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CHARACTERIZATION OF RECYCLED SELF-COMPACTING CONCRETE PREPARED WITH GLASS FIBERS

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ABSTRACT

An investigation was performed to improve the properties of recycled self-compacting concrete (RSCC) using demolitions as a coarse aggregate (crushed red brick and crushed ceramic). Glass fibers were used in RSCC to achieve the purpose of this investigation. Glass fiber volume fraction varied from 0.0 to 0.4% by the volume of concrete with aspect ratio 480, 960 and 1920. Forty seven concrete mixes were prepared. Slump flow, J-ring and V-funnel tests were performed to assess the fresh properties of RSCC. Compressive strength, tensile strength, flexural strength tests were performed in order to investigate mechanical properties. Also the density of the mixes was calculated. Using Ceramic as a recycled aggregate improved the workability of the concrete mixture compared to use red brick as a recycled aggregate. At aspect ratio 480, the optimum volume fraction of glass fibers were 0.05% for the mixes contained crushed red brick and ceramic as a coarse aggregate respectively. For the RSCC mixes with glass fibers; 24% and 25% increasing in the compressive strength for the mixes with crushed red break and crushed ceramic, respectively with respect to control mix was observed.

Keywords: self-compacted concrete; red brick; ceramic; recycled materials; glass fibers.

1. INTRODUCTION

Recycled material helps save the limited landfill space. Different types of recycled materials, concrete waste accounts for about 50% of the total waste. Recycling concrete waste as the recycled aggregate is one of the methods to reduce the concrete waste [1]. In recent years, using self-compacting concrete (SCC) becomes increasing. The frequency of using SCC is the highest type of concrete in many countries such as Sweden and Japan, where SCC was originally developed. In the last two decades, a significant amount of papers has been done to establish guide lines for SCC mixes [2-6]. Grdic et al [5] 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 mix proportions of SCC were calculated by Domone [7]. He reported that 31.2 % by volume of concrete were the coarse aggregate; 34.8% were paste content; 500 kg/m^3 were the powder content; 0.34 by weight was water/powder ratio and the 47.5% by volume were fine aggregate/mortar. On the other hand, Khaleel et al. [3] founded that the flow-ability of SCC decrease with the increase in the maximum size of coarse aggregate and using crushed aggregate with the same water to powder ratio and superplasticizer dosage. Uysal and Yilmaz [8] mentioned that the used marble powder was the most suitable for the measured properties of the fresh state of SCC. Felekoğlu et al [10] 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. Recycled fine aggregates (RFA) from waste concrete as a

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new cementitious material was used by Kima et al. [11]. They focused on applying the RFA to produce SCC. The results cleared that the RFA is suitable for developing strength and flowability of the SCC. 25% of RFA were found suitable to produce SCC. The results indicate that among levels of a mixture of the physical and mechanical analysis, the RFA could be applied up to replacement. Recycle glass fiber reinforced plastic (GRP) waste powder and fiber was used by Asokan et al. [12] in producing concrete and cement composites in concrete. The results shoen that, the use of 5%–50% GRP waste powder; the compressive strength of concrete composites ranged between 37 N/mm^2 to 19 N/mm^2. As increasing in the content of GRP waste as decreasing in the compressive strength. At 5% GRP waste powder, the compressive strength was increased to 45.75 N/mm^2. The increasing in the compressive strength was due to the increasing in curing duration (14–180 days). The density was reduced by about 12% as compared to the control sample at 50% GRP waste powder. The use of GRP waste recycling in precast construction products was recommended by this research. Uysal et al [13] evaluated the effectiveness of different types of minerals on the properties of SCC. Fly ash (FA), granulated blast furnace slag (GBFS), limestone powder (LP), basalt powder (BP) and marble powder (MP) were used. The results show that, increased in the workability of SCC was increased by using FA and GBSF. The use of GBFS by 20% as a replacement of portland cement (PC) strength increased more than 78 Mpa at 28 days. Fiber reinforced self-compacted concrete (FRSCC) with different types of fibers; including steel fibers, poly-vinyl alcohol fibers, polypropylene, glass fibers, nylon bundles, and carbon fibers have studied. Type, size, geometry, aspect ratio, volume fraction, tensile strength stiffness, surface properties and fiber matrix bond effects on the properties if concrete [14-15]. Babu et al. [16] investigated the properties of SCC and glass fiber reinforced self-compacting concrete due to the effect of using glass fiber. The behavior of stress-strain of SCC and glass fiber reinforced self-compacting concrete was studied. It is observed by adding glass fibers to SCC mix; the ultimate strength was improved. Also an improvement was noticed in ductility of SCC incorporation of glass fibers. An empirical equation is proposed to predict the stress-strain behavior of this type of concrete under compression. Barluenga et al [17] evaluated the effect of Alkali Resistant (AR) glass fibers on cracking control ability in conventional concrete and SCC. The results cleared that the types of AR-glass fiber with low volume fractions can control the cracking produced specially at early age shrinkage on both conventional concrete and SCC. A microscopic study illustrated that the cracked surface can be dispersed by using AR-glass fibers on cracking control. The same performance was noticed in the hardened state for SCC and conventional although the drying shrinkage for SCC was larger than conventional concrete. The initiation of stress corrosion cracking (SCC) due to the effect of sand blasting was examined by Kumosa et al. [18] E-glass/polymer composite materials with modified polyester, epoxy and vinyl resins were used. It has been shown; the sand blasting slightly increases the resistance of the composites to the initiation and propagation of stress corrosion cracks. The effect of recycled glass (RG) on the properties of SCC was studied by Kou et al [19]. 10%, 20% and 30% of RG was used to replace Sand River. RG was used to replace10 mm granite with 5%, 10% and 15%. Clearly that, increasing in recycled glass increases in the slump flow, blocking ratio, air content of the RG–SCC mixes. Moreover, increasing in recycled glass aggregate content decreased in the compressive strength, tensile splitting strength and static modulus of elasticity. Moreover, the resistance to chloride ion penetration increased and the drying shrinkage of the RG–SCC mixes decreased. The aim of this investigation was using glass fibers development the fresh and hardened properties of self-compacted concrete incorporated with the recycled aggregate.

