An Experimental Study on Self-Compacting Concrete Using Tyre Rubber and Recycled Aggregate

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Abstract. The present study carried out for an experimental investigation on both fresh and hardened properties of self-compacting concrete (SCC) containing waste tyre rubber and recycled aggregate (RA). The tyre rubber replaced 5% and 10% with coarse aggregate by its weight. The recycled aggregate replaced 5% and 10% with coarse aggregate by its weight. Totally 7 mix were prepared including the combination of 5% tyre rubber with 5% recycled aggregate and 10% tyre rubber with 10% recycled aggregate. The 5 mm and 10 mm size of rubber chips are used. The M30 grade concrete mix design was adopted for the present work. For SCC preparation, the coarse aggregate amount decreased by 35% and fine aggregate amount increased 35% with water cement ratio (w/c) 0.43 and super plasticizer (SP) 0.4%. To obtain fresh properties slump flow test, T500 test, J-ring test, V-funnel test, L-box test and U-box test is conducted. For hardened concrete properties the compressive strength, flexural strength and split tensile strength tests are conducted. An attempt has been taken to identify the combine potential effect of tyre rubber and recycled aggregate in concrete and necessity of fresh and hardened properties for the SCC mix.

1. Introduction
Due to modernization and maintaining of day-to-day life, people are modified their life style. According this the old motor vehicles and buildings were replaced with new vehicles and building respectively. This modernization causes the growth of waste material in worldwide. In this research two waste materials were adopted i.e. waste tyre rubber from motor vehicles and recycled aggregate (RA) from demolished building. There was no other way to discard the tyre rubber and building waste completely. To avoid the increment of the waste amount the researcher started reused it in construction field. Both the waste was used as the replacement of the coarse aggregate. This helps to save the natural resources. The conclusion drawn from previous research studies that when tyre rubber replaced with coarse aggregate it having less mechanical strength, increase ductile nature in concrete and absorb vibration. Similarly, the concrete made from recycled aggregate (RA) gives less in strength, more in drying shrinkage, creep and less resistance for chloride ion penetration as compare to normal concrete using natural coarse aggregate.

According to Kheder and Al-Windawi [1] due to the w/c ratio of the SCC mix the compressive strength of recycled aggregate concrete varies. Levy and Helene [2] stated that the workability and
compressive strength have same value for both the concrete made with recycle coarse aggregate (RCA) with 20 %, 50 % and 100 % replacement and natural coarse aggregate (NCA) concrete in the range of 20 - 40 MPa at 28 days. When RCA replaced 20 % with NCA then the strength result was equal and sometimes better than the control mix made with 100 % NCA. According to Mishra and Panda [3] the strength reduces in CRC as compare to the SCRC. As the rubber chips amount increases in SCRC the performance of concrete for workability test was better in less time period. The strength of SCC enhances after addition of super plasticiciser in early age. The 5 % replacement of rubber chips in SCC has more strength than other replacement. When strength comparison occurs in between 5 % replacement and control mix the variation of strength was very less in both CRC and SCRC. According to Mishra and Panda [4] they used 0 %, 5 %, 10 %, 15 % and 20 % of rubber chips as the replacement of coarse aggregate in SCRC (self-compacting rubberized concrete). 40 % and 60 % of rubber volume used from 5 mm and 10 mm size respectively for the concrete mix. The M30 grade concrete mix design was adopted for the work. After analyzing the test results of fresh and hardened concrete the quality of strength was depending on the quantity of rubber chips. As the quantity of rubber chips increases the strength decreases. Up to 15 % of rubber chips replacement was adoptable for construction work beyond that the strength decreases. Mishra and Panda [5] stated that, recycled coarse aggregate (RCA) has been partially replaced by 0 %, 10 % and 20 % with NCA (natural coarse aggregate). Similarly the silpozz also partially replaced by 10 % with cement of its weight. The M30 grade concrete was designed with w/c ratio 0.43 and super plasticizer (SP) of 0.35 and 0.5 %. The results obtained from this experimental work that due to use of RCA the strength decreased but after adding silpozz the strength increased. RCA can be used as a partially replacement of NCA hence proved. Najim and Hall [6] studied the mechanical and dynamic properties of self-compacting crumb rubber modified concrete (SCCRMC). The advantages of using SCCRMC in vibrator plant are productivity rate increased, manpower decreased and destruction of noise and fuel consumption. As compare with plain concrete, the SCCRMC has fully self-compacted ability under its own weight. It also has high flowing and filling ability. It reduces the blocking in congested reinforced areas, resist in high segregation, maximum durability, less permeability and more compressive strength. Current research work focuses on the increment of compatibility when crumb rubber particles used as the replacement of fine aggregate in self-compacting concrete due to its high compacted and dense microstructure, which results in high mechanical strength and brittle failure modes. According to Padhi and Panda [7] in this experimental work fine rubber (FR) particles from scrap rubber tires has partially replaced with the fine aggregate (FA) and Silpozz has been used 5 %, 10 % and 15 % as the partial replacement of cement in addition of super plasticiser (SP) which help to increase the strength of concrete at early age. The fresh concrete test results indicate that the workability for both CRC (conventional rubberized concrete) and SCRC decreases as FR quantity increases. It has been observed that upto 5 % FR replacement with natural fine aggregate (NFA) leads the decrease of compressive strength (CS) with the increase of flexural strength (FS). In SCRC the strength enhances due to the replacement of silpozz in cement. Panda et al. [8] investigated on the influence of the rubber content on fresh and hardened properties of rubberized concrete with 0 % (i.e. without rubber) 3 %, 6 %, 9 % and 12 % rubber content with the partial replacement of coarse aggregate in the M20 grade concrete. As the replacement percentage of rubber increased the compressive strength decreased but in 3 % rubber replacement the concrete gives slightly high compressive strength than without rubber replacement concrete. According to Panda and Bal [9] the RCA was replaced partially i.e. 10 %, 20 %, 30 % and 40 % with NCA in the M25 grade concrete. As the RCA replacement ratio increases the strength of SCC decreases. In SCC mix up to 30 % RCA replacement achieves the acceptable compressive strength. Rehman et al. [10] performed experiment on the fundamental properties of rubber modified self-compacting concrete (RMSCC) rubber particles obtained from the waste tyre was partially replaced with fine aggregate. The test was conducted to obtain the fresh and hardened properties of the RMSSCC. Normally concrete incorporate with rubber particles because of its poor bonding. If the quantity of rubber kept within 20 - 30 % replacement of fine aggregate then it may be the preferred material over the applications. The mixture may provide an advantage of
absorbing vibration without compromising its strength. According to Sami and Akmal [11] the RCA has higher toughness and soundness percentage. As compare with NCA the value was less but it remained within the permissible limits. The objective of this experiment is to study the strength of self-compacting concrete after replacement of rubber chips and recycled aggregate.

