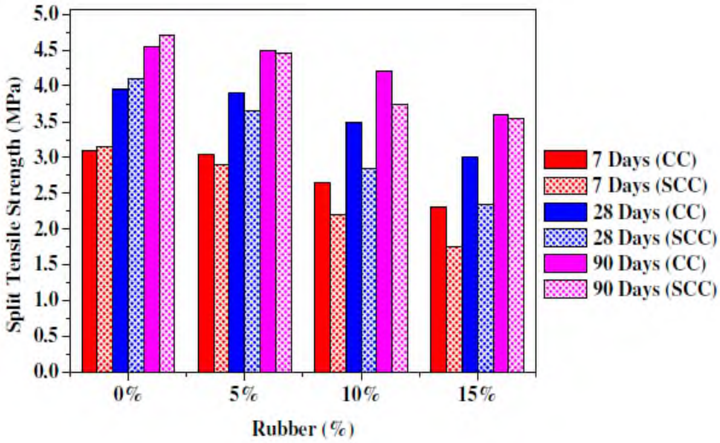

Fig. 11 Comparison of split tensile strength for CC and SCC

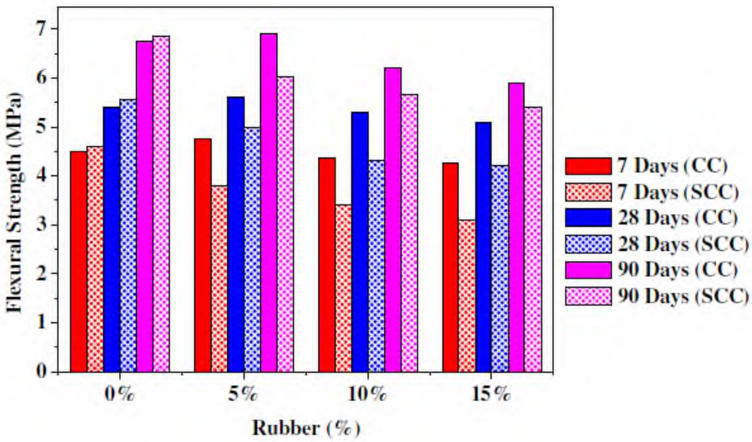

Fig. 12 Comparison of flexural strength for CC and SCC

are 36.95 Mpa, 51.15 Mpa and 62.50 MPa respectively and SCR0 is 37.50 Mpa, 46.00 Mpa and 63.75 MPa respectively. The compressive strength of SCR0 is higher than CR0 in all curing periods except 28 days strength. Use of SP increases the compressive strength by enhancing the effectiveness of compaction to produce denser concrete. Curing plays a major role in developing strength of concrete. The rate of increase in strength from 7 to 28 days is more as compared to 28 to 90 days except SCR0 mix. This indicates without rubber and silpozz, the strength enhancement of SCR0 concrete from 7 to 28 days is slightly higher than 28 to 90 days. From Fig. 7, it is observed that the compressive strength of control mix is more than the other mixes. With the increase percentage of rubber substitution, the compressive strength value decreases. The loss of strength is mainly due to the lack of adhesion between rubber particles and cement paste. Same observation also obtained from the split tensile test results as shown in Fig. 9. From Fig. 8, for flexural test, replacement of 5% FR with sand shows slightly higher value than the control specimen. In CR, the split tensile strength difference between CR5 and the control mix is very less. Ageing increases the strength value. Strength values from compressive, split, flexural tests at 90 days are more than 7 and 28 days**.** Smaller reduction is observed in flexural strength than to compressive and split tensile strength with increase in rubber amount**.**

4.3 Comparison between CC and SCC

The comparison of compressive, split tensile and flexural strength of CC and SCC with FR are shown in Figs. 10-12. The compressive, split and flexural strength values of SCC is more than CC except 28 days compressive strength whereas in rubberized concrete, the value of CRC is more than SCRC in all replacement level. With increase in fine rubber content, decreases the compressive, split and flexural strength. As observed from Fig. 10, the maximum decrease in compressive strength of the specimen CR15 w.r.t. control specimen is 37.1%, 34.5% and 41.2% after 7, 28 and 90 days respectively whereas for SCR15, 51.33%, 41.3% and 44.31% respectively. From Fig. 11, the maximum decrease in split tensile strength of the specimen CR15 w.r.t control specimen after 7, 28 and 90 days is 22.03%, 24.05% and 20.88% respectively, whereas for SCR15, 44.44%, 42.70% and 24.70% respectively. From Fig. 12, the maximum decrease in flexural strength of specimen CR15 w.r.t control specimen after 7, 28 and 90 days is 5.55%, 5.55% and

