Indian Journal of Science and Technology, Vol 8(29), DOI: 10.17485/ijst/2015/v8i29/86799, November 2015
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

An Experimental Study on Fresh and Hardened Properties of Self Compacting Rubberized Concrete

M. Mishra[1*] and K. C. Panda[2]

[1]Department of Civil Engineering, NIST, BPUT, Berhampur-761008, Odisha, India; mishramadhusmita1986@gmail.com
[2]Department of Civil Engineering, ITER, Siksha 'O' Anusandhan University, Bhubaneswar-751030, Odisha, India; kishoriit@gmail.com

Abstract

Now-a-days lot of waste material is generated owing to population growth and life style. With Enormous use of motor vehicles, the waste rubber tyre became a big environmental issue as it is not easily biodegradable. Hence, the research efforts are focussed to use this waste advantageously by understanding the performance and durability characteristics of rubberized concrete. The present study is carried out an experimental investigation on fresh and hardened properties of Self Compacting Concrete (SCC) containing waste tyre rubber. In Self Compacting Rubberized Concrete (SCRC), the replacement of aggregate is 0%, 5%, 10%, 15% and 20% with coarse rubber chips. The size of rubber chips are used in the present study is 5mm and 10mm. The total volume of rubber chips are replaced in coarse aggregate i.e. 40% from 5mm size and 60% from 10mm size. To obtain fresh properties in SCRC the slump, T_{500}, J-Ring, V-Funnel, L-Box and U-Box tests are conducted whereas for hardened properties the Compressive, Flexural and Split Tensile tests are conducted. The grade of concrete used in the present study is M30, whereas for SCC, the mix design is carried out in trial basis. The fine aggregate quantity increased 34% and coarse aggregate quantity decreased 34% with Water Cement ratio (W/C) 0.375 and 0.4% of Super plasticizer. In this study, an attempt has been made to identify the fresh and hardened properties necessary for the design of concrete mix. The study demonstrates the potential use of rubber chips in concrete.

Keywords: Rubber Chips, Self Compacting Rubberized Concrete (SCRC), Super Plasticizer (SP), Workability

1. Introduction

The behavior and performance of SCC is becoming more important as use of this type of concrete mix grows more common. The utilization of rubber in SCC can be seen as a positive step forward in supporting sustainable development as scrap road vehicle tyres form a major part of a World's Solid Waste Management problem and will continue in coming years. As compare with Conventional Concrete (CC), SCC contains larger quantities of fine aggregates. The brittleness and low tensile strength of cement-based materials are detrimental to their durability[1]. Researchers are trying to eliminate brittleness of concrete and they have been working on the possibility to make the concrete tough by introducing waste rubber phases among the traditional components (Cement, Water and Aggregates). It has been estimated that around one million tyres are withdrawn from use in the world every year[2]. Disposal of waste tyres has been a major issue to the cities all around the world. Consequently, the use of Rubber Aggregate (from scrap vehicle tyres) in concrete has become increasingly popular generating significant research interest over the past 20 years. Owing to the large increase in number of cars worldwide, the accumulation of huge volumes of scrap tyres has become a major Waste Management Problem[3].The vast majority of countries avoid Stockpiling or Landfill of Scrap Tyres, providing a significant incentive for exploring recycling strategies. One such strategy involves processing them into alternative aggregates thus generate increased economic value

* Author for correspondence

whilst reducing primary aggregate consumption[4]. Adding flexible rubber particles offers an attractive solution to counteract the Shrinkage Cracking and Strain Failure of SCC through incorporating waste rubber particles which lead to more deformability under Pre-Failure loads, as well as an increased Toughness, Impact Resistance and Ductility[5]. The objective of present experiment is to study the fresh and hardened properties of SCRC using rubber chips as replacing materials of coarse aggregates from 0-20% and by conducting six different fresh concrete tests and three different hardened concrete tests.

