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# Effect of steel fibers on the properties of recycled self-compacting concrete in fresh and hardened state

**M.M. Kamal[1], M.A. Safan[1], Z.A. Etman[1,]*, M.A. Abd-elbaki[2]**

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***Abstract***

*The current research intends to study the possibility of producing fiber recycled self-compacting concrete (FRSCC) using demolitions as a coarse aggregate (crushed red brick and crushed ceramic). Steel fibers were used in recycled self-compacting concrete (RSCC) to improve fresh and hardened properties of this type of concrete. Thirty nine concrete mixes were prepared to achieve the aim proposed in this paper. Steel fiber volume fraction varied from 0 to 2.0% by the volume of concrete with aspect ratio 65. The fresh properties of FRSCC were evaluated using slump flow, J-ring and V-funnel tests. Compressive strength, tensile strength, flexural strength and density tests were performed in order to investigate mechanical properties. The optimum volume fraction of steel fibers was 0.25% and 1.0% for the mixes contained crushed red brick and ceramic as a coarse aggregate respectively. At optimum content of steel fibers, the compressive strength for the RSCC mixes with steel fibers; improved by 11.3% and 31.8% for the mixes with crushed ceramic and crushed red brick, respectively with respect to control mix. Also the tensile strength and the flexural strength for the mixes were improved.*

***Keywords:*** *Self-compacted concrete, Red brick, Ceramic, Recycled materials, Steel fibers, Polypropylene fibers.*

## 1. Introduction

Ever since the first report of the development of SCC in Japan in 1988 by Ozawa et al using super plasticizer and viscosity agent and in 1922, they again identified the factors controlling self compactability namely coarse and fine aggregate content. They again developed test methods to check the self compactability and found that the water-powder ratio governs the self compactability [1]. The fresh and hardened properties of self-compacted concrete (SCC) due to the effect of using different types of mineral admixtures were studied by Uysal and Yilma [2]. They noticed the fresh properties of SCC were enhanced especially when used marble powder. On the other hand, Khaleel, et al [3] illustrated that maximum nominal size, texture and type of coarse aggregate have a direct effect on improving SCC. They found that; decreasing in the flow-ability of SCC increasing in the maximum nominal size of coarse aggregate. Also the flowabiltiy of SCC decreases as using crushed aggregate. Felekoğlu et al [4] reported that using of SCC with its improving production techniques is increasing every day in concrete production. However, mix design methods and testing procedures are still developing.

* *Corresponding author: dr_zeinab_2006@yahoo.com*
*1 Department of Civil Engineering, Faculty of Engineering, Menoufia University*
*2 Civil Engineer and Postgraduate Fellow*

Zhu and Bartos [5] studied that Permeation properties, which include permeability, absorption, diffusivity etc., these parameters have been widely used to quantify durability characteristics of SCC. The results indicated that the SCC mixes had significantly lower oxygen permeability and captivity than the vibrated normal reference concretes of the same strength grades. The SCC mixes containing no additional powder but using a viscosity agent were found to have considerably higher diffusivity than the reference mixes and the other SCC. Grdic et al [6] reported environmental advantages of SCC in comparison to the normal concrete. For producing SCC; coarse recycled aggregate obtained from crushed concrete was researched. In this research, three types of concrete mixtures were made. The percentages of recycled aggregated were 0%, 50% and 100% as a replacement of coarse aggregate. The results indicated that recycled aggregate can be used for making SCC. The effects of using mineral admixtures were evaluated by Uysal et al [7]. Fly ash (FA), granulated blast furnace slag (GBFS), limestone powder (LP), basalt powder (BP) and marble powder (MP) were used in producing SCC mixes. Significant increased in the workability of SCC was noticed by using FA and GBFS. Using GBFS by 20% as a replacement of Portland cement (PC) strength was more than 78 MPa at 28 days. The possibility of reusing the demolition as a coarse aggregate in producing concrete was studied by Rao et al [8]. Reuse of waste aggregate was especially in lower level applications. The effect of the use of waste as a coarse aggregate on the fresh and hardened



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properties was summarized. Major factor was considered in the use of recycled aggregate (RA) as non specifications/codes for reusing aggregates in concrete. Fiber-reinforced SCC (FRSCC) should spread into a place under its own weight and achieve consolidation without internal or external vibration, ensure proper dispersion of fibers, and undergo minimum entrapment of air voids and loss of homogeneity until hardening [9]. According to ACI Committee 544.4R-2002, the steel volume fraction used in ranges from 0.5% to 1.5% by volume of concrete, whereas the aspect ratio of the steel fibers used is between 50 and 100 [10]. A significant amount of research has been done in the last two decades to establish proper guide lines for SCC mixes [11-14]. Researchers have studied FRSCC with different kinds of fibers including steel fibers, poly-vinylalcohol fibers, polypropylene, glass fibers, nylon bundles, and carbon fibers. SCC has shown a densified matrix with a better bonding between steel and concrete [15] Therefore, taking the advantage of SCC properties by including steel fibers should provide a positive new feature and a new dimension in concrete technology, which could lead to better behavior in the mechanical performance of self-fiber reinforced self-compacted concrete (SFRSCC) in the hardened state. The effect of fibers depends on several parameters including type, size, geometry, aspect ratio, volume fraction, tensile strength stiffness, surface properties and fiber matrix bond [16, 17]. Previous studies have talked about the limitations of the workability of fresh properties beyond 1% steel fiber volume fraction because higher fiber volume fraction causes greater hindrance in the spreading of fresh concrete. The incorporation of steel fiber in concrete improved bond strength between the steel reinforcing bar and concrete matrix, and increased compressive strength and flexural strength of the concrete [18]. Tamrakar [18] reported the advantages of steel fiber reinforced self-consolidated concrete (SFRSCC). 0 to 2.4 % of steel fiber volume fraction was used. The fresh and hardened properties of SCC were evaluated. Qian et al [19] used hybrid polypropylene-steel fiber in concrete. They investigated the optimization of fiber content, fiber size, and fly ash content. Mechanical properties of this concrete were investigated. The results notice fly ash is necessary to use to distribute disperse fibers. The differences in mechanical properties due to different sizes of steel fibers were studied. Also the effect of additions of a small fiber type was a significant influence on the compressive strength, but slightly effects on the splitting tensile strength. An investigation on mechanical properties of SFRSCC was conducted by Dhonde et. al [13] on two different types of steel fibers and variable amounts of hooked steel fiber. They used Dramix RC 80/60 BN, which has a “trough” shape with hooked end steel fiber, and ZP305, a short steel fiber with a hooked end as well. The aspect ratios of Dramix RC 80/60 BN and ZP305 were 80 and 50, respectively. Three different types of steel fiber reinforced self-consolidated concrete (SFRSCC) in total were prepared with 0.5% and 1% by volume of concrete. Only one mix of SFRSCC with Dramix RC 80/60 BN at 0.5% by volume, and the other two mixes of SFRSCC with ZP305 at 0.5% and 1% by volume were prepared. The results showed that the non-fibrous mixture exhibited sudden failure with brittle characteristics, while the fibrous concrete cylinders were quite ductile. The study showed that the cylinders with short fibers had slightly higher 28-day compressive strengths than those with the longer fibers, despite having the same exact fiber volume percentage. Another study done by Yildirim et.al. [16] showed a slight increase in 28-day compressive strength after the increment of fiber volume percentage was increased from 0.3% to 1.2%. Overall, the short fiber samples showed a higher modulus of rupture in fibrous concrete mixtures compared with non-fibrous concrete [13]. The behavior of reinforced SCC beams under flexural load was investigated by Barros et al [20]. 1% steel fiber volume fraction with aspect ratio of 50 was used. The results showed the resistance capacity of reinforced SCC beams increases as using steel fibers in SCC. This yield to lower deflections at mid-span, lower deformations of the reinforcement bars, and improved cracking control, compared to beams cast with normal concrete, with or without steel fibers. The properties of plain SCC and NC with steel fiber were studied by Rao and Ravindra [21]. 0, 0.5, 1.0 and 1.5% steel fiber volume fractions with aspect ratio (0, 15, 25 and 35) were used. The results observed that enhanced in the ductility by using fibers. 1.0 % steel fiber volume fraction with 25 aspect ratio was the optimum consideration of fiber for better performance in terms of strength.