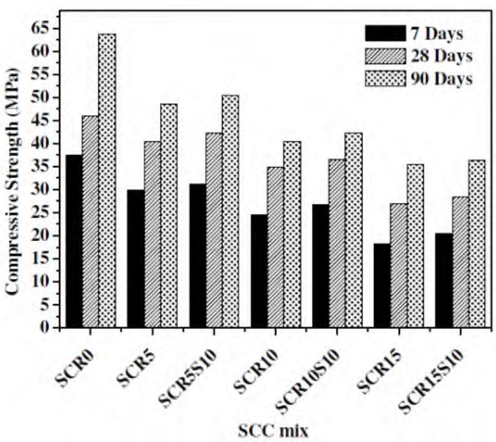

Fig. 13 Comparison of compressive strength at different curing condition

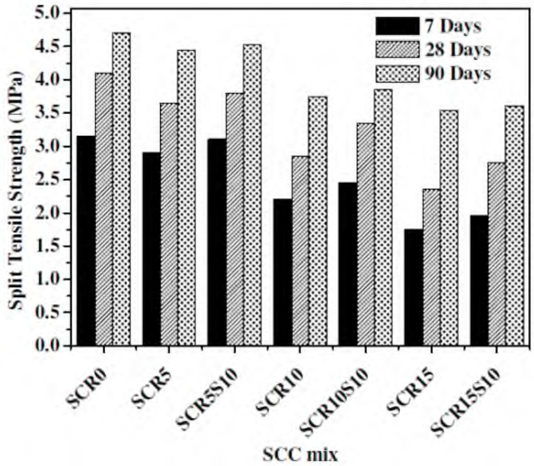

Fig. 14 Comparison of split tensile strength at different curing condition

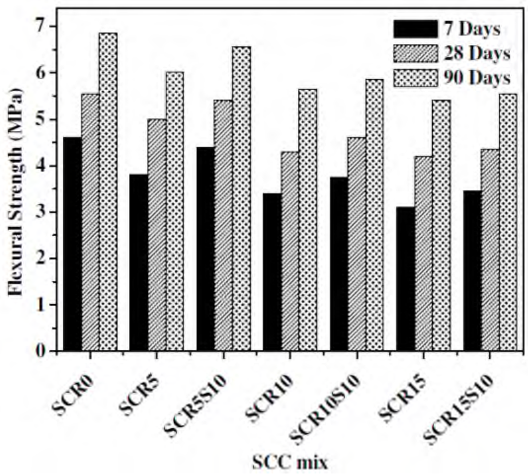

Fig. 15 Comparison of flexural strength at different curing condition

12.6% respectively, whereas for SCR15, 32.6%, 24.32% and 21.17% respectively. It is observed that the percentage of decrease in strength in SCRC is more than CRC. Vibration plays a significant role in CRC, whereas in SCRC without vibration some voids left between fine rubber and fine aggregate, so the strength obtain is less as compared to CRC. For compressive, split and flexural strength the value of CRC is more than SCRC for 7, 28 and 90 days. The percentage decrease in compressive strength is more than split and flexural strength.

4.4 Comparison between SCR and SCRS

The comparative graph for compressive, split tensile and flexural strength of SCR and SCRS are presented in Figs. 13-15. It may be observed from the figure that the strength of control specimen is more than the other specimens. Increase in amount of rubber results in decrease of

Table 5 Unit weights, water absorption and depth of carbonation of rubberized concrete