2. Material Used
For this experimental work OPC 43 grade cement, zone III fine aggregate, natural coarse aggregate (NCA) (20 mm downgraded), waste Tyre rubber chips (5 mm and 10 mm size), RA (20 mm downgraded), water reducing high end super plasticizer (SP) and normal water. The tyre rubber chips replaced 5 % and 10 % with NCA by its weight. The recycled aggregate also replaced 5 % and 10 % with NCA by its weight in SCC mix with water cement ratio (w/c) 0.43. The details properties of fine, natural and recycled coarse aggregate tests were conducted in laboratory and presented in Table 1. The used sample details for this study were represented in Figure 1.

| Characteristics of test | As per the value obtained from IS 383-1970 |
|-------------------------|------------------------------------------|
|                         | FA  | NCA | RCA |
| Fineness modulus        | 3.03 (Zone-III) | 7.00 | 6.87 |
| Specific Gravity        | 2.67 | 2.86 | 2.55 |
| Water Absorption        | 0.40 | 0.20 | 0.10 |
| Bulk Density (kg/m$^3$) | 1568 | --- | --- |
| Abrasion Value (%)      | --- | 34.78 | 55.42 |
| Impact Value (%)        | --- | 24.00 | 29.46 |
| Crushing Value (%)      | --- | 23.30 | 32.90 |

Figure 1. Tyre rubber chips (5mm and 10mm size), Recycled coarse aggregate (RCA 20 mm downgraded) and water reducing high-end super plasticizer (SP)

| Mix Identity | NCA(%) | Tyre Rubber (%) | RA(%) |
|--------------|--------|-----------------|-------|
| SCT0R0       | 100    | 0               | 0     |
| SCT5R0       | 95     | 5               | 0     |
| SCT10R0      | 90     | 10              | 0     |
| SCTOR5       | 95     | 0               | 5     |
| SCTOR10      | 90     | 0               | 10    |
| SCT5R5       | 90     | 5               | 5     |
| SCT10R10     | 80     | 10              | 10    |

3. Mix Proportions
For this experimental work, the SCC mix has prepared by increasing 35 % of fine aggregate quantity and by decreasing 35 % of coarse aggregate quantity. The M30 grade SCC mix was design as per
EFNARC guidelines 2002 and 2005. The SCC mix was prepared in three batches, in first batch the replacement of RA was zero and the replacement of tyre rubber was 0%, 5% and 10% with NCA. In second batch mix, the tyre rubber was zero and the replacement of RA was 0%, 5% and 10% with NCA. In third batch mix, the combination of tyre rubber and RA equally replaced 5% and 10% with NCA. The details of mix proportion along with identifications for SCC mix are given in Table 2. The details of mixing quantity for SCC mix in Kg/m³ were presented in Table 3.