Suchithra S. and Malathy R. studied the effect of steel fibers on beams and beam-column joints of SCC specimens, using three different fiber volume fractions (0.5%, 1% and 1.5%). Mix design for strength of 20 MPa (low strength) was considered. The results revealed that the behavior of load-deflection, ductility and energy absorption was found to be more for the steel fibres having volume fraction 1.0% for SCC with partial replacement of cement with silica fume. SCC classes are reduced by increasing the steel fiber volume fraction, and using different forms of mineral admixtures,[22].

Kamal M. M. et al studied the possibility of producing fiber recycled self-compacting concrete (FRSCC) using demolitions as a coarse aggregate (crushed red brick and crushed ceramic). Polypropylene fibers were used in recycled self-compacting concrete (RSCC) to improve fresh and hardened properties of this type of concrete. Polypropylene fiber volume fraction varied from 0 to 1.5% of the volume of concrete with aspect ratio 12.5. The results cleared that; the optimum volume fraction of polypropylene fibers was 0.19% and 0.75% for the mixes contained crushed red break and ceramic as a coarse aggregate, respectively, [23].

## 2. Research Significant

The aim of this research was to investigate the possibility of improvement the fresh and hardened properties of recycled self-compacted concrete by using steel fibers. Furthermore, the optimum volume fraction of steel fibers was investigated.



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## 3. Experimental Program

To achieve the aim of the research, thirty nine mixes were prepared using demolition (crushed red brick and crushed ceramic) as a coarse aggregate. Different percentages (25, 50, 75 and 100 %) of recycled materials were used as a replacement of coarse aggregate (dolomite). Steel and polypropylene fibers were used to improve the properties of RSCC. The optimum content of fibers used in the fresh state of SCC was investigated. A total of 144 cubes 10×10×10 cm were tested to determine the compressive strength and density of the mixes at 7 and 28 days. Cylinders of 10 cm in diameter and 20 cm in length were studied to determine the splitting tensile strength of the mixes. To determine the flexural strength of mixes; 10×10 × 50-cm prisms were used.

### *3.1. Materials*

Well graded siliceous sand was used with a specific gravity of 2.60, absorption of 0.78 %, and a fineness modulus of 2.61. Coarse aggregate of crushed dolomite with maximum nominal sizes of 10 mm was used, with a specific gravity 2.65 and absorption of 2%. Crushed red brick and ceramic from the demolition of buildings were used as a coarse aggregate. Crushed red brick with maximum nominal size of 10 mm was used, with specific gravity 1.64 and absorption of 4%. Crushed ceramic with maximum nominal size of 10 mm was used, with specific gravity 2.66 and absorption of 1.9%. Locally produced Portland cement (CEMI: 42.5 N) conforming to the requirements Egyptian Standard Specifications (373/2007) was used. Imported class (F) fly ash meeting the requirements of ASTM C618 [24] with a specific gravity of 2.1 was used. The cement content was 400 kg/m$^3$ and the water powder ratio (W/P) ranged from (0.5-0.55). Tap water was used for mixing the concrete. A high range water reducer (HRWR) with trade name; Addicrete BVF was used as superplasticizer meeting the requirements of ASTM C494 (type A and F) [25]. The admixture is a brown liquid having a density of 1.18 kg/liter at room temperature. The amount of HRWR ranged from (2.0-2.5%) of the cement weight. Steel fibers with 0.2 mm diameter and 13 mm length with aspect ratio (L/D) 65 were used.

### *3.2. Casting and Testing Procedures*

Coarse aggregate, fine aggregate, cement and the fibers were mixed for at least 1 minute in the dry state before the water and admixtures have been added. The mixing time after slurry (water, fly ash, and HRWR) was added for (3-4) minutes to insure full mixing of the SCC. Based on the results reported in paper [26], the control mixes (L) were selected in this research based on the technical requirements of SCC this mixes contains dolomite as coarse aggregate. Also RSCC mixes were selected as reported in [26]. THE RSCC mixes was made using recycled aggregate with a maximum nominal size of 10 mm (red brick and ceramic) replaced by crushing dolomite. The replacement levels by weight of dolomite were 25%, 50%, 75%and 100%. In this research steel fibers were used to improve the properties of RSCC. The properties of RSCC and fibers RSCC were determined by different methods which included the normal slump test, V-funnel test and J-ring test. Table (2) shows the mix proportions of RSCC. The concrete specimens were cast and kept at the steel molds for 24 hours. After 24 hours they removed from the molds and submerged in clean water at 20°C& until taken out for testing. Compressive strength testing machine with 2000 KN capacity was used in the determination of the compressive strength and splitting tensile strength. Flexural strength testing machine with 100 KN capacities was used in the determination of the flexural strength of the prism. The flexural strength was determined by the four point loading. The test specimens were designed by letter C for crushed ceramic aggregate or R for crushed red brick aggregated followed by the percentage of recycled, followed by the letter S denotes the specimens of steel fibers.