Type of mixes	Unit weight			Water absorption (%)	Depth of Carbonation (mm)
	7 Days	28 Days	90 Days		
CR0	24.84	24.88	24.94	0.35	7.60
CR5	24.77	24.94	24.83	0.43	6.00
CR10	24.21	24.29	24.22	0.51	5.50
CR15	24.18	24.50	24.03	0.59	8.30
SCR0	23.42	23.69	23.95	0.25	5.80
SCR5	23.18	23.43	22.97	0.74	4.30
SCR10	23.14	23.33	22.48	0.83	3.20
SCR15	23.07	23.24	22.00	0.92	3.00
SCR5S10	21.26	22.16	20.46	0.80	2.00
SCR10S10	21.22	22.15	21.38	0.94	1.80
SCR15S10	21.19	22.08	22.50	0.97	1.30

strength values. As observed from Fig. 13, the maximum decrease in compressive strength of the specimen SCR15 w.r.t. control specimen (SCR0) after 7, 28 and 90 days is 51.33%, 41.3% and 44.31% respectively whereas for SCR15S10, 45.33%, 38.04% and 43.02% respectively. From Fig. 14, the maximum decrease in split tensile strength of the specimen SCR15 w.r.t control specimen (SCR0) after 7, 28 and 90 days is 44.44%, 42.70% and 24.70% respectively, whereas for SCR15S10, 38.1%, 32.92% and 23.40% respectively. From Fig. 15, the maximum decrease in flexural strength of specimen SCR15 w.r.t control specimen (SCR0) after 7, 28 and 90 days is 32.6%, 24.32% and 21.17% respectively, whereas for SCR15S10, 25%, 21.62% and 18.98% respectively. It is observed that the percentage decrease in strength is less for silpozz based rubberized SCC as compared with normal rubberized SCC. It is concluded that by adding silpozz to rubber aggregate increase the strength values at different percentage of mix. It is also observed that percentage decrease in compressive strength is more than split and flexural strength. Rubber does not have any hydraulic or pozzolanic activity to contribute to hydration, occur more C-S-H gels and gain compressive strength in concrete with elapsed time. Besides cement capable of hydraulic reaction and silpozz having pozzolanic activity improves the hydration and strength gain related to concrete age.

4.5 Durability test results

The unit weight of concrete, water absorption and depth of carbonation is presented in Table 5. From the Table 5, it can be noticed that the unit weight of concrete increases upto 28 days and decreases that is for 90 days except CR0 and SCR0. As rubber content increases for CR, SCR and SCRS, the unit weight of concrete drops. As CR and SCR compared, the unit weight of SCR is less than CR. The unit weight of concrete decreases as silpozz is also added in SCR. The optimum results for unit weight are found at 28 days. According to Najim and Hall (2010) rubber aggregate mixes create reduced value of unit weight with utmost level of air entrainment that can be easily pumped at higher flow rates and give improved level of thermal and/or acoustic insulation. Self compacting rubberized concrete having less unit weight than conventional rubberized concrete because of its ability to flow beneath its own weight and does not necessitate vibration for placing and compaction. It may be concluded that, for plain CC and SCC, the density increases as age of

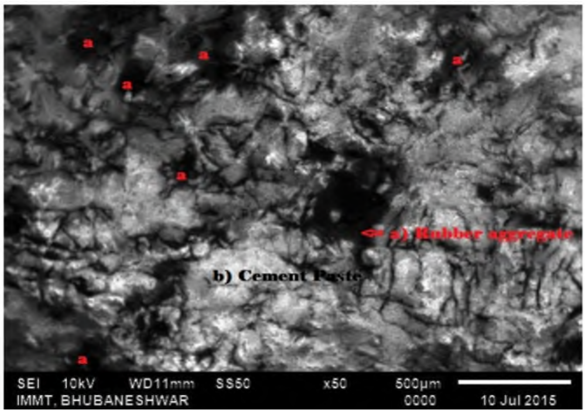

Fig. 16 SEM observation for sample CR10 (50X, marker 500µm). (a) Rubber aggregate (b) Cement Paste