2. Experimental Program

2.1 Material used and Properties

In this study, Ordinary Portland Cement 43 grade (OPC), the physical properties satisfy as specification given in IS 8112:1989[6], zone I Fine Aggregate, Natural Coarse Aggregate (20 mm passing), Waste Tyre Rubber (5 mm and 10 mm), High End Super Plasticizer (SP) i.e.Cera Hyperplast XR-W40, new generation Polycarboxylate base water reducing admixture provided by Cera-Chem India Ltd, Chennai and Tap water were used. The rubber is replaced with coarse aggregate i.e.0-20% of its weight in SCRC. The properties of Fine Aggregate and Coarse Aggregate obtained experimentally as per IS: 383-1970[7] is presented in the Table 1. The rubber chips and SP sample is shown in Figure 1 a, b.

Table 1. Properties of Fine and Coarse Aggregates

Characteristics	Fine aggregate Value obtained experimentally as per IS: 383-1970	Coarse aggregate Value obtained experimentally as per IS :383-1970
Abrasion value (%)	-	27.02
Bulk density(kg/m^3)	1568	1418
Crushing value (%)	-	28.70
Fineness modulus	3.48 (Zone 1)	7.95
Impact value (%)	-	24.00
Specific gravity	2.63	2.84
Water absorption (%)	0.30	0.10

2.2 Mix Proportion and Identifications

The mix design of SCC is totally different than CC. In SCC, the Fine Aggregates quantity is more and Coarse Aggregates Quantity is less. The grade of concrete used in the present study is M30, whereas for SCC, the mix design is carried out in trial basis. The Water/Cement ratio (w/c) is used constant i.e.0.375. The first trial mix was prepared by increasing 30% of Fine Aggregate Quantity and by decreasing 30% of Coarse Aggregate Quantity with 0.30% of Super plasticizer. Then in second trial, Fine Aggregate Quantity increases 32% and Coarse Aggregate Quantity decreases 32% with 0.35% of Super plasticizer. In both the trial the concrete mix was not satisfy the EFNARC[8-9] Guidelines. Then in third trial, Fine Aggregate Quantity increases 34% and Coarse Aggregate Quantity decreases 34% with 0.40% of Super plasticizer. Finally, the third trial satisfied the EFNARC[8-9] guidelines. SP increases the flowing, filling and passing ability of concrete.

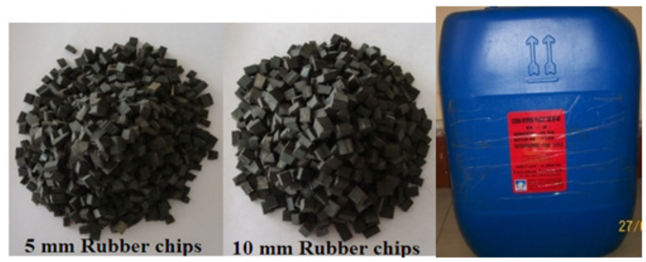

Figure 1. **(a)** 5 mm and 10 mm Rubber Chips Samples. **(b)** High End Superplasticiser (CERA HYPERPLAST XR-W40).

Five concrete mixes are prepared with variation of rubber from 0-20%. Two sizes of rubber chips are used for this experiment i.e.5 mm and 10 mm. 40% of rubber used from 5 mm size and 60% of rubber used from 10 mm size as the replacement of Coarse Aggregates. The detail mix proportion along with their identification is designated according to their replacement as given in Table 2. The details of mix quantities per cubic meter of concrete are presented in Table 3.