From the Table (1) the basic requirements of flow ability as specified by technical specification for SCC, [27] are satisfied for the mix (L). Where the slump flow diameter and $T_{50cm}$ was 705 mm and 2.0 sec, respectively. The v-funnel flow time was 7.86 sec. The values of blocking ratio (H2-H1) were 5mm for mix L. These results indicate that the requirements for SCC were achieved for these mixes. The workability values are maintained by adding suitable quantities of materials and super-plasticizers.

**Table 1** Rheological Properties of Trial Self-Compacted Concrete Mixes, [26].

| Mix code | Slump test | | | V-funnel test | | | J-ring test | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dav. (mm) (600 mm)* | T50cm (sec) (2-5 sec)* | Tf (sec) | T (sec) (6-12 sec)* | T5min (sec) (9-15 sec)* | Velocity (m/sec) | T (sec) | Dav. (mm) | H2-H1 (mm) (0-10 mm)* |
| E | 440 | | 1.5 | | | | | | |
| F | 390 | None | 1.2 | | | None | | | |
| G | 410 | | 1.25 | | | | | | |
| H | 690 | 1.5 | 13 | 2 | 3.55 | 0.32 | 2 | 540 | 5 |
| I | 650 | 2.5 | 9.1 | 6.5 | 6.9 | 0.1 | 7 | 600 | 10 |
| J | 580 | 1.3 | 5.1 | 5.06 | 8.21 | 0.12 | 3 | 520 | 10 |
| K | 630 | 1 | 6.2 | 3.19 | 4.96 | 0.2 | 6 | 545 | 10 |
| L | 705 | 2 | 7 | 7.86 | 9.85 | 0.1 | 6 | 590 | 5 |

Dav: The average of the flow diameter for the slump test and the j- ring test (mm).
T50cm: Time at diameter of concrete equal 50 cm (sec).
Tf: The time which the concrete stop spreading in the slump test (sec)
* Requirements of technical specification of self-compacted concrete [27]


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The fresh properties of RSCC mixes are referring to as workability. The results of slump, V-funnel and J-ring test was shown in Table 2. Figs. 2 and 3 show the effect of percentage of recycled materials on the flow diameter and flow time ($T_{50cm}$). Fig. 2 cleared that an increase in flow diameter as a percentage of recycled aggregate increase for both crushed red brick and crushed ceramic. All mixtures using crushed ceramic or crushed red brick as a recycled aggregate show a slump flow diameter between 705-1020 mm and achieve the requirements of SCC. This shows that all mixtures have enough deformability under their own weight. Fig. 3 illustrated that an increase of $T_{50cm}$ as percentage of recycled aggregate increase on both crushed red brick and crushed ceramic.

**Table 2** Concrete proportions of Recycled self-compacted concrete mixes (kg/$m^3$), [26].

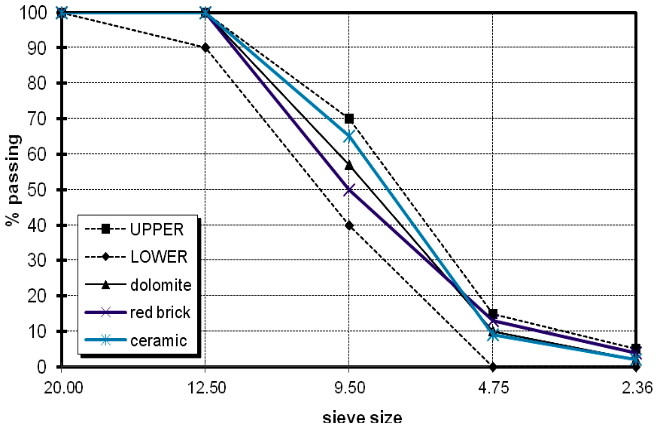
| Mix code | Cement | W/C | Sand | Dolomite | Recycled aggregate | Fly ash | BVF1 |
|---|---|---|---|---|---|---|---|
| Control mix (L) | | | | 663 | 0 | | |
| C25% | | | | 534 | 134 | | |
| C50% | | 0.55 | 974 | 440 | 220 | | |
| C75% | | | | 380 | 285 | | |
| C100% | 400 | | | 0 | 668 | 40 | 11 |
| R25% | | | | 465 | 116 | | |
| R50% | | 0.50 | 1005 | 364 | 182 | | |
| R75% | | | | 294 | 221 | | |
| R100% | | | | 0 | 250 | | |

**Control Mix (L): the best trial self-compacted concrete mix.**
**C: refer to the mixes with crushed ceramic as a recycled aggregate.**
**R: refer to the mixes with crushed red brick as a coarse aggregate.**


(a) Steel Fibers


(b) Rred Brick Aggregate


(c) Ceramic Aggregate



(d) Grading of Aggregate

**Fig. 1** Recycled Materials as a Coarse Aggregate

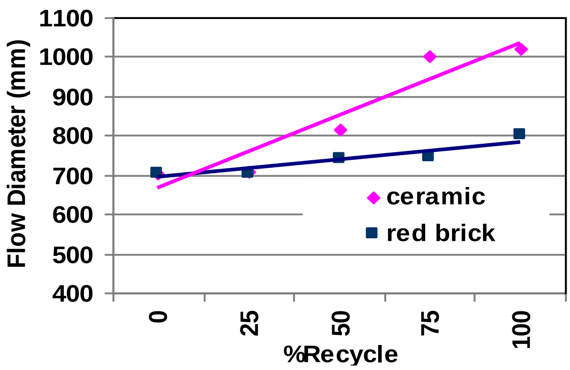


**Fig. 2** Effect of Percentage of Recycled as a Coarse Aggregate on the Flow Diameter

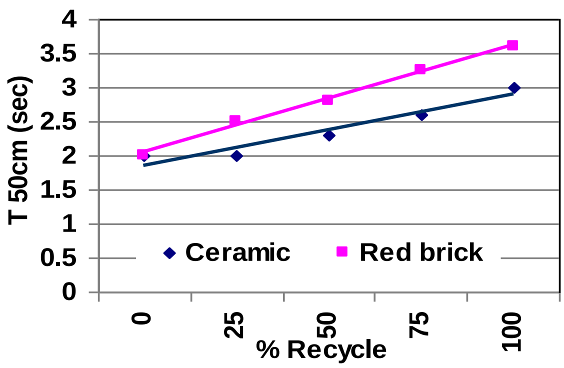


**Fig. 3** Effect of Percentage of Recycled as a Coarse Aggregate on the Flow Time.

When using When using ceramic as a recycled aggregate $T_{50cm}$ ranged from 2 –3 sec. While in mixes with crushed red brick $T_{50cm}$ ranged from 2.5 –3.6 sec. This shows that all mixtures achieve the requirements of SCC and have enough viscosity to flowability. This is due to the type, the manufacturing process and properties of the recycle aggregated used in concrete mix. Fig. 4 presents the flowabilty of C25% and R25% mixes.