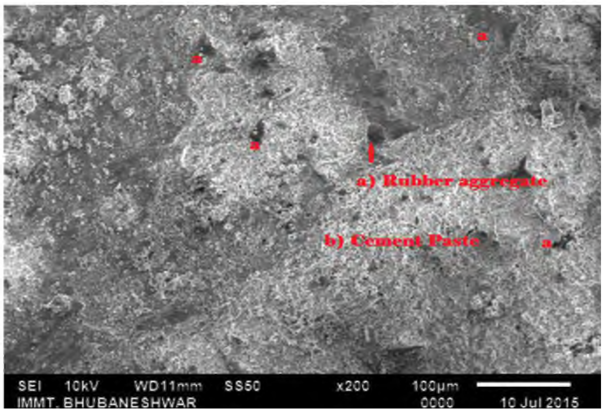

Fig. 17 SEM observation for sample CR10 (200X, marker 100µm). (a) Rubber aggregate (b) Cement Paste

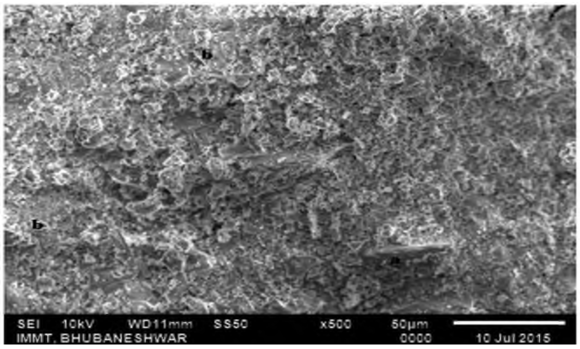

Fig. 18 SEM observation for sample CR10 (500X, marker 50µm).

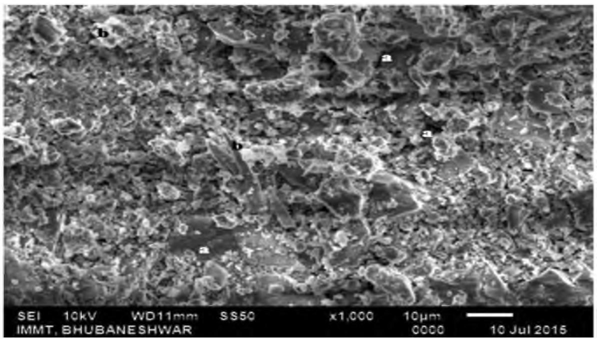

Fig. 19 SEM observation for sample CR10 (1000X, marker 10µm)

curing increases, whereas in rubberized concrete, the density decreases after 28 days in all the mixes. The lighter weight of the rubberized concrete was partly due to lack of fine aggregates which were replaced by fine rubber. Another reason could be from the flocculation of the rubber particles during the concrete mix with rubber contents.

It is observed from Table 5 that, the water absorption of concrete obtained from different mix shows that as the amount of rubber increases, the voids in mix also increases which further increases the water absorption capacity. According to Bignozzi (2006) water absorption increases due to porosity with the rubber phase in the mixes due to deviation of rubber particles from sand grain size arrangement and due to which slightly higher amount of air was cornered during the mixing procedure of rubberized concrete. From the results it can be observed that SCR is having more water absorption than CR and it further increases with the addition of silpozz. In this study, the water absorption of natural river sand is 0.4%. So the results obtained from the water absorption test of all concrete mixes are less than 1%. The water absorption of concrete is low value it might be due to the reduction in porosity of concrete due to filling of the voids with well graded fine rubber.

It is observed from Table 5 that, the carbonation decreases upto 10% of crumb rubber substitution in CRC thereafter the carbonation depth increases. CR shows more effect due to

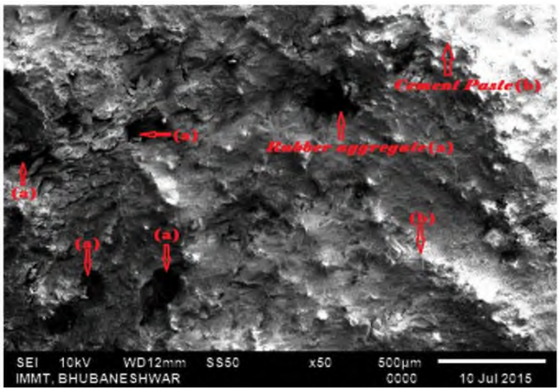

Fig. 20 SEM observation for sample SCR10 (50X, marker 500µm). (a) Rubber aggregate (b) Cement Paste