Table 2. Details of Concrete Mix (SC) Proportion Along with Identification

Concrete mix proportion	Mix identification
SC Concrete mix with 100% NCA + 0% Rubber chips + w/c 0.375 + SP 0.4%	SCRC0
SC Concrete mix with 95% NCA + 5% Rubber chips + w/c 0.375 + SP 0.4%	SCRC5
SC Concrete mix with 90% NCA +10% Rubber chips + w/c 0.375 + SP 0.4%	SCRC10
SC Concrete mix with 85% NCA + 15% Rubber chips + w/c 0.375 + SP 0.4%	SCRC15
SC Concrete mix with 80% NCA + 20% Rubber chips + w/c 0.375 + SP 0.4%	SCRC20

Table 3. Details of Mix (SC) Quantity Per m^3 of Concrete

Mix Identification	Mix quantity of different constituents m^3 of concrete						
	Cement (kg)	Sand (kg)	NCA (kg)	Rubber chips (kg) 5 mm (40%)	Rubber chips (kg) 10 mm (60%)	Super plasticiser (kg)	Water (kg)
SCRC0	511.00	706.18	798.12	-	-	2.044	191.6
SCRC5	511.00	706.18	758.21	15.96	23.95	2.044	191.6
SCRC10	511.00	706.18	718.31	28.25	42.37	2.044	191.6
SCRC15	511.00	706.18	678.40	47.89	71.83	2.044	191.6
SCRC20	511.00	706.18	638.50	63.85	95.77	2.044	191.6

2.3 Fresh Concrete Test

Fresh Concrete Test is conducted for SCC to know the details about Flow, Filling and Passing ability of concrete. Six tests are conducted for fresh concrete i.e. Slump Flow, T_{500}, J-Ring, V-Funnel, L-Box and U-Box. Out of these tests slump test is conducted to know about the filling and flow ability of concrete, T_{500} and V-Funnel Test are conducted to know the flow ability of concrete and J-Ring, L-Box and U-Box tests are conducted to know the passing ability of concrete.

2.3.1 Slump Flow Test / T_{500} test

The Slump Flow and T_{500} is used to assess the Horizontal Free Flow of SCC in the absence of obstructions. This is a quick test Procedure. The base plate and level ground is essential for this test. It is the most commonly used test and gives a good knowledge of filling ability. The Base Plate and Slump Cone are placed in a level surface as shown in Figure 2a. Then the Base Plate and Inside Slump Cone are moisten properly. Then the concrete mix is pouring in Slump Cone by Scoop. After filling the slump cone make the top surface level by trowel. Do not tamp. Then lift the Slump Cone straight in a stroke, allow the concrete to flow freely. The concrete will flow by its own weight. After completion of flow the diameter of concrete will measure from different perpendicular sides then take the average of measured diameter. The unit of Slump-Flow result is mm. In T_{500} test, the time of flow of concrete is measured from lifting the slump cone to reach the concrete of 500 mm diameter. The result is in second.

2.3.2 J-Ring Test

The J-Ring test is used to determine the passing ability of the concrete. Moisten the base plate and inside of Slump Cone, place the base-plate on level ground. Place the J-Ring centrally on the base plate. The Slump Cone placed centrally inside the Slump Cone and hold down firmly. Fill the cone with the Scoop. Do not tamp, simply level the top of the cone with the trowel as shown in Figure 2b. Remove any surplus concrete from around the base of the cone. Raise the cone vertically and allow the concrete to flow out freely. Measure the final diameter of the concrete in three perpendicular directions. Calculate the average of the three measured diameters (in mm). Measure the difference in height between the concrete just inside the bars and that just outside the bars. Calculate the average of the difference in height at four locations (in mm).

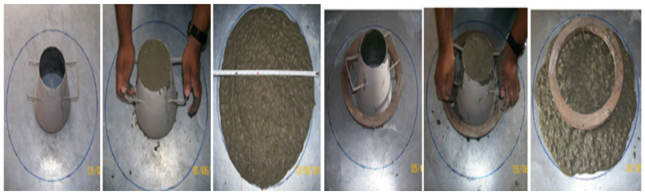

Figure 1. **(a)** Details of Slump Flow and T_{500} test. **(b)** Details of J-Ring Test.