2. EXPERIMENTAL PROGRAM

To achieve the aim of the research, forty seven 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). Glass fibers were used to improve the properties of RSCC. The optimum content of glass fiber used in the fresh state of RSCC was investigated. A total of 282 cubes 10×10×10 cm^3 were tested to

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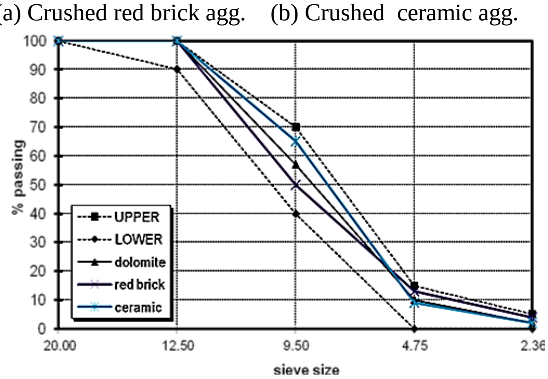
determine the compressive strength and density of the mixes at 7 and 28 days. Cylinders of 10 cm in diameter and 20 cm in length were studied to determine the splitting tensile strength of the mixes. To determine the flexural strength of mixes; 10×10 × 50 cm^3 prisms were used.

2.1. Materials

Well graded siliceous sand was used with a specific gravity of 2.65, absorption of 0.78 %, and a fineness modulus of 2.63. Coarse aggregate of crushed dolomite with maximum nominal sizes of 10 mm was used, with a specific gravity 2.65, absorption of 2% and a crushing modulus of 19%. Crushed red brick and ceramic were used as coarse aggregate. Crushed red brick with a maximum nominal size of 10 mm was used, with specific gravity 1.68 and absorption of 4%. Crushed ceramic with maximum nominal size of 10 mm was used, with specific gravity 2.7 and absorption of 1.9%. Figure (1) shows the recycled aggregate used.

(a) Crushed red brick agg. (b) Crushed ceramic agg.



(c) Grading of coarse aggregate
Figure (1) recycled materials as a coarse aggregate

Locally produced Portland cement (CEM I 42.5 N) conforming to the requirements Egyptian Standard Specifications (373/2005) was used. Imported class (F) fly ash meeting the requirements of ASTM C618 [20] with a specific gravity of 2.1 was used. The cement content was 400 kg/m3 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) was used as superplasticizer meeting the requirements of ASTM C494 (type A and F) [21]. The admixture is a brown liquid having a density of 1.18 kg/liter at room temperature. The amount of HRWR was 2.5% of the powder weight. Glass fiber with 0.025 mm diameter with aspect ratio (L/D) 1920, 960 and 480 were used.

2.2. Casting and Testing Procedures

Coarse aggregate, fine aggregate, and the cement were mixed for at least 1 minute in the dry state before water and the admixtures were added. The mixing time after slurry (water, fly ash, and HRWR) was added for (3-4) minutes to ensure full mixing of the SCC. RSCC was made using recycled aggregate with a maximum nominal size of 10 mm (red brick and ceramic) replaced by crushed dolomite. The replacement levels by weight of dolomite were 25%, 50%, 75%and 100%. Glass fiber was used to improve the properties of RSCC. The properties of RSCC and glass fiber recycled self-compacted concrete (GRSCC) were determined by different methods, which included the normal slump test, V-funnel test and J-ring test. The concrete specimens were cast and kept at the steel moulds for 24 hours. After 24 hours, they were removed from the molds and submerged in water at 20°C until. 2000 KN capacity compressive strength testing machine 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 points loading. Test specimens were designed by letter C for ceramic aggregate or R for red brick aggregated followed by the percentage of recycle, followed by the letter G denoting the Specimens of glass fiber. For examples, GC25 means that mixes with 25% crushed ceramic as a recycled coarse aggregate with glass fibers. Table [1] shows the mix proportions of RSCC.