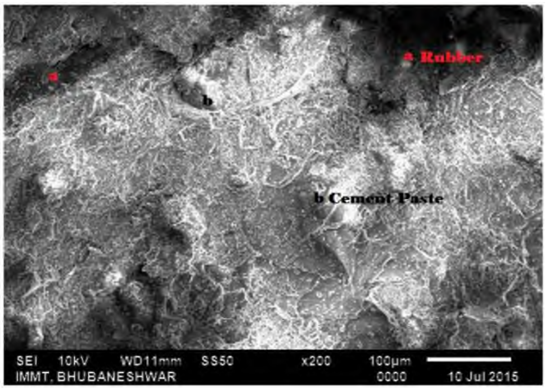

Fig. 21 SEM observation for sample SCR10 (200X, marker 100µm). (a) Rubber aggregate (b) Cement Paste

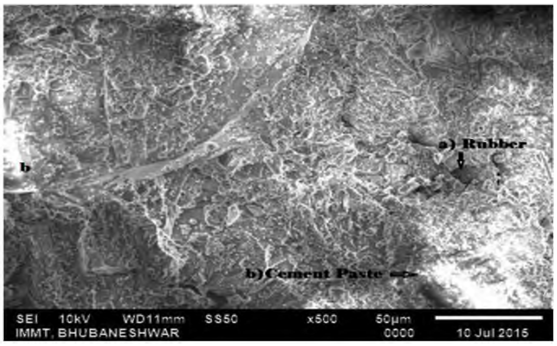

Fig. 22 SEM observation for sample SCR10 (500X, marker 50µm).

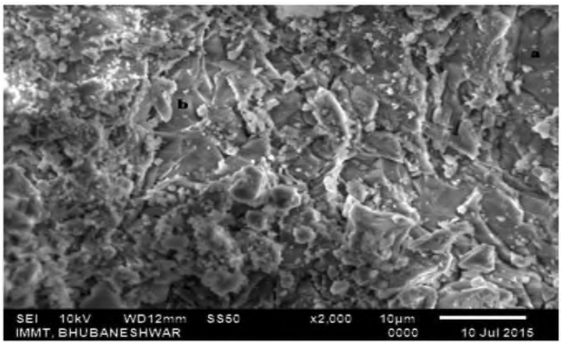

Fig. 23 SEM observation for sample SCR10 (2,000X, marker 10µm)

carbonation than SCR. With the addition of silpozz in SCR the effect due to carbonation decreases. It is the average values of ten observations along the different sides of sample taken for the test. The depth of carbonation decreases due to improved pore structure. The pore structure of SCC is better which can be seen through microstructure images. Further addition of silpozz improves pore structure in a better way. The fine aggregate and the replaced crumb rubber were almost the same size (ZONE III) and those closely packed rubber particles along with the NA in concrete may prevent the entry of CO_2 in to the concrete. The rubber powder of size between 300 microns to 150 microns might have provided a filler effect in the concrete to reduce the depth of carbonation.

4.6 Microscopical study

The micro structural study of rubberized concrete was done by SEM analysis. According to Segre and Jokes (2000) SEM was used to individuate the rubber particles and to discover the interface between the rubber and the cement matrix. The SEM studies of specimen CR10 at different magnifications are shown in Figs. 16-19. The SEM studies of specimen SCR10 at different magnifications are shown in Figs. 20-23. In rubberized concrete no convergence bonding between cement paste and rubber tire has been maintained. Rubber seems as a hole between the cement pastes and develops a weak bond with cement mortar. Rubber serves as a barrier and can reduce the initial crack growth. SCC is having higher compressive strength and very compact microstructure. Tyre particles appear well covered by cement matrix and also visible for higher magnification.

5. Concluding remarks

Based on the experimental results of the present study, the following conclusions may be drawn:

• The workability of both CRC and SCRC decreases as rubber content increases.

• As rubber content increases, the amount of superplasticiser required more for SCRC to satisfy the EFNARC guidelines.

• Mechanical strength such as compressive and split tensile strength decreases with the increased amount of rubber content whereas the flexural strength increases upto 5% replacement, thereafter the strength decreases. This could be facilitated by poor adhere between cement paste and tyre chips.

• The unit weight of both CRC and SCRC decreases as rubber content increases.