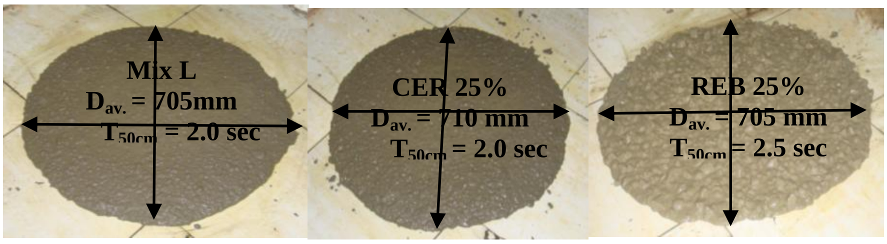



**Fig. 4** Flowability for Different Mixes

As presented in Figs. 5 and 6 show the effect of percentage of recycled aggregate on the compressive strength of the RSCC. At 28 days, decrease in the compressive strength with the increases in the percentage of the recycle aggregate. This is supported by a previous study conducted by Cachim, (2009) and Grdic et al. (2010). This is due to the type, the manufacturing process and properties of the recycle aggregated used in concrete mix. Fig. 5 shows higher compressive strength for the concrete mixtures with crushed ceramic than for the concrete mixtures with crushed red brick for the same percentage of recycling. Moreover the reduction in the compressive strength for mixes with ceramic was lower that that concrete with crushed red brick. This due to the flat shape and distribution of these aggregate. The maximum compressive strength was (19.7 and 28.3 MPa) obtained for concrete mixture with 25% crushed ceramic at 7 and 28 days respectively. The maximum compressive strength was (19.5 and 29 MPa) was obtained for concrete mixture with 25% crushed red brick at 7 and 28 days respectively. A maximum reduction increase in compressive strength about 31% for concrete mixtures with ceramic has been observed at 100% percentage of recycled aggregate, whereas for crushed red brick was 45 % at 100% percentage of recycled aggregate.

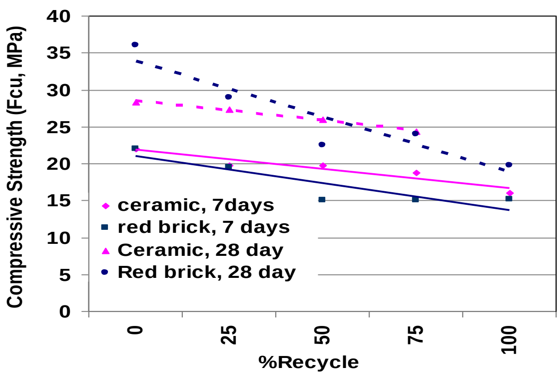



**Fig. 5** Compressive Strength for Recycled Self-Compacting Concrete

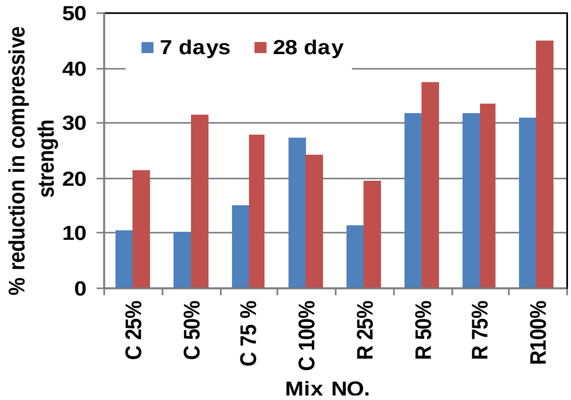



**Fig. 6** Reduction in Compressive Strength of Recycled Self-Compacting concrete

## 4. Effect of Steel Fibers on the Fresh and Hardened Properties of Recycled Self-Compacted Concrete

At this stage steel fibers with aspect ratio 65 and volume fraction ranged from (0.0 to 2%) were used to improve the properties of RSCC mixes. A total of eleven RSCC mixtures with 25% recycled aggregate were developed. At the end of this stage the optimum volume fraction of steel fibers was assigned. Steel fibers recycled self-compacted concrete mixes (kg/m$^3$). Tables 3 and 4 clear the mix proportions of RSCC and its fresh properties.

**Table 3** Concrete Proportions of Steel Fibers Recycled Self-Compacted Concrete Mixes (kg/m$^3$).

| Mix Code | L/D | $V_F$ % | Cement | W/C% | Sand | Dolomite | Recycled agg. | Fly ash | BVF1 |
|---|---|---|---|---|---|---|---|---|---|
| R25% | 0 | 0 | | | | | | | |
| S1R25% | | 0.038 | | | | | | | |
| S2R25% | 65 | 0.25 | | 0.5 | 1005 | 465 | 116 | | |
| S3R25% | | 0.5 | | | | | | | |
| S4R25% | | 1 | | | | | | | |
| C 25% | 0 | 0 | 400 | | | | | 40 | 11 |
| S1C25% | | 0.25 | | | | | | | |
| S2C25% | | 0.5 | | 0.55 | 974 | 534 | 134 | | |
| S3C25% | 65 | 1 | | | | | | | |
| S4C25% | | 1.5 | | | | | | | |
| S5C25% | | 2 | | | | | | | |