2.3.3 V-Funnel

The V-Funnel Test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20 mm. After preparation of mix the funnel is filled with concrete and the time set when the trap door is removed. Set the V-funnel on firm leveled ground. Fill the Funnel completely with concrete without compacting or tamping, simply level the top with the trowel as shown in Figure 3a. Open the trap door within 10 sec after filling the concrete and allow the concrete to flow out under gravity. Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (the flow time). This is taken to be when light is seen from above through the funnel. The whole test has to be performed within 5 minutes.

2.3.4 U-Box Test

The U-Box Test is used to measure the filling ability of SCC. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown in Figure 3b. An opening with a sliding gate is fitted between the two sections. Set the apparatus on firm levelled ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove water from apparatus. Fill the one compartment of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the other compartment. After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled in two places and calculate the mean (H_1). Measure also the height in the other compartment (H_2). Calculate H_1 - H_2, the filling height. The whole test has to be performed within 5 minutes.

2.3.5 L-Box Test

The L-Box Test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. The apparatus consists of a rectangular section box in the shape of an 'L' with a vertical and horizontal Section, separated by a movable gate, in front of which vertical lengths of three reinforcement bars are fitted. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water. Fill the vertical section of the apparatus with the concrete sample as shown in Figure 4.Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously, Start the Stopwatch and Record the times taken for the concrete to reach the 200 and 400 mm marks. When the concrete stops flowing, the distances "H_1" and "H_2" are measured. Calculate H_2 / H_1 ,the Blocking Ratio. The whole test has to be performed within 5 minutes.

Figure 3. **(a)** Details of V-Funnel Test **(b)** Details of U-Box Test.

Figure 4. Details of L-Box Test.

2.4 Hardened Concrete Test

The strength properties of hardened concrete specimens such as cubes for compressive strength ,prism for Flexural Strength and Cylinder for split tensile strength were tested at 7, 28 and 90 days of curing under water. The concrete Cubes of size 150 x 150 x 150 mm, Prism of size100 x 100 x 500 mm and Cylinder of size 100 mm Diameter x 200 mm height are used in the present study. The setup for Compressive, Flexural and Split Tensile strength is shown in Figure 5. The Compressive Strength,Flexural Strength and Split Tensile Strength were computed using the expressions such as for Cube f_{ck} = P/B^2, for Prism f_b = PL/bd^2 and for Cylinder, f_{sp} = 2P/ πLD respectively. Where, f_{ck} is compressive strength in MPa, P is Maximum applied load in Newton, B is size of the Cube Specimen in mm, f_b is Flexural Strength in MPa, b is width of the Specimen in mm, d is Depth of the Specimen in mm, f_{sp} is the Split Tensile Strength in MPa, L is Length of the Cylinder Specimen in mm and D is Diameter of the Cylinder in mm.

Figure 5. Test Setup for Compression, Split Tensile and Flexural Strength of Concrete Specimen.

3. Test Results

3.1 Fresh Concrete Results

Table 4 presented the Fresh Concrete Test result of Slump Flow, T_{500} and J-Ring Test. It is observed from Table 4 that, the Slump Flow result for SCRC0 and SCRC5 are comes in between 550 and 650. According to EFNARC 2005 guidelines the SCRC0 and SCRC5 results belong to Slump Flow Class SF1. The Slump Flow result of other three mix, SCRC10, SCRC15 and SCRC20 are comes in between 660 and 750 due to increase of rubber quantity. According to EFNARC (2005) guidelines SCRC10, SCRC15 and SCRC20 belongs to Slump Flow Class SF2. In EFNARC (2005) guidelines, T_{500} test result is classify into two classes i.e.VS1 and VS2. For VS1 class the result is ≤ 2 and for VS2 class the result is > 2. From Table 4, the T_{500} test result for all mixes > 2 so it comes under VS2 class. According to EFNARC 2002 guidelines the J-Ring Test results are lies in between 0 and 10 mm. From Table 4, all mixes SCRC5, SCRC10, SCRC15 and SCRC20 results satisfy the EFNARC 2002 guidelines criteria, but for mix SCRC0 the result comes more than the EFNARC 2002 guidelines criteria.