• Water absorption value increases with the increased amount of rubber due to increase in voids.

• Adding of silpozz was not able to induce any substantial development to workability in unification with replacement of rubber aggregate. To satisfy the EFNARC Guidelines, SP with an increased amount was used.

• Addition of silpozz to SCR improves the flow ability and maintains the J-ring step height according to EFNARC (2002). But to satisfy guidelines the dosage of SP was needed to be increased.

• Conventional rubberized concrete shows more effect due to carbonation than the self-compacting rubberized concrete. With the addition of silpozz to the self-compacting rubberized concrete the effect of carbonation decreases.

• The compressive strength of SCRC increases in addition of silpozz which is due to high pozzolanic effect.

• As most of the areas of CR and SCR samples turns purple by spraying phenolphthalein solution, indicates that it is unaffected by carbonation. Depth of carbonation decreases with the replacement of FR with sand upto 10%, then increases.

• In micro structural study of SCR was better than CR i.e. better bonding properties and compactness were observed in SCR.

• From SEM studies it can be observed that rubber particles create void spaces results in weak bond.

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References

Batayneh, M.K., Marie, I. and Asi, I. (2008). "Promoting the use of crumb rubber concrete in developing countries", *Waste Manag.*, **28**(11), 2171-2176.

Bignozzi, M.C. and Sandrolini, F. (2006), "Tyre rubber waste recycling in self-compacting concrete", *Cement Concrete Res.*, **36**(4), 735-739.

EFNARC (2002), "Specification and guidelines for self-compacting concrete", EFNARC, Association House, 99 West Street, Farnham, Surrey GU9 7EN, UK.

EFNARC (2005), "The European guidelines for self-compacting concrete specification", Production and use.

Eldin, N.N. and Senouci, A.B. (1993), "Rubber-tire particles as concrete aggregate", *J. Mater. Civil Eng.*, **5**(4), 478-96.

Emiroglu, M., Yildiz, S. and Kelestemur, H. (2015), "A study on dynamic modulus of self-consolidating rubberized concrete", *Comput. Concr.*, **15**(5), 795-805.

Fattuhi, N.I. and Clark, L.A. (1996), "Cement based materials containing shredded scrap truck tyre rubber", *Constr. Build. Mater.*, **10**(4), 229-236.

Gesoğlu, M., Güneyisi, E., Khoshnaw, G. and Ipek, S. (2014), "Investigating properties of pervious concretes containing waste tire rubbers", *Constr. Build. Mater.*, **63**, 206-213.

Guneyisi, E., Gesoglu, M., Mermerdas, K. and Ipek, S. (2014), "Experimental investigation on durability performance of rubberized concrete", *Adv. Concrete Constr.*, **2**(3), 193-207.

Hall, M.R., Najim, K.B. and Hopfe, C.J. (2012), "Transient thermal behavior of crumb rubber-modified concrete and implications for thermal response and energy efficiency in buildings", *Appl. Therm. Eng.*, **33**, 77-85.

IS: 10262 (2009), "Concrete mix proportioning-guidelines", *Bureau of Indian Standards*, New Delhi, India.

IS: 383 (1970), "Indian standard specification for coarse and fine aggregates from natural sources for concrete (second revision)", *Bureau of Indian Standards*, New Delhi, India.

IS: 8112 (1989), "Indian standard 43 grade ordinary portland cement specification (first revision)", *Bureau of Indian Standards*, Manak Bavan, 9 Bahadur Shah Zafar Marg, New Delhi, India.

Khatib, Z.K and Bayomy, F.M. (1999), "Rubberized Portland cement concrete", *Mater. Civil Eng.*, **11**(3), 206-13.

Li, G., Stubblefield, M.A., Garrick, G., Eggers, J., Abadie, C. and Huang, B. (2004), "Development of waste tyre modified concrete", *Cement Concrete Res.*, **34**(12), 2283-2289.

Merino, M., Astorqui, J. and Mariano, G. (2007), "Viability analysis and constructive applications of lightened mortar (Rubber Cement Mortar)", *Constr. Build. Mater.*, **21**(8), 1785-1791.

Mishra, M. and Panda, K.C. (2015), "Influence of rubber on mechanical properties of conventional and self compacting concrete", *Adv. Struct. Eng.(Springer India)*, 1785-1794.