Table 1. Proportions of recycled self-compacted concrete mix (kg/m^3).

Mix code	Cement	W/C	Sand	Dolomite	Recycled aggregate	Fly ash	BWF1
Control mix (L)	400	0.55	974	649	0	40	11
C25				487	162		
C50				324.5	324.5		
C75				162	487		
C100				0	649		
R25		0.5	1005	503	167		
R50				335	335		
R75				167	503		
R100				0	670		

The basic requirements of flow ability as specified by technical specification for SCC, [22] are satisfied for the mix (L) as a control mix. In this mix dolomite as a

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coarse aggregate was used. The slump flow diameter and flow time (T_{50cm}) were 705 mm and 2.0 sec, respectively. The v-funnel flow time was 7.86 sec. The value of blocking ratio (H_2-H_1) was 5 mm. The workability values are maintained by adding suitable quantities of materials and super-plasticizers. The fresh properties of RSCC mixes are referred to as workability. Figures (2) and (3) show the effect of percentage of recycled materials on the flow diameter and flow time (T_{50cm}). Figure (2) clears that an increase in flow diameter as percentage of recycled aggregate increases 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.

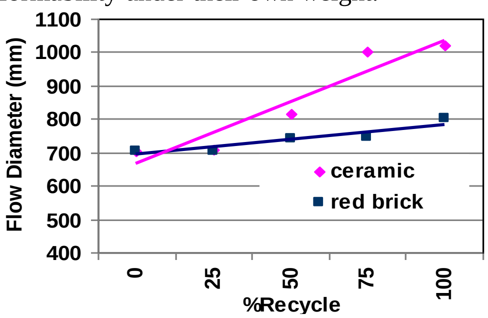

Figure (2) effect of percentage of recycled as a coarse aggregate on the flow diameter.

Figure (3) illustrated that an increase of T_{50cm} as percentage of recycled aggregate increases on both crushed red brick and crushed ceramic. 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 the concrete mix.

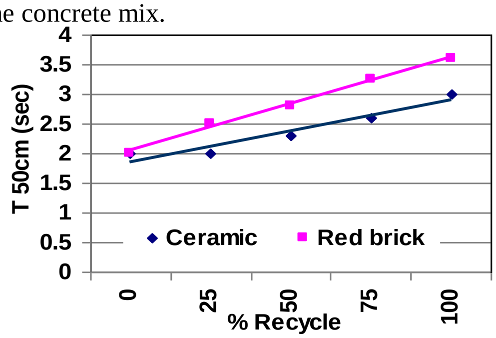

Figure (3) effect of percentage of recycled as a coarse aggregate on the flow Time.

Figure (4) presents the flowability of C25 and R25 mixes.

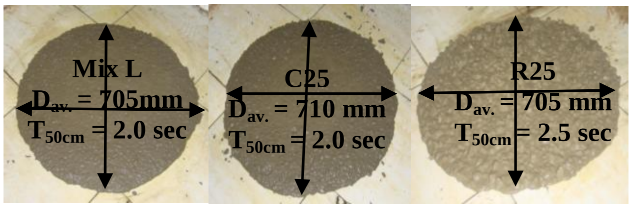

Figure (4) the flowability for different mixes

As presented in Figures (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 recycled aggregate was observed. This is supported by a previous study conducted by Cachim, (2009) and Grdic et al. (2010) [5]. This is due to the type; the manufacturing process and properties of the recycle aggregated used in the concrete mix. Figure (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 recycle. Moreover, the reduction in the compressive strength for mixes with ceramic was lower than 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 the concrete mixtures 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 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 the same percentage of recycled aggregate.

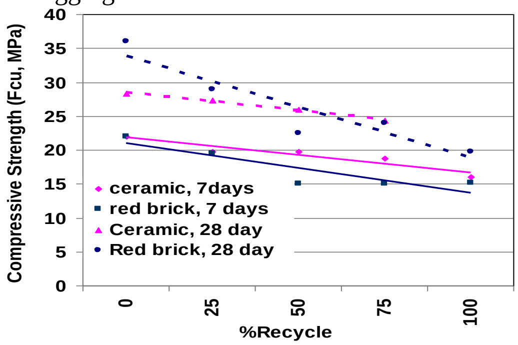

Figure (5) compressive strength for recycled self-compacting concrete.

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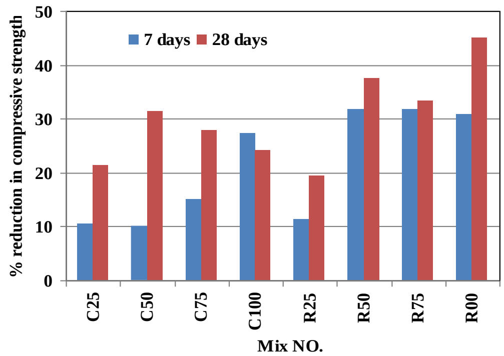

Figure (6) Reduction in compressive strength of recycled self-compacting concrete.