**Table 4** Rheological Properties of Fresh Steel Fibers Recycled Self-Compacted Concrete Mixes.

| Mix No. | L/D | $V_F$ % | Slump test: $D_{av.}$ (mm) | | Slump test: $T_{50cm}$ (sec) | | V-funnel: $T_f$ (sec) | V-funnel: T (sec) | | V-funnel: $T_{5min}$ (sec) | | V-funnel: Velocity (m/sec) | J-ring test: T (sec) | J-ring test: $D_{av.}$ (mm) | J-ring test: $H_2$-$H_1$ (mm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R25% | 0 | 0 | 705 | (600 mm)* | 2.5 | (2-5 sec)* | 6 | 6.07 | (6-12 sec)* | 7.07 | (9-15 sec)* | 0.1 | 5.2 | 640 | 8 | (0-10 mm)* |
| S1R25% | | 0.038 | 650 | | 1.7 | | 4.5 | 6 | | 7.8 | | 0.11 | 4.5 | 600 | 10 | |
| S2R25% | 65 | 0.25 | 660 | | 2 | | 4 | 6.5 | | 8 | | 0.11 | 3.9 | 570 | 10 | |
| S3R25% | | 0.5 | 640 | | 2.57 | | 3.5 | 7.3 | | 7.5 | | 0.08 | 3.4 | 530 | 10 | |
| S4R25% | | 1 | 605 | | 1.82 | | 3 | 5.2 | | 7 | | 0.12 | 3 | 500 | 15 | |
| C25% | 0 | 0 | 710 | | 2.6 | | 4 | 6.8 | | 8.7 | | 0.09 | 4.36 | 625 | 10 | |
| S1C25% | | 0.25 | 735 | | 1.8 | | 4.5 | 5 | | 7 | | 0.12 | 5.5 | 660 | 10 | |
| S2C25% | | 0.5 | 780 | | 1.65 | | 5 | 6.3 | | 7.5 | | 0.1 | 6 | 680 | 10 | |
| S3C25% | 65 | 1 | 750 | | 2.1 | | 4.3 | 6.2 | | 8 | | 0.12 | 5.4 | 650 | 10 | |
| S4C25% | | 1.5 | 710 | | 2.82 | | 4 | 6.8 | | 7.4 | | 0.09 | 4.9 | 620 | 8 | |
| S5C25% | | 2 | 660 | | 1.5 | | 3.5 | 6.5 | | 7 | | 0.09 | 4 | 600 | 8 | |

*4.1. Workability for steel fiber recycled self-compacted concrete mixes*

Fig. 7 shows a decrease in slump flow diameter as steel fiber volume fraction increases for SRSCC. The volume fraction for the SRSCC mixes with crushed ceramics was ranged from (0.0 to 2 %). The optimum volume fraction that obtained from the results was 1.0% after this point the flow diameter decreases. The flow diameter for the SRSCC mixes with crushed ceramic ranged from (660 to 780 mm). In fact, a significant decrease in flow diameter has been observed beyond 1.0 % fiber volume fraction. This might be due to the effect of the higher amount of steel fibers as well as higher internal resistance of the steel fibers in fresh concrete mixtures. For the SRSCC mixes with crushed red brick; the volume fraction changed from (0.0 to 1%). The flow diameter for theses mixes decreases due to steel fibers volume fraction increases. The optimum volume fraction that obtained from the results was 0.25%. The flow diameter for theses mixes ranged from (605 to 660 mm). Also flow diameter decrease beyond 0.25% fiber volume fraction. It is noticed that the optimum volume fraction for SRSCC with crushed ceramic was higher than that of SRSCC with crushed red brick. Moreover the flow diameter for SRSCC with crushed ceramic was higher than that of SRSCC with red brick. The reduction in flow diameter for SRSCC with crushed ceramic was lower than that of SRSCC with crushed red brick. All theses noticed were due to the mechanical and physical properties of the aggregate used. The results of flow meet the requirements of SCC [27]. During the slump flow test, the time required to reach the 500mm diameter was also measured and recorded as $T_{50cm}$ (sec), which indicates the viscosity of the concrete. Fig. 8 shows the effect of steel fiber volume fraction on T50cm compared to the control mixture (with 25% recycled aggregate and without fibers). Increase in volume fraction increases the $T_{50cm}$ measurement. S2R25%, S3R25%, S3C25% and S4C25% including the control are in the requirements the technical specifications of SCC which is characterized by the viscosity of the concrete with high segregation resistance. T50cm for the SRSCC mixes with crushed red brick ranged from (1.7 to 2.57 sec). The optimum volume fraction was 0.25% at T50cm 2.0 sec. The T50cm for the SRSCC mixes with crushed ceramic ranged from (1.5 to 2.82 sec). The optimum volume fraction was 1% at $T_{50cm}$ 2.1 sec. Fig. 10 shows the increment of T50cm measurement with the flow diameter for SRSCC mixes. It cleared that as a flow diameter decrease as flow time increases. Fig. 9 shows the flow diameter for SRSCC mixes.

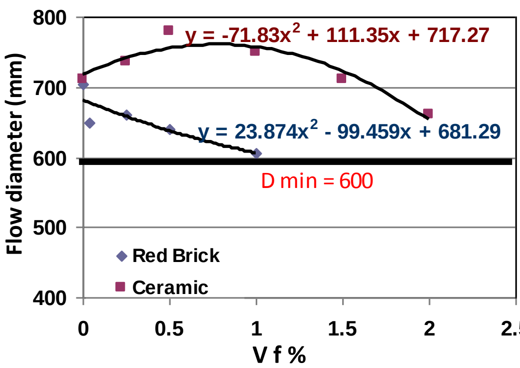



**Fig. 7** Effect of The Steel Fiber Volume Fraction of the Flow Diameter

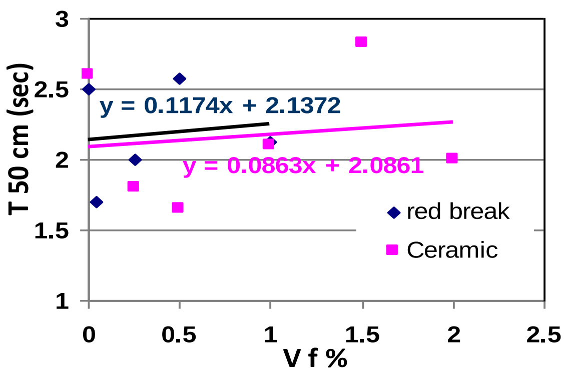



**Fig. 8** Effect of the Steel Fiber Volume Fraction of the Flow Time ($T_{50cm}$)



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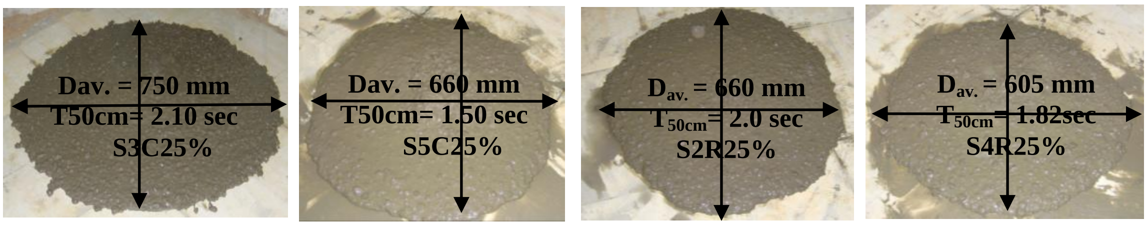