Najim, K.B. and Hall, M.R. (2010), "A review of the fresh/hardened properties and applications for plain-(prc) and self-compacting rubberised concrete (scrc)", *Constr. Build. Mater.*, **24**, 2043-2051.

Panda, K.C. and Prusty, S.D. (2015), "Influence of silpozz and rice husk ash on enhancement of concrete strength", *Adv. Concrete Constr.*, **3**(3), 203-221.

Panda, K.C., Parhi, P.S. and Jena, T. (2012), "Scrap-tyre-rubber replacement for aggregate in cement concrete - an experimental study", *Int. J. Earth Sci. Eng.*, **5**(1), 1692-1701.

Rahman, M.M., Usman, M. and Al-Ghalib Ali, A. (2012), "Fundamental properties of rubber modified self-compacting (RMSCC)", *Constr. Build. Mater.*, **36**, 630-637.

Segre, N. and joekes, I. (2000), "Use of tire rubber particles as addition to cement paste", *Cement Concrete Res.*, **30**(9), 1421-1425.

Siddique, R. and Naik, T.R. (2004), "Properties of concrete containing scrap-tire rubber- an overview", *Waste Manag.*, **24**(6), 563-569.

Sukontasukkul, P. (2009), "Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel", *Constr. Build. Mater.*, **23**, 1084-1092.

Sukontasukkul, P. and Chaikaew, C. (2006), "Properties of concrete pedestrian block mixed crumb rubber",

Constr. Build. Mater., **20**(7), 450-457.
Thomas, B.S. and Gupta, R.C. (2015a), “Long term behavior of cement concrete containing discarded tire rubber”, *J. Clean. Prod.*, **102**, 78-87.
Thomas, B.S. and Gupta, R.C. (2016a), “A comprehensive review on the applications of waste tire rubber in cement concrete”, *Renew. Sust. Energy Rev.*, **54**, 1323-1333.
Thomas, B.S. and Gupta, R.C. (2016b), “Properties of high strength concrete containing scrap tire rubber”, *J. Clean. Prod.*, **113**, 86-92.
Thomas, B.S. and Gupta, R.C. (2016c), “Recycling of waste tire rubber as aggregate in concrete:durability related performance”, *J. Clean. Prod.*, **112**, 504-51
Thomas, B.S., Gupta, R.C. and Panikar, V.J. (2015b), “Experimental and Modeling studies on high strength concrete containing waste tire rubber”, *Sustain. Cities Soc.*, **19**, 68-73, Elsevier.
Thomas, B.S., Gupta, R.C., Kalla, P. and Csetenyi, L. (2014), “Strength, abrasion and permeation characteristics of cement concrete containing discarded rubber fine aggregates”, *Constr. Build. Mater.*, **59**, 204-212.
Thomas, B.S., Gupta, R.C., Mehra, P. and Kumar, S. (2015c), “Performance of high strength rubberized concrete in aggressive environment”, *Constr. Build. Mater.*, **83**, 320-326.
Topcu, I.B. (1995), “The properties of rubberized concrete”, *Cement Concrete Res.*, **25** (2), 304-310.
Topcu, I.B. and Bilir, T. (2009), “Investigation of some fresh and hardened properties of rubberized self-compacting concrete”, *Mater. Des.*, **30**(8), 3056-3065
Topcu, I.B. and Demir, A. (2007), “Durability of rubberized mortar and concrete”, *J. Mater. Civil Eng.*, **19**(2), 173-178.
Toutanji, H.A. (1996), “The use of rubber tire particles in concrete to replace mineral aggregates”, *Cement Concrete Compos.*, **18**(2), 135-139.
Turatsinze, A., Bonnet, S. and Granju, J.L. (2007), “Potential of rubber aggregates to modify properties of cement based-mortars: improvement in cracking shrinkage resistance”, *Constr. Build. Mater.*, **21**, 176-181.
Turatsinze, A., Granju, J.L. and Bonnet, S. (2006), “Positive synergy between steel-fibres and rubber aggregates: Effects on the resistance of cement-based mortar to shrinkage cracking”, *Cement Concrete Res.*, **36**(9), 1692-1697.

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