3. EFFECT OF GLASS FIBER ON THE PROPERTIES OF RECYCLED SELF-COMPACTED CONCRETE ON FRESH AND HARDENED STATE

At this stage glass fiber with aspect ratio 1920, 960 and 480 and volume fraction ranged from (0.0 to 0.4%) were used to improve the properties of RSCC mixes. A total of 33 GRSCC mixtures with 25% recycled aggregate were developed. Table [2] illustrates the rheological properties of fresh glass fiber recycled self-compacted concrete mixes.

Table [2] Rheological properties of fresh glass fiber recycled self-compacted concrete mixes

Mix No.	L/D	V F%	Slump test			V-funnel			J-ring test		
			$D_{av.}$ (mm)	T_{50cm} (sec)	T_f (sec)	T (sec)	T_{5min} (sec)	Velocity (m/sec)	T (sec)	$D_{av.}$ (mm)	H_2-H_1 (mm)
R25	0	0	675	2.5	6	6.07	7.07	0.1	5.2	640	8
G1R25	1920	0.02	640	2.17	5.5	8	9	0.07	4.5	570	5
G2R25		0.025	520	3	3	5.8	7.5	0.1	4	560	17
G3R25		0.05	550	3.2	3.8	6	8	0.105	3.5	540	13
G4R25		0.1	400	2.03	2.03	4.3	5.8	0.14	3	520	16
G5R25	960	0.02	604	1.6	4	8.5	9.3	0.07	6.25	550	10
G6R25		0.025	610	2	3.9	6.5	9	0.09	5	510	10
G7R25		0.05	620	2.75	3.8	7	9.5	0.09	4.5	500	8
G8R25		0.1	580	2.1	3.4	5.1	9	0.12	4	490	15
G9R25	480	0.02	647	2.45	4.65	6.5	9.54	0.09	5.5	600	8.5
G10R25		0.025	655	2.2	4.5	7.3	9.8	0.08	5.2	575	9
G11R25		0.05	695	2.5	4.8	8	8.97	0.07	5.1	560	5
G12R25		0.1	650	2.33	4.5	8.5	10	0.07	5	540	9.5
G13R25		0.2	635	2.15	4	8.7	10.4	0.07	4.7	510	12
G14R25		0.3	612	2.3	3.8	8.85	9.89	0.07	4.3	500	14.5
G15R25		0.34	600	2.45	3.2	9	10.33	0.07	4	490	15
G16R25		0.4	583	2.6	3	9.15	11	0.06	3.5	490	16
C25	0	0	665	2.6	4	6.8	8.7	0.09	4.36	625	10
G1C25	1920	0.02	635	1.16	3.27	6.9	8	0.09	4	600	8.5
G2C25		0.025	600	1.8	2.23	7.12	8.9	0.08	3.5	540	9
G3C25		0.05	500	1.9	1.9	5.3	7.5	0.11	2.8	490	13
G4C25		0.1	400	2	2	5.42	7.3	0.11	2.4	400	12
G5C25	960	0.02	720	1.5	5.25	6.79	8	0.09	4.5	625	5
G6C25		0.025	698	2	5.5	6.9	8.5	0.09	4	615	8.5
G7C25		0.05	710	2.1	5	7.12	9	0.08	3.5	600	5
G8C25		0.1	595	1.7	2.5	5.9	7.5	0.1	2.5	540	11
G9C25	480	0.02	720	1.58	3.05	7	8.5	0.09	4.5	640	8
G10C25		0.025	685	1.81	3	6.3	8.8	0.1	4.2	610	5
G11C25		0.05	770	2.5	4.5	6	9	0.1	4.8	675	9
G12C25		0.1	765	2.12	4.8	6.5	8.5	0.09	4.3	630	7
G13C25		0.13	736	2.59	5	7.13	9.5	0.08	3.8	610	8.6
G14C25		0.16	675	3.15	4.5	8.18	10	0.07	3.4	570	10.8
G15C25		0.185	600	3.75	4.5	9.3	10.6	0.06	3	530	13.2
G16C25		0.2	548	4.17	4.6	10.2	11	0.06	2.5	490	14.9

At the end of this stage the optimum volume fraction of glass fiber was assigned.