### Table 3. The details of mixing quantity for SCC mix in Kg/m³

| Mix Identity | Cement (kg) | FA (kg) | NCA (kg) | Tyre Rubber (kg) | RCA (kg) | SP (kg) | Water (kg) |
|--------------|-------------|--------|----------|------------------|----------|--------|-----------|
| SCT0R0       | 395         | 1043.55| 787.15   | -                | -        | 1.58   | 158       |
| SCT5R0       | 395         | 1043.55| 747.75   | 23.64            | 15.76    | 1.58   | 158       |
| SCT10R0      | 395         | 1043.55| 708.45   | 47.22            | 31.48    | 1.58   | 158       |
| SCT0R5       | 395         | 1043.55| 747.75   | -                | -        | 39.4   | 1.58      |
| SCT0R10      | 395         | 1043.55| 708.45   | -                | 78.7     | 1.58   | 158       |
| SCT5R5       | 395         | 1043.55| 708.35   | 23.64            | 39.4     | 1.58   | 158       |
| SCT10R10     | 395         | 1043.55| 629.75   | 47.22            | 31.48    | 78.7   | 1.58      |

### 4. Mixing and Casting

The mentioned quantity of cement, fine aggregate, natural and recycled coarse aggregate was placed in concrete mixture for one minute dry mix in batch wise and then add the calculated amount of water and super plasticizer to form the SCC mix paste. Then the workability test was conducted to find the properties of fresh concrete. For SCC mix six test were conducted in laboratory i.e. slump flow test, T500 test, J-ring test, V-funnel test, L-box test and U-box test. To find the mechanical properties of SCC mix the compressive strength, flexural strength and split tensile strength test were conducted after 7 and 28 days of curing on the cube, prism and cylinder specimens respectively. The details of lab set up for workability test were shown in Figure 2 and Figure 3. The details of lab set up for the compressive strength, split tensile strength and flexural strength test was shown in Figure 4.

**Figure 2.** Lab set up for slump cone, T500 and J – ring test

**Figure 3.** Lab set up for V-funnel, L-box and U-box test
Figure 4. Lab set up for compressive strength, split tensile strength and flexural strength test

5. Result and Discussion
To know about the flowing, passing and filling ability of SCC mix the workability test was performed in laboratory. The test conducted in fresh concrete after preparation of each batch mix. To check the flowing ability performance of SCC mix the slump cone test and T₅₀₀ test were performed. Similarly, to check the passing ability performance of SCC mix the J- ring test and V- funnel test were performed. Again to check the filling ability performance of SCC mix the L- box test and U- box test were performed. After performing the entire tests for workability in fresh SCC mix then the test continues for hardened concrete. To analyses the hardened properties of SCC mix the cube, prism and cylinder specimen were cast and curing for 7 and 28 days in order to determine the compressive strength, flexural strength and split tensile strength respectively [12-15].

Table 4. The test results for the flowing ability of SCC mix with EFNARC guidelines (2005) criteria

| Mix Identity | Slump Flow (mm) | T₅₀₀ Test (Seconds) |
|--------------|-----------------|---------------------|
|              | TestResult      | EFNARC(2005)Criteria | TestResult | EFNARC(2005)Criteria |
| SCT0R0       | 565             | 550-650              | 15         | >2                   |
| SCT5R0       | 625             | 550-650              | 12         | >2                   |
| SCT10R0      | 690             | 660-750              | 9          | >2                   |
| SCT0R5       | 560             | 550-650              | 18         | >2                   |
| SCT0R10      | 555             | 550-650              | 21         | >2                   |
| SCT5R5       | 595             | 550-650              | 14         | >2                   |
| SCT10R10     | 660             | 660-750              | 16         | >2                   |