**Fig. 9** Flowability for SRSCC Mixes

The V-Funnel Time represents the filling ability of the concrete mixtures and measures their viscosity. Figs. 11 and 12 show that an increase in the fiber volume fraction increases V-funnel time and V-funnel time at 5min. A significant increase in V-funnel time beyond 0.25% and 1% of fiber volume has been observed in SRSCC mixtures with crushed red brick and crushed ceramic as a recycled aggregate respectively. This shows the effect of the higher amounts of steel fibers and also illustrates the effect of steel fibers in the narrow opening of the V-Funnel at the bottom beyond 0.25% and 1% of the fiber volume fraction for crushed red brick and crushed ceramic recycled aggregate). Moreover, the trend lines in the figures show that V-funnel time for the crushed red brick is higher than that of the crushed ceramic for the same fiber volume fraction. This may be because of the difference in properties of the type of aggregate ones in the narrow opening at the bottom of the V-funnel. For the mixes which containing crushed red brick, the v-funnel time ranged from (6.07–7.3 sec) at (0.0-0.5%) and decreased to (5.2 sec) at volume friction steel fibers equal 1.0%. For the mixes with crushed ceramic, the v-funnel time ranged from (5.0– 6.8 sec) at (0.0%-2.0%) steel fiber volume fraction.

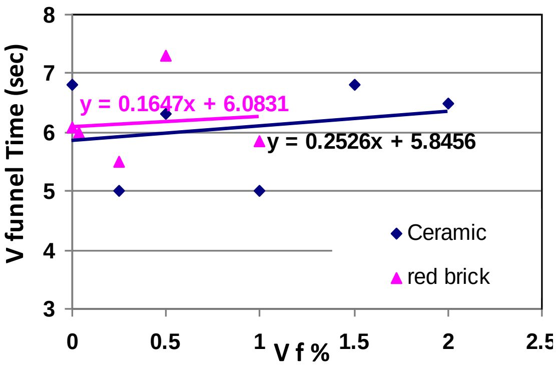


**Fig. 11** Effect of Steel Fiber Volume Fraction on V-Funnel Time

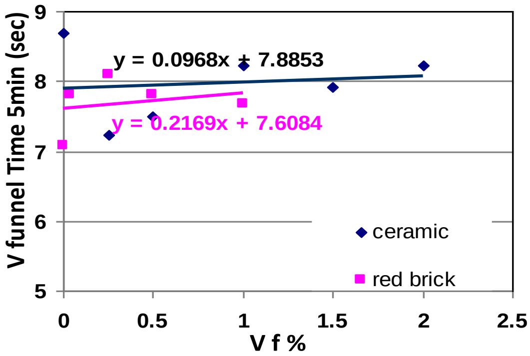


**Fig. 12** Effect of Steel Fiber Volume Fraction on V-Funnel Time after 5 min

Fig. 13 shows the same trends that noticed at slump flow diameter. The figure illustrates that the flowability for the mixes with recycled crushed ceramic higher than that for crushed red brick. Fig. 14 shows the flow diameter with all mixes with recycled aggregate. The flow time for the J-ring test indicates the rate of deformation with specified flow distance. In general, $T_{50cm}$ for j-ring is higher than the normal slump flow time $T_{50cm}$, as flow is restricted by the reinforcing bars. Like the $T_{50cm}$ time for slump flow test, the $T_{50cm}$ time measurement for J-ring test gets longer with increased fiber volume fraction for all concrete mixtures. In addition, the crushed ceramic recycled aggregate show lower $T_{50cm}$ time than the crushed red brick for the same percentage of fiber volume fraction, as expected. $H_2$-$H_1$ for the SRSCC with crushed red brick was higher than SRSCC with crushed ceramic mixture as shown in Figs. 15.

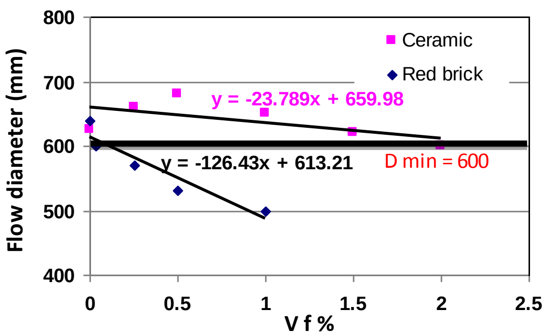


**Fig. 13** Effect of the Steel Fiber Volume Fraction on the Flow Diameter

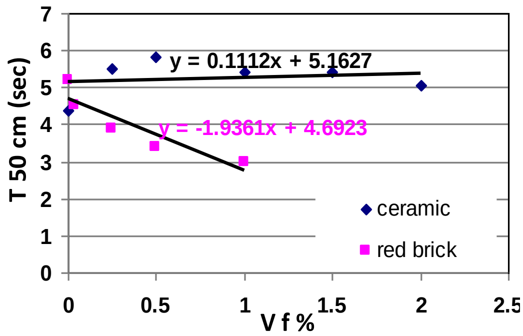


**Fig. 14** Effect of the Steel Fiber Volume Fraction on the Flow Time



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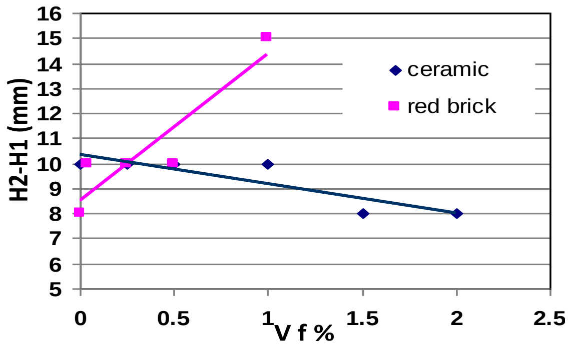


**Fig. 15** Effect of Steel Fiber Volume Fraction on the Blocking Ratio

*4.2. Mechanical properties of steel fibers recycled self-compacted concrete mixes*