Table 5 presented the Fresh Concrete Test result of U-Box, V-Funnel and L-Box. It is observed from Table 5 that, the U-Box result for all mixes of SCRC comes less than 80 and it satisfy the EFNARC 2005 guidelines criteria. From observation the test result is more for SCRC0 and then it reduces gradually when the rubber amount increases. It indicates that the lesser values having better passing ability. For V-Funnel Test all the mix results satisfy the EFNARC 2005 guidelines criteria and results come in between 7 and 27 seconds. As percentage of rubber amount increases in SCC, the time period decreases for complete the test. The Flow ability is less in SCRC0. For L-Box Test, all the mix results satisfy the EFNARC 2005 guidelines criteria and results come>0.75. The greater value indicates the SCC having better passing ability than the lower value.

3.2 Compressive Strength Test Results

The hardened concrete test results such as Compressive Strength, Flexural Strength and Split Tensile Strength of SCRC is presented in Table 6. The compressive Strength of SCRC versus age is presented in Figure 6 and the Compressive Strength Results for different curing periods is presented in Figure 7. It is observed that the Compressive Strength of SCRC increases as curing period increases. Also observed that, in SCRC the Compressive Strength decreases as the percentage of rubber replacement increases. The percentage change in compressive strength of SCRC5 at 7,28 and 90 days are 12.46, 10.55 and 12.41 respectively as compared to SCRC0, whereas the percentage change in strength of SCRC20 at 7,28 and 90 days are 52.39, 47.32 and 47.72 respectively. The reduction of Compressive Strength in SCRC20 is almost 50% as compared with control specimen. It is also observed that the early age strength of concrete is higher than later age

Table 4. Fresh Concrete Properties of Self Compacting Rubberized Concrete

Mix Identity	Slump Flow (mm)		T_{500} Test (Seconds)		J-ring Test		
	Test Result	EFNARC (2005) Criteria	Test Result	EFNARC (2005) Criteria	Step height result (mm)	Total flow result (seconds)	EFNARC (2002) Criteria
SCRC0	570	550-650	8	>2	12	15	0 – 10
SCRC5	650	550-650	7	>2	10	13	0 – 10
SCRC10	690	660-750	6	>2	08	11	0 – 10
SCRC15	710	660-750	5	>2	06	10	0 – 10
SCRC20	730	660-750	5	>2	05	9	0 – 10

Table 5. Fresh Concrete Properties of Self Compacting Rubberized Concrete

Mix Identity	U-Box (mm)		V- Funnel (Seconds)		L-Box (Passing Ability)			
	Test Result	EFNARC (2005) Criteria	Test Result	EFNARC (2005) Criteria	Test Result H_2/H_1	T_{20} Sec.	T_{40} Sec	EFNARC (2005) Criteria
SCRC0	78	≤ 80	15	7 - 27	0.76	9	14	≥ 0.75
SCRC5	70	≤ 80	13	7 - 27	0.78	7	10	≥ 0.75
SCRC10	60	≤ 80	12	7 - 27	0.80	5	8	≥ 0.75
SCRC15	55	≤ 80	10	7 - 27	0.82	4	6	≥ 0.75
SCRC20	50	≤ 80	9	7 - 27	0.90	3	5	≥ 0.75

Table 6. Summary of Compressive, Flexural, Split Tensile Strength Test Results for SCRC

Mix Identity	7 Days			28 Days			90 Days		
	Compressive Strength (MPa)	Flexural Strength (MPa)	Split Tensile Strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Split Tensile Strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Split Tensile Strength (MPa)
SCRC0	54.09	5.50	3.88	65.40	6.80	4.65	73.35	7.44	5.35
SCRC5	47.35	5.30	3.70	58.50	6.55	4.43	64.25	7.22	5.21
SCRC10	38.15	4.80	3.34	45.38	6.22	4.15	50.35	6.85	4.95
SCRC15	33.45	4.55	3.05	39.85	5.85	3.78	43.25	6.60	4.52
SCRC20	25.75	4.30	2.85	34.45	5.35	3.55	38.35	6.12	4.24

strength. The high end Super plasticizer plays a key role for enhancement of early age strength of concrete.