3.1 Workability for Glass Fiber Recycled Self-Compacted Concrete Mixes

Figure (7) shows the effect of glass fiber volume fraction on the flow diameter for the mixes with crushed red brick and crushed ceramic as a coarse aggregate. The slump flow diameter decrease as glass fiber volume fraction increases for GRSCC. The volume fraction for the GRSCC mixes with crushed ceramics was ranged from (0.0 to 0.2 %). As the aspect ratio decreases the flowabiltity of the GRSCC increases. Using glass fiber with aspect ratio 480 gets best fresh properties of GRSCC. The optimum volume fraction that obtained from the results was 0.05 % at aspect ratio 480 after this point the flow diameter decreases. The flow diameter for the GRSCC mixes with crushed ceramic ranged from (400 to 770 mm). In fact, a significant decrease in flow diameter has been observed beyond 0.05 % fiber volume fraction. This might be due to the effect of the amount of glass fiber as well as higher internal resistance of the glass fiber in fresh concrete mixtures. For the GRSCC mixes with crushed red brick; the volume fraction changed from (0.0 to 0.4%). The flow diameter for these mixes decrease due to glass fiber volume fraction increases. Using glass fiber with aspect ratio 480 gets best fresh properties of GRSCC. The optimum volume fraction that obtained from the results was 0.05%. The flow diameter for these mixes ranged from (400 to 695 mm). Also flow diameter decrease beyond 0.05% fiber volume fraction. It is noticed that the same optimum volume fraction for GRSCC with crushed ceramic and crushed red brick. Moreover, the flow diameter for GRSCC with crushed ceramic was higher than that of GRSCC with red brick. The reduction in flow diameter for GRSCC with crushed ceramic was lower than that of GRSCC with crushed red brick. All these noticed were due to the mechanical and physically properties of the aggregate used. The results of flow diameter meet the requirements of SCC [22].

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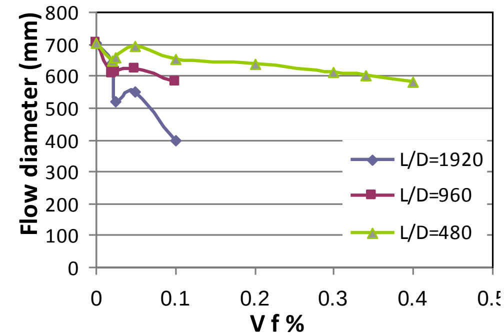

Figure (7.a) Crushed Red Brick Aggregate.

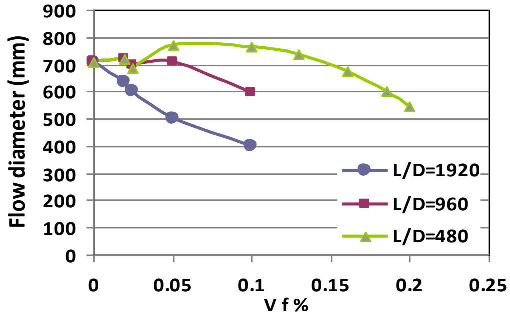

Figure (7.b) Crushed Ceramic Aggregate.
Figure (7) Effect of Glass Fiber Volume Fraction on the Flow Diameter for the Mixes.

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. Figure (8) shows the effect of glass fiber volume fraction on T_{50cm}. Increase in volume fraction increases the T_{50cm} measurement. T_{50cm} for the GRSCC mixes with crushed red brick ranged from (1.6 to 3.2 sec) for the different aspect ratio. The optimum volume fraction was 0.05 % at T_{50cm} 2.5 sec for mixes with glass fibers aspect ratio 480. The T_{50cm} for the GRSCC mixes with crushed ceramic ranged from (1.16 to 4.17 sec). The optimum volume fraction was 0.05 % at T_{50cm} equal 2.5 sec for mixes with glass fibers aspect ratio 480. It cleared that as a flow diameter decrease as flow time increases.

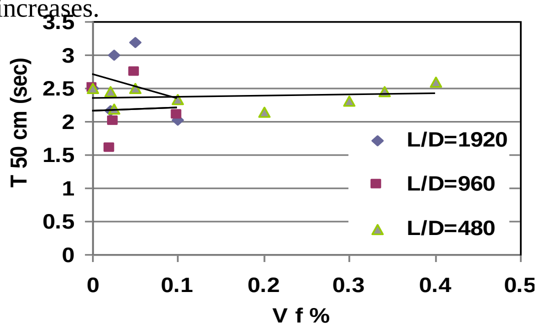

Figure (8.a) Crushed Red Brick Aggregate.

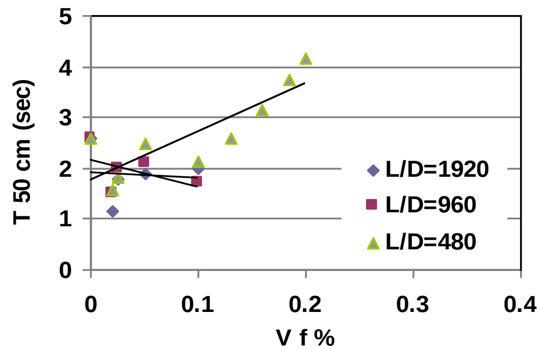

Figure (8.b) Crushed Ceramic Aggregate.
Figure (8) Effect of Glass Fiber Volume Fraction on the Flow Time for the Mixes.

The flow diameter for some GRSCC mixes was shown in Figure (9).