Table 5. The test results for the passing ability of SCC mix with EFNARC guidelines (2002) and EFNARC guidelines (2005) Criteria

| Mix Identity | V- funnel (Seconds) | J - ring Test |
|--------------|---------------------|---------------|
|              | TestResult | EFNARC(2005) Criteria | Step height result(mm) | Total flow result(sec) | EFNARC(2002) Criteria |
| SCT0R0       | 19        | 7 - 27              | 13          | 15                    | 0 – 10             |
| SCT5R0       | 14        | 7 - 27              | 9           | 11                    | 0 – 10             |
| SCT10R0      | 12        | 7 - 27              | 8           | 9                     | 0 – 10             |
| SCT0R5       | 18        | 7 - 27              | 11          | 16                    | 0 – 10             |
| SCT0R10      | 21        | 7 - 27              | 12          | 18                    | 0 – 10             |
| SCT5R5       | 16        | 7 - 27              | 10          | 13                    | 0 – 10             |
| SCT10R10     | 17        | 7 - 27              | 9           | 14                    | 0 – 10             |
The test results for the flowing ability of SCC mix with EFNARC guidelines (2005) criteria was presented in Table 4. Similarly, the test results for the passing ability of SCC mix with EFNARC guidelines (2002) and EFNARC guidelines (2005) criteria was presented in Table 5. Also the test results for the filling ability of SCC mix with EFNARC guidelines (2005) criteria was presented in Table 6.

To determine the mechanical properties of SCC mix the compressive strength test, flexural strength test and split tensile strength test were conducted for concrete specimen after 7 and 28 days of curing. Cube concrete specimen was adopted for compressive strength test. Prism specimen was adopted for flexural strength test. Similarly, cylinder specimen was adopted for split tensile strength test. The comparison of compressive strength with days for SCC mix was represented in Figure 5. The comparison of flexural strength with days for SCC mix was represented in Figure 6. The comparison of split tensile strength with days for SCC mix was represented in Figure 7.

### Table 4. The test results for the filling ability of SCC mix with EFNARC guidelines (2005) Criteria

| Mix Identity | U - Box (mm) | L - Box | EFNARC(2005) Criteria |
|--------------|--------------|---------|-----------------------|
| TestResult   | H2/H1        | T20     | T40       | Criteria     |
| SCT0R0       | 77           | ≤ 80    | 0.76      | 10 15        | ≥ 0.75      |
| SCT5R0       | 65           | ≤ 80    | 0.84      | 6 10         | ≥ 0.75      |
| SCT10R0      | 60           | ≤ 80    | 0.86      | 4 8          | ≥ 0.75      |
| SCT0R5       | 73           | ≤ 80    | 0.77      | 8 12         | ≥ 0.75      |
| SCT0R10      | 75           | ≤ 80    | 0.78      | 9 13         | ≥ 0.75      |
| SCT5R5       | 70           | ≤ 80    | 0.80      | 7 11         | ≥ 0.75      |
| SCT10R10     | 67           | ≤ 80    | 0.82      | 5 9          | ≥ 0.75      |

Figure 5. The comparison of compressive strength with days for SCC mix

The observation was made from Figure 5 that the control mix (SCT0R0) gives highest compressive strength at all age. When the tyre rubber replaced the NCA the strength started decrease as compare to
the control mix. As the replacement quantity increase the strength started decrease due to its poor bonding. At 5% replacement of tyre rubber (SCT5R0), the compressive strength was high from 10% tyre rubber replacement (SCT10R0). When the RA was replaced the NCA that to 5% and 10%, the 5% replacement (SCT0R5) gives more compressive strength than 10% replacement of RA (SCT0R10). As compare with control mix (SCT0R0) the compressive strength of 5% replacement of RA (SCT0R5) was minimum. When the combine effect of tyre rubber and RA was considered, whatever strength was decreased due to addition of rubber chips the concrete gradually regain the strength after addition of RA. The 5% replacement combination of tyre rubber and RA (SCT5R5) gives more strength than the 5% and 10% replacement of tyre rubber with NCA. When the replacement amount of tyre rubber chips and recycled aggregate amount increases in SCC mix the bonding become weak and the failure in specimen occurs at the inter face of the rubber chips and recycled aggregate. Up to 15% of rubber chips replacement in coarse aggregate was acceptable after that the strength started decreases to a non-acceptable limit.