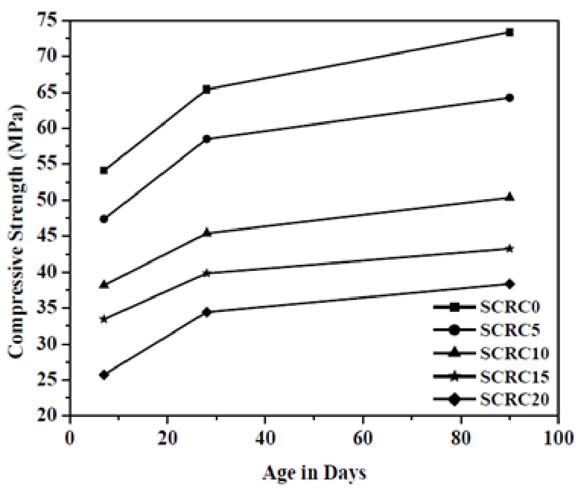

Figure 6. Compressive Strength Versus Age.

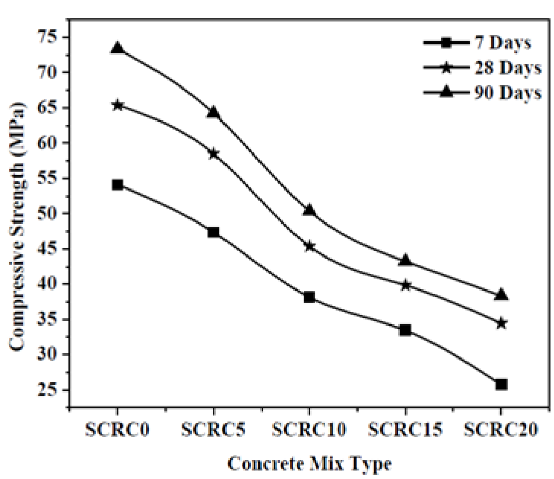

Figure 7. Compressive Strength Results for Different Curing Periods.

3.3 Flexural Strength Test Results

The Flexural Strength of SCRC versus age is presented in Figure 8 and Flexural Strength for different curing periods is presented in Figure 9. It is observed that, the Flexural Strength of SCRC increases as curing period increases. It is also observed that, the Flexural Strength decreases as the percentage of rubber replacement increases. The strength is more in SCRC0 as compared with all other mixes. In SCRC5, the difference of strength from control specimen is less as compared to other specimens i.e. in 7 days 3.63%, 28 days 3.68% and 90 days 2.96% whereas in SCRC20, the percentage change in strength at 7, 28 and 90 days are 21.82%, 21.32% and 17.74 % respectively. The percentage change in strength is depending on the rubber chips replacement amount.