After investigating the compressive strength of mixtures with SRSCC has been discussed. The results showed that the concrete mixtures without steel fibers exhibited sudden brittle failure, while the concrete mixtures with steel fibers exhibited a ductile failure because of the energy absorbing capacity of the fibrous concrete. Fig. 16 represents the 7 days and 28 days compressive strength of SRSCC mixtures. 7 days compressive strength of mixtures with crushed red brick varies from 20.6 MPa to 25 MPa while those with recycled ceramic are between 22.0 MPa to 29.8 MPa. 28 days compressive strength of mixtures with crushed red brick varies from 24.0 MPa to 30.0 MPa while those with recycled ceramic are between 29.5 MPa to 32 MPa. An improving in the compressive strength for the mixes with steel fibers compared to without steel fibers by 9.8% and 5.8% for the mixes with crushed ceramic and crushed red brick respectively. Also, it is noticed that the compressive strength for the mixtures with crushed ceramics more than that with crushed red brick by 3.4 %. Figs. 17 and 18 show the other mechanical properties (tensile strength and flexural strength) the density of theses mixes is showed in Fig. 19. The same trend was noticed for the tensile and flexure strength. As increasing the volume fraction of the fibers as increasing the tensile and flexural strength. The tensile strength and the flexural strength for the mixes with steel fibers compared to without steel fibers enhanced by an average 17.18 % and 19 % for the mixes with crushed ceramic. The tensile strength and the flexural strength for the mixes with steel fibers compared to without steel fibers enhanced by an average 31% and 7.4 % for the mixes with crushed red brick. The tensile strength for the mixtures with crushed ceramics was more than the mixtures with crushed red brick by 3.7%. The flexural strength for the mixtures with crushed ceramics more than the mixtures with crushed red brick by 0.7%.

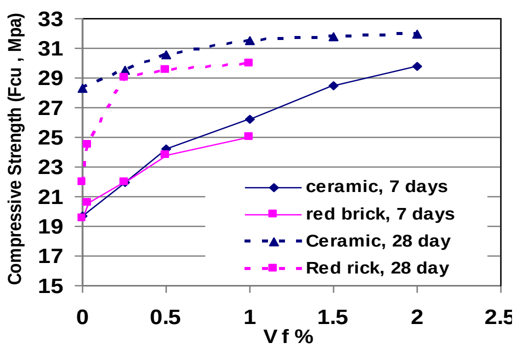


**Fig. 16** Effect of Steel Volume Fraction on the Compressive Strength

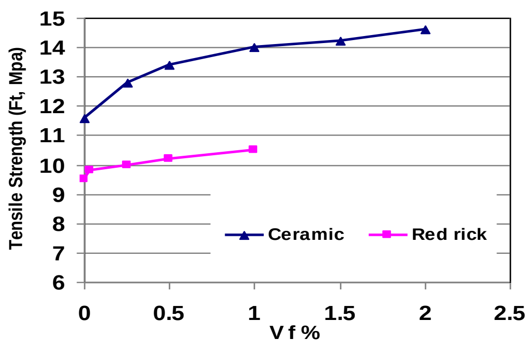


**Fig. 17** Effect of Steel Volume Fraction on the flexural Strength

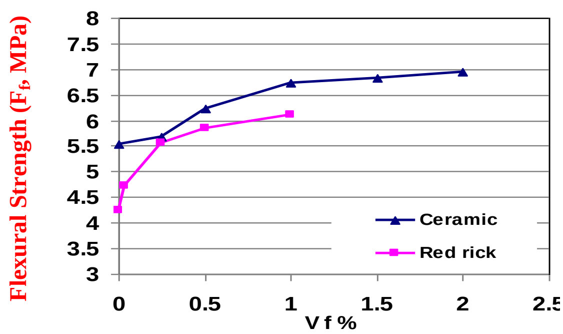


**Fig. 18** effect of Steel Volume Fraction on the tensile Strength

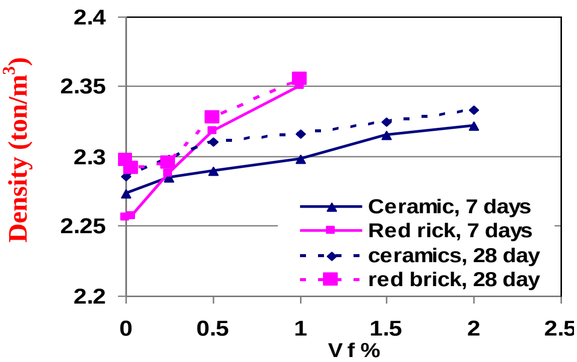


**Fig. 19** Effect Of Steel Volume Fraction on the Density



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At different percentage of recycled material, fresh properties for SRSCC were evaluated at optimum volume friction for steel fibers. The different percentages of recycled Aggregated were (50%, 75% and 100%) as a replacement of coarse aggregate (dolomite). The optimum volume fraction for SRSCC was 0.25 % and 1% for mixes with crushed red brick and crushed ceramic respectively. Table (5) gives the fresh properties of these mixes.

**Table 5** Rheological Properties of Fresh Steel Fibers SRSCC Mixes at Optimum Volume Fraction.

| Mix No. | L/D | $V_F$% | Slump test | | | | J-ring test | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $D_{av.}$ (mm) | | $T_{50cm}$ (sec) | | $T_f$ (sec) | T (sec) | $D_{av.}$(mm) | $H_2$-$H_1$ mm) | |
| S2R25% | 65 | 0.25 | 660 | (600 mm)* | 2 | (2-5 sec)* | 4 | 3.9 | 570 | 10 | (0-10 mm)* |
| S21R50% | | | 665 | | 1.9 | | 3.2 | 2.6 | 580 | 9 | |
| S22R75% | | | 715 | | 1.75 | | 3.4 | 2.8 | 605 | 8.5 | |
| S23R100% | | | 810 | | 1.6 | | 3.2 | 3 | 685 | 5 | |
| S3C25% | | 1.0 | 750 | | 2.1 | | 4.3 | 5.4 | 650 | 10 | |
| S31C50% | | | 720 | | 1.8 | | 4 | 3.7 | 585 | 9 | |
| S32C75% | | | 935 | | 1.8 | | 3.5 | 3.6 | 785 | 5 | |
| S33C100% | | | 1025 | | 1.8 | | 3.5 | 3.6 | 800 | 5 | |

Figs. 20 and 21 show the relationship between the flow diameter and the T50cm with the percentage of recycling material. Fig. 20 represents that as the percentage of recycled aggregate increases as the flow diameter increase for the RSCC with and without steel fibers. Also the flow diameter for the mixes without steel fibers was higher than that with steel fibers. This due to the amount of steel fibers as well as higher internal resistance of the steel fibers in fresh concrete mixtures. $T_{50cm}$ for theses mixes illustrated in Fig. 21. It is clear that as the percentage of recycled aggregate increases as the $T_{50cm}$ increase for the RSCC with and without steel fibers. Also the $T_{50cm}$ for the mixes with steel fibers was higher than that without steel fibers. These results meet the requirements of SCC [28].