![Figure 6](image)

**Figure 6.** The comparison of flexural strength with days for SCC mix.

The observation was made from Figure 6 that the control mix (SCT0R0) gives highest flexural strength at all age. When the tyre rubber replaced the NCA the strength started decrease as compare to the control mix. As the replacement quantity increase the strength started decrease. At 5% replacement of tyre rubber (SCT5R0) the flexural strength was high from 10% tyre rubber replacement (SCT10R0). When the RA was replaced the NCA that to 5% and 10%, the 5% replacement (SCT0R5) gives more flexural strength than 10% replacement of RA (SCT0R10). As compare with control mix (SCT0R0) the flexural strength of 5% replacement of RA (SCT0R5) was minimum. When the combine effect of tyre rubber and RA was considered, whatever strength was decreased due to addition of rubber chips the concrete gradually regain the strength after addition of RA. The 5% replacement combination of tyre rubber and RA (SCT5R5) gives more strength than the 5% and 10% replacement of tyre rubber with NCA. The 10% combination of tyre rubber and RA (SCT10R10) having less strength as compare to all the mix. When the replacement amount of tyre rubber chips and recycled aggregate amount increases in SCC mix the bonding become weak and the failure in specimen occurs at the inter face of the rubber chips and recycled aggregate. Up to 15% of rubber chips replacement in coarse aggregate was acceptable after that the strength started decreases to a non-acceptable limit.
The observation was made from Figure 7 that the control mix (SCT0R0) gives highest split tensile strength at all age. When the tyre rubber replaced the NCA the strength started decrease as compare to the control mix. As the replacement quantity increase the strength started decrease. At 5 % replacement of tyre rubber (SCT5R0) the split tensile strength was high from 10 % tyre rubber replacement (SCT10R0). When the RA was replaced the NCA that to 5 % and 10 %, the 5 % replacement (SCT0R5) gives more split tensile strength than 10 % replacement of RA (SCT0R10). As compare with control mix (SCT0R0) the split tensile strength of 5 % replacement of RA (SCT0R5) was minimum. When the combine effect of tyre rubber and RA was considered, whatever strength was decreased due to addition of rubber chips the concrete gradually regain the strength after addition of RA. The 5 % replacement combination of tyre rubber and RA (SCT5R5) gives more strength than the 5 % and 10 % replacement of tyre rubber with NCA. The 10 % combination of tyre rubber and RA (SCT10R10) having less strength as compare to all the mix. When the replacement amount of tyre rubber chips and recycled aggregate amount increases in SCC mix the bonding become weak and the failure in specimen occurs at the inter face of the rubber chips and recycled aggregate. Up to 15 % of rubber chips replacement in coarse aggregate was acceptable after that the strength started decreases to a non-acceptable limit.

![Figure 7](image)

**Figure 7.** The comparison of split strength with days for SCC mix.

6. Conclusion
The flow ability of SCC mix was more and it satisfied the second class criteria as mentioned EFNARC guide lines 2005 when the tyre rubber quantity was increased. From the seven mix the SCT10R0 and SCT10R10 satisfied the second class criteria as per EFNARC guidelines and the rest mix satisfied the first class criteria as per EFNARC guide lines. In $T_{500}$ test, the replacement of rubber takes less time to complete the test. Because the rubber chips were not properly bond with concrete so it separated and flow with water. Although the RA had the same problem of bonding but it tooks little more time to complete the test. For this $T_{500}$ test, all the mix satisfied the second class criteria of EFNARC guidelines (2005). The passing ability of SCC mix was more in rubber chips replacement mix due to poor bonding. As rubber chips replacement quantity increases the segregation occurs and the mix passes quickly. In the case of RA replacement, the mix takes time to pass through small opening and gap between rods. To know the filling ability, the rubber replaced mix filled the compartment with small height variation. The RA replaced concrete take more time for filling and the height variation between two compartments was more than rubber replaced mix. All the SCC mix with different mix proportion satisfies the EFNARC guidelines (2002 & 2005). The compressive strength was more in
control mix as the tyre rubber replaced quantity increases the compressive strength decreases. When RA was replaced with NCA, the difference of compressive strength with control mix was very minimum in percentage. The 5 % replacement of RA (SCT0R5) gives more compressive strength at all age with comparison of all other replacements. The combine effect of 5 % replacement of tyre rubber and RA (SCT5R5) was acceptable for construction field. This gives strength as well as ductility and vibration absorbing quality. The combine effect of 10 % replacement of tyre rubber and RA (SCT10R10) gives minimum strength at all age as compare with all other mixes. In comparison between SCT5R5 and SCT10R10 the compressive strength, flexural strength and split tensile strength was more in SCT5R5. As compare with SCT5R0 and SCT0R5 the strength was more in SCT5R5 at all age. The concrete with rubber chips gives very good vibration absorbing quality. Although this type of concrete is not suitable for high strength carrying structure but it can be used for small work like footpath, pedestal etc.

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