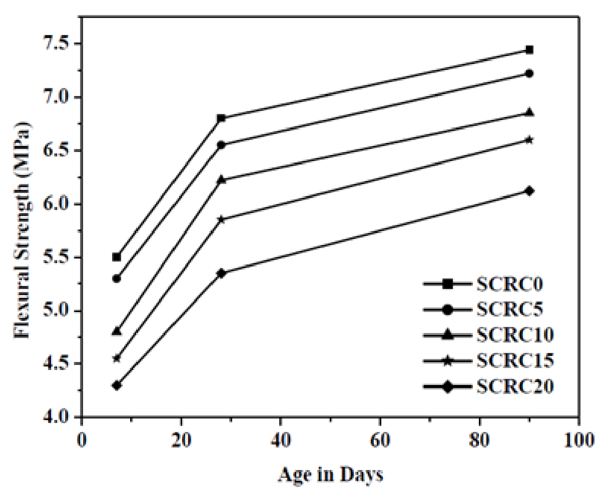

Figure 8. Flexural Strength Versus Age

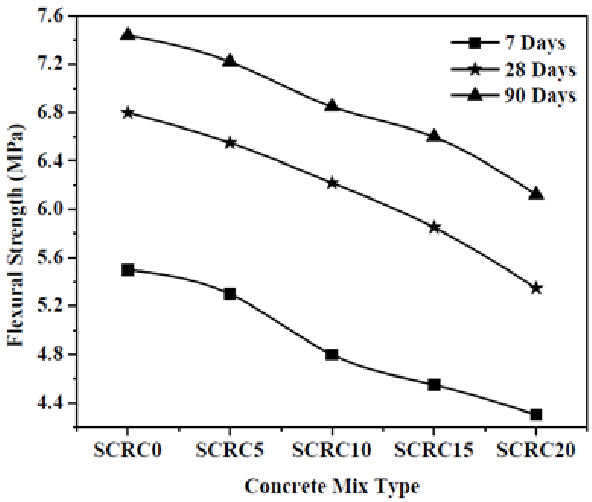

Figure 9. Flexural Strength Results for Different Curing Periods.

3.4 Split Tensile Strength Test Results

The Split Tensile Strength of SCRC versus age is presented in Figure 10 and the Split Tensile Strength Results for different curing periods is presented in Figure 11. It is observed that the strength of SCRC0 is more as compared with all other concrete mixes. When rubber is added in SCC the strength is reduced at all age. The concrete mix SCRC10, SCRC15 and SCRC20 gives less value than SCRC5. In SCRC5 the percentage change in strength at 7,28 and 90 days are 4.64, 4.73 and 2.62 respectively, whereas in SCRC20 the percentage change in strength at 7,28 and 90 days are 26.55, 23.66 and 20.75 respectively. In SCRC5, the difference of Split Tensile Strength is less due to less rubber amount, whereas in other mixes the difference of strength is more due to increasing rubber amount as compared with control specimen.

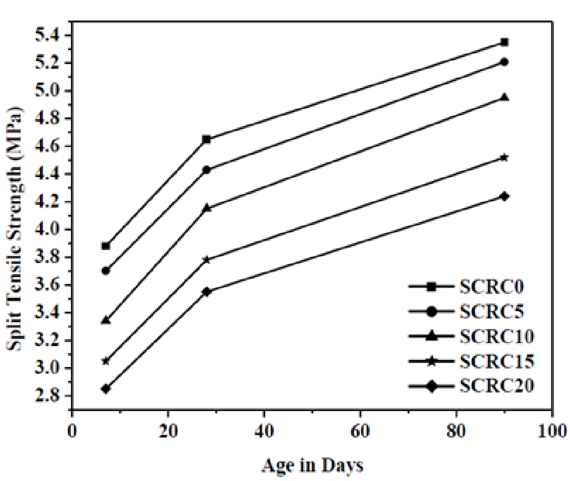

Figure 10. Split Tensile Strength Versus Age

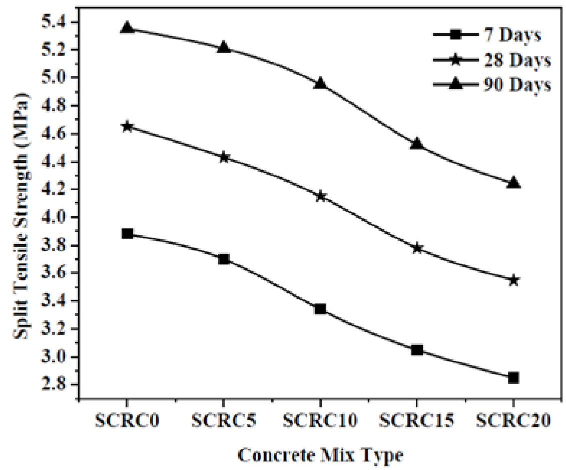

Figure 11. Split Tensile Strength Results for Different Curing Periods.