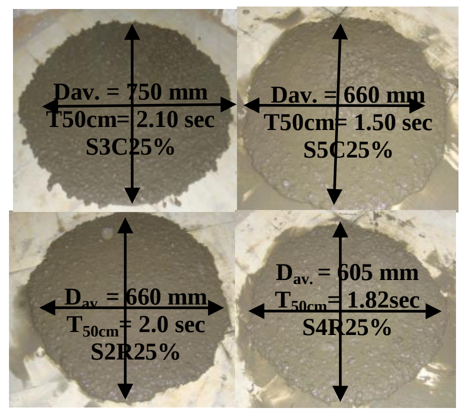

Figure (9) Flow Diameter for GRSCC Mixes.

The V-Funnel Time represents the fillingability of the concrete mixtures and measures their viscosity. Figures (10) and (11) show that an increase in the fiber volume fraction increases V-funnel time and V-funnel time at 5min. Furthermore, as the fillingability of GRSCC improved as the aspect ratio of glass fiber decreased. Clearly, glass fiber with aspect ratio 480 gets the best fresh properties. At aspect ratio 480; a significant increase in V-funnel time beyond 0.05% of fiber volume has been observed in GRSCC mixtures with crushed red brick and ceramic as a recycled aggregate, respectively. This shows the effect of the higher amounts of glass fiber in the narrow opening of the V-Funnel beyond 0.05% of the fiber volume fraction for crushed red brick and ceramic. Moreover, the trend lines in the figure show that V-funnel time for the crushed red brick is higher than that of the crushed ceramic at the same fiber volume fraction. This may be because of the

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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 (4.3 – 9.15 sec) at volume fraction ranged from (0.0 - 0.4%). For the mixes with crushed ceramic, the v-funnel time ranged from (5.3 – 10.2 sec) at volume fraction ranged from (0.0% - 0.2%) glass fiber volume fraction.

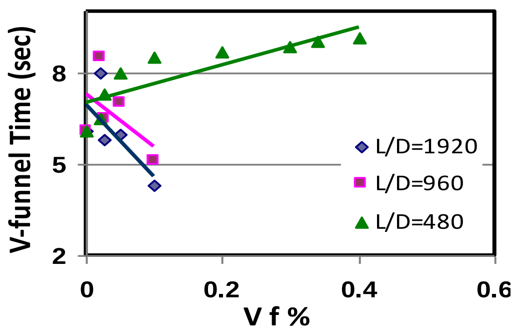

Figure (10.a) Crushed Red Brick Aggregate.

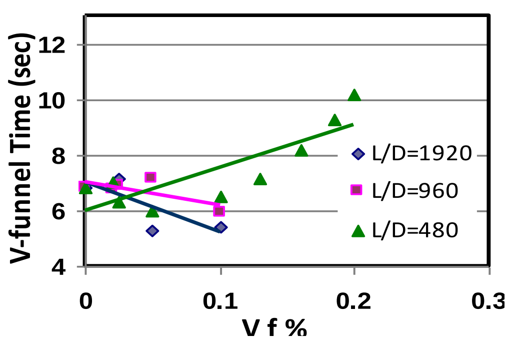

Figure (10.b) Crushed Ceramic Aggregate.
Figure (10) Effect of Glass Fiber Volume Fraction on V-Funnel Time.

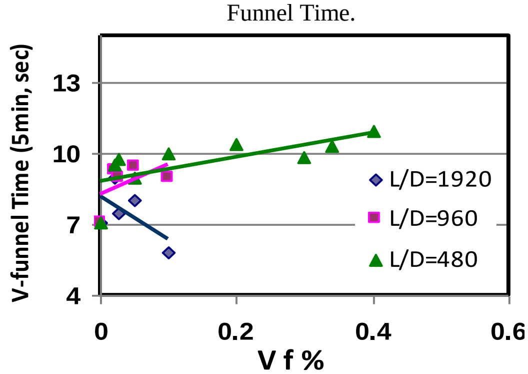

Figure (11.a) Crushed Red Brick Aggregate.

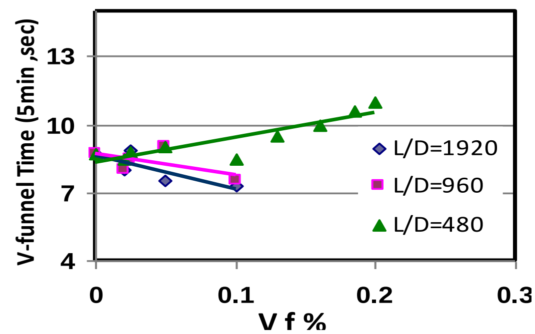

Figure (11.b) Crushed Ceramic Aggregate.
Figure (11) Effect of Steel Fiber Volume Fraction on V-Funnel Time after 5 min.