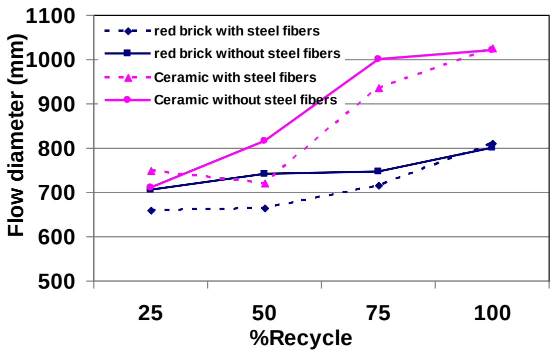


**Fig. 20** Flow Diameter and % Recycling Relationship for Slump Test

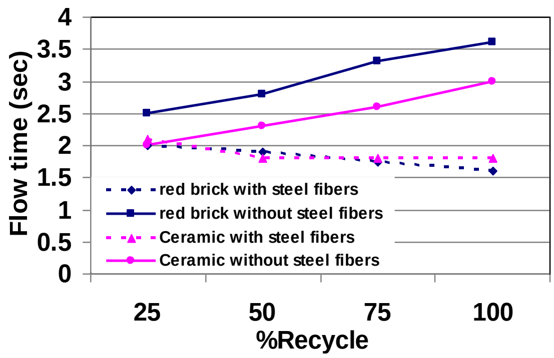


**Fig. 21** Flow Time and % Recycling Relationship for Slump Test

Figs. 22 and 23 show the relationship between the flow diameter and the H2-H1 with the percentage of recycling Aggregate for J-ring test. The same trend was observed.

Fig. 24 presents the compressive strength for the SRSCC with the optimum volume fraction of steel fibers.

It noticed that 28-day compressive strength for the mixes with crushed ceramic varied from (26 Mpa to 31.5MPa) and varied from (18.5 Mpa to 29 Mpa) for the mixtures with crushed red brick as a recycled aggregate. The density for the mixtures was shown in Fig. 25.

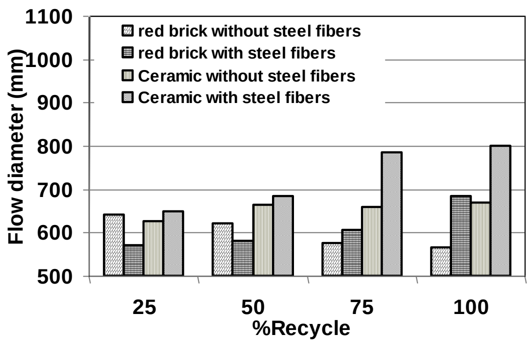


**Fig. 22** Flow Diameter and % Recycling Relationship for J-Ring Test

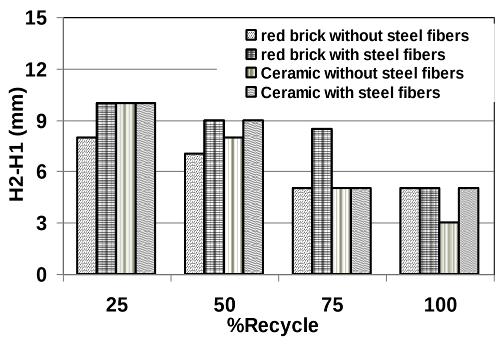


**Fig. 23** Flow Time and % Recycling Relationship for J-Ring Test



[ DOI: 10.22068/IJCE.13.4.400 ]

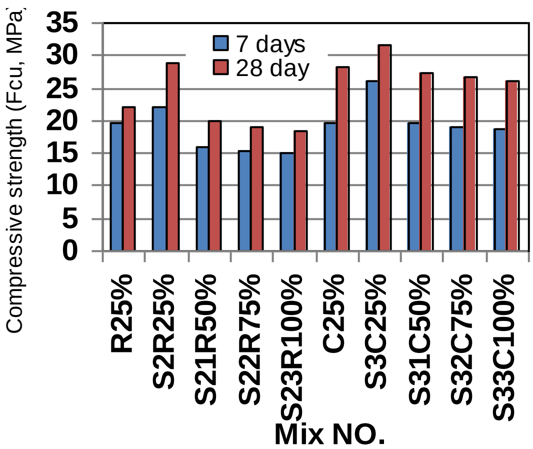

**Fig. 24** Compressive Strength of SRSCC

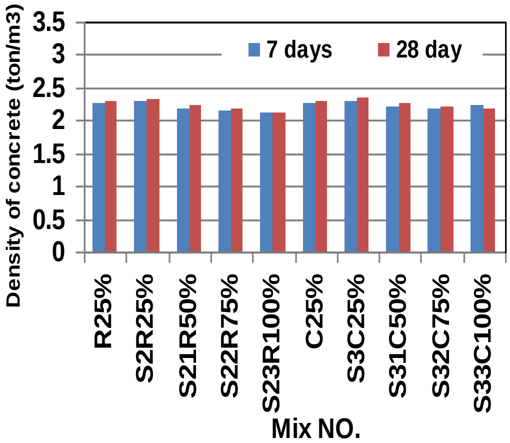

**Fig. 25** Density of SRSCC

## 5. Conclusions

The following conclusions can be drawn:

1. The concrete mixtures with crushed ceramic having fiber volume fraction of steel fibers more than 2% shows no passing ability. Also, the concrete mixtures with crushed ceramic up to 2% of volume of the steel fibers behave as SCC.

2. The concrete mixtures with crushed red brick having a fiber volume fraction of steel fibers more than 1% shows no passing ability while up to 1 % of volume of the steel fibers behave as SCC.

3. The optimum content for volume fraction of steel fibers was 1% and 0.25 % for the concrete mixture with crushed ceramic and red brick respectively.

4. The compressive strength for the dolomite mix was 36 MPa at 28 days. The use of 25, 50, 75 and 100% of crushed red brick as coarse aggregate replacement decreased the compressive strength by 19.4%, 37.5%, 33.33% and 45%, respectively. Moreover, the use of 25, 50, 75 and 100% of crushed ceramic of coarse aggregate replacement decreased the compressive strength by 21.4%, 31.4%, 27.8%and 24.2%, respectively

5. At optimum content of steel fibers, improving in the compressive strength for the mixes with steel fibers by 11.3% and 31.8% for the mixes with 25% crushed ceramic and crushed red brick, respectively compared to RSCC mixes without steel fibers and this lead to improving in the tensile and flexural strength.

6. At optimum dosage of SRSCC mixes with 25, 50, 75 and 100% crushed ceramic yields to improve in the compressive strength by 8.6, 36, 40 and 40%, respectively compared to the mixes with crushed red brick as a recycled aggregate.

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