4. Concluding Remarks

- As rubber chips amount increases in SCRC the Flow, Filling and Passing ability are more in less time period.
- In Slump Flow Test, the result for replacement of rubber chips from 0-5% satisfy the 1st class criteria and 10- 20% replacement satisfy the 2nd class criteria and in T_{500} test results for 0-20% replacement comes in 2nd class criteria according EFNARC 2005 guidelines.
- In J-Ring Test, the 0% replacement of rubber chips dose not satisfy the criteria of EFNARC 2002 guidelines, whereas other replacement i.e.5-20% results satisfy the guidelines.
- In V-Funnel Test, all the replacement results satisfy the 2nd class criteria of EFNARC 2005 guidelines.
- In L-Box Test, all replacement of rubber chips results satisfies the criteria of EFNARC 2005 guidelines. As rubber percentage increases the blocking ratio increases, this indicates good passing ability.
- In U-Box Test, all replacement of rubber chips results satisfies the criteria of EFNARC 2005 guidelines. As rubber percentage increases the height difference decreases, this indicates good passing ability.
- As age of Curing Increases, Compressive, Flexural and Split Tensile Strength of SCC with or without rubber chips increases.
- The addition of Super plasticizer in SCC gives more strength in early age.
- The strength is more in 5% replacement of rubber in SCRC than 10,15 and 20% replacement at all age because rubber having poor bonding with concrete as amount increases the strength reduces.

- Use of tyre rubber chips as a replacement of coarse aggregate in the SCC is appropriate for the places where strength is not needed but durability is important. It is commonly used for its High Flow Ability and Passing Ability.
- Rubberized Concrete Control Vibration and Improve Structural Reliability from Natural Hazards, Accidental Load, Hydrostatic and Wind Loading, Explosive Blasts, Fragmentations in buildings, Crash Barriers on roads and Highways, Sound Barriers and in agricultural purposes as Fences and Poles.

5. Acknowledgements

The author would like to thanks to ITER, Siksha 'O' Anusandhan University, Bhubaneswar and Odessa for the support of conducting the experimental works.

6. References

1. Turantsinze A, Granju JL, Bonnet S. Positive Synergy between Steel-Fibres and Rubber Aggregates: Effect on the Resistance of Cement-Based Mortars to Shrinkage Cracking. Cem.Concr.Res. 2006; 36:1692–7.
2. Colom X, CarrilloF, Canavata J. Composites Reinforced with Reused Tyres: Surface Oxidant Treatment to Improve the Interfacial Compatibility. Compos part A: Appl. Sci. Manuf. 2007; 38:44–50.
3. Ganjian E, Khorami M Maghsoudi AA. Scrap-Tyre-Rubber Replacement for Aggregate and Filler in Concrete .Constr. Build. Mater. 2009; 23:1828–36.
4. Najim KB. Modulus of Elasticity and Impact Resistance of Chopped Worn-Out Tyres Concrete. Iraqi J. Civil Eng. 2005; 1:83–96.
5. Rahman MM, Usmanand M, Al-Ghalib AA. Fundamental Properties of Rubber Modified Self-Compacting Concrete (RMSCC). Constr. Build. Mater. 2012; 36: 630–7.
6. IS:8112-1989;Indian Standard, 43 Grade Ordinary Portland Cement Specification (First Revision). Bureau of Indian Standards. ManakBavan 9 Bahadur Shah Zafar Marg; New Delhi; India.
7. IS: 383-1970;Indian Standard Specification for Coarse and Fine Aggregates from Natural Sources for Concrete (Second Revision).Bureau of Indian Standards; New Delhi.
8. EFNARC 2002; Specification and Guidelines for Self-Compacting Concrete. EFNARC, Association House, 99 West Street; Farnham; Surrey GU9 7EN:UK.
9. EFNARC 2005; The European Guidelines for Self-Compacting Concrete Specification, Production and Use.