Figure (12) shows the effect of glass fiber volume fraction on the flow diameter for J-ring test. The effect of the volume fraction on the flow diameter is the same trends that noticed at the slump flow diameter. The figure illustrates that the flowability for the mixes with recycled crushed ceramic higher than that for crushed red brick. 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} for slump flow test, the T_{50cm} measurement for J-ring test gets longer with the increased fiber volume fraction for all concrete mixtures as shown in figure (13). In addition, the crushed ceramic recycled aggregate show lower T_{50cm} than the crushed red brick for the same percentage of fiber volume fraction, as expected. The H_2-H_1 for the GRSCC with crushed red brick was higher than GRSCC with the crushed ceramic mixture as shown in figures (14). From these results can be drawn that improving in flowability of GRSCC by decreasing the glass fiber aspect ratio. Also at 0.05 % volume fraction with 480 aspect ratio gets the best flowability.

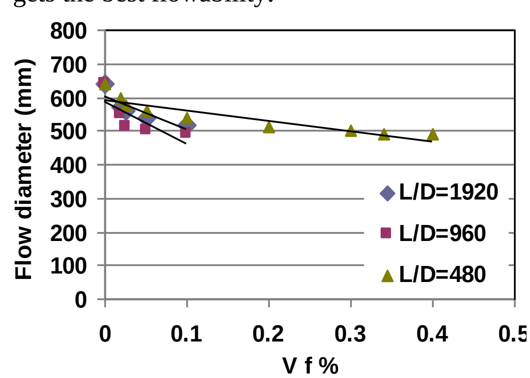

Figure (12.a) Crushed Red Brick Aggregate.

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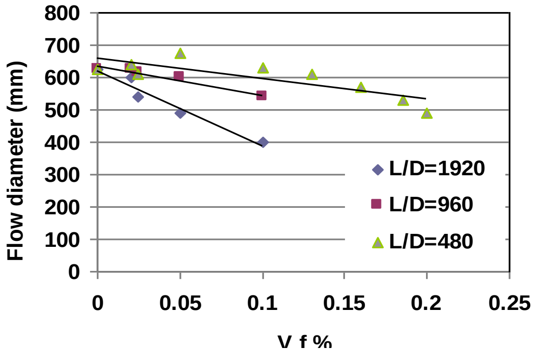

Figure (12.b) Crushed Ceramic Aggregate.
Figure (12) Effect of Glass Fiber Volume Fraction on the Flow Diameter.

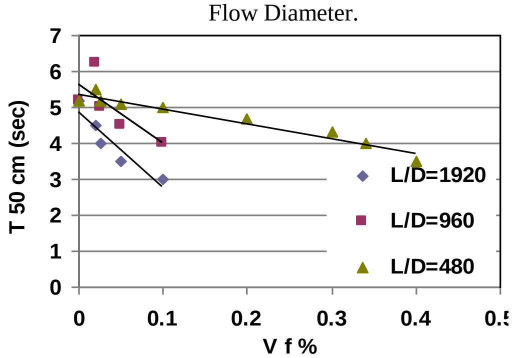

Figure (13.a) Crushed Red Brick Aggregate.

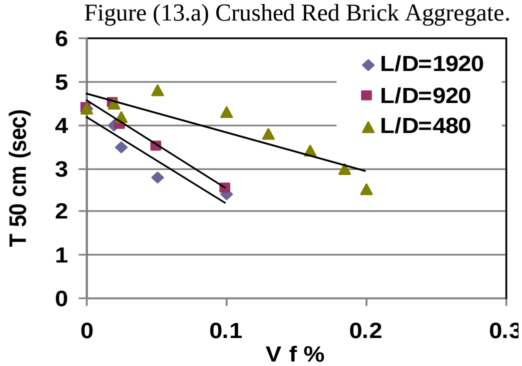

Figure (13.b) Crushed Ceramic Aggregate.
Figure (13) Effect of Glass Fiber Volume Fraction on the Flow Time.

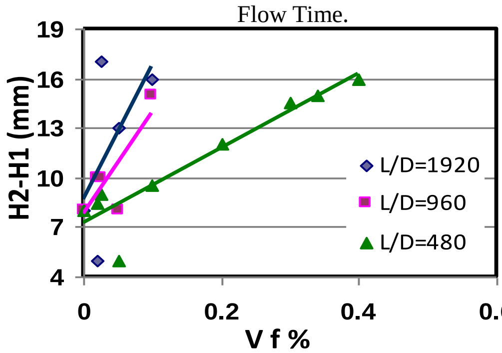

Figure (14.a) Crushed Red Brick Aggregate.

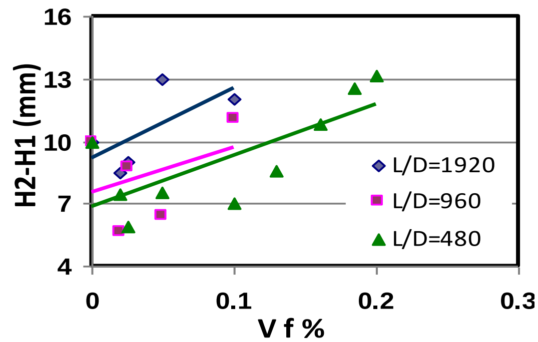

Figure (14.b) Crushed Ceramic Aggregate.
Figure (14) Effect of Glass Fiber Volume Fraction on the Blocking Ratio.

3.2 Mechanical Properties of Glass Fibers Recycled Self-Compacted Concrete Mixes

The compressive strength of mixtures with GRSCC are presented in this section. The results show that the concrete mixtures without glass fibers exhibit sudden brittle failure, while the concrete mixtures with glass fibers exhibit a ductile failure because of the energy absorbing capacity of the fibrous concrete. Figure (15) represents the 7 and 28 days compressive strength of GRSCC mixtures. 28 days compressive strength varied from (23.6 MPa to 30.6 MPa) for all different aspect ratios of glass fibers. For mixes with glass fiber at aspect ratio equal 480; 7 days compressive strength of mixtures with crushed red brick varies from 20.5 MPa to 26.8 MPa while the compressive strength varied from 25.5 MPa to 26.8 MPa for the mixes with crushed ceramic. 28 days compressive strength of mixtures with crushed red brick varies from 25.5 MPa to 29.0 MPa while varied from 27.5 MPa to 29.2 Mpa for the mixes with crushed ceramic. An improving in the compressive strength for the mixes with glass fibers compared to without glass fibers by 25 % and 24 % for the mixes with crushed ceramic and red brick, respectively. For mixes with glass fiber at aspect ratio equal 960; 7 days compressive strength of mixtures with crushed red brick varies from 22.5 MPa to 26 MPa while those with recycled ceramic are between 25.0 MPa to 27 MPa. 28 days compressive strength of mixtures with crushed red brick varies from 24.70 Mpa to 29 MPa while those with crushed ceramic are between 28 MPa to 31 MPa. An improving in the compressive strength for the mixes with glass fibers compared to without glass fibers by 31% and 21.8% for the mixes with crushed ceramic and crushed red brick respectively. For mixes with glass fiber at aspect ratio equal 1920; 7 days compressive

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strength of mixtures with crushed red brick varies from 21.5 MPa to 24 MPa while those with recycled ceramic are between 26 MPa to26.8 MPa. 28 days compressive strength of mixtures with crushed red brick varies from 23.6 MPa to 28.5 MPa while those with crushed ceramic are between 30 MPa to 31 MPa. An improving in the compressive strength for the mixes with glass fibers compared to without glass fibers by 33.6% and 19% for the mixes with crushed ceramic and crushed red brick respectively. It is noticed that the compressive strength for the mixtures with crushed ceramics more than that with crushed red brick by 1%, 9.2% and 14.6% at 480, 960, 1920 aspect ratios respectively.

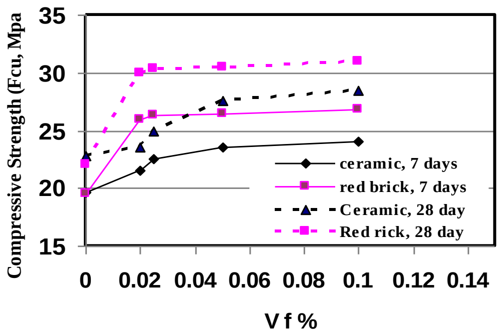

Figure (15.a) Aspect Ratio = 1920.

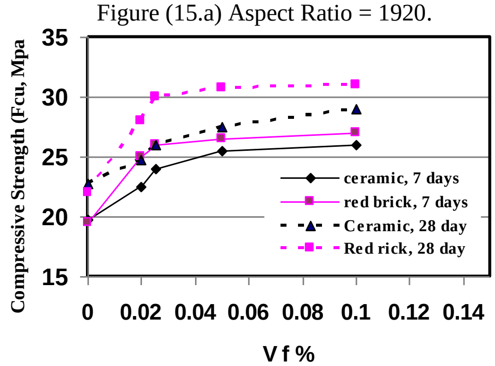

Figure (15.b) Aspect Ratio = 960.

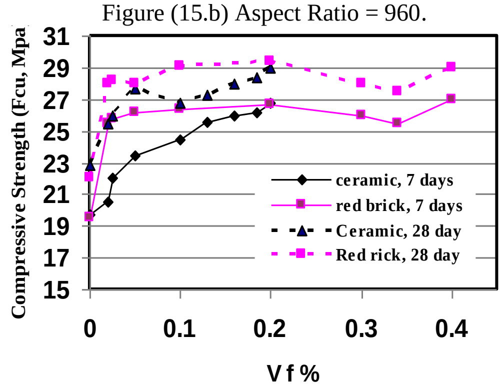

Figure (15.c) Aspect Ratio = 480.
Figure (15) Effect of Glass Volume Fraction on the Compressive Strength.

Figures (16 and 17) show the other mechanical properties (tensile strength, flexural strength and density). The same trend was noticed for the other mechanical properties. The mixtures with crushed ceramics having the tensile strength more than mixtures with crushed red brick by 3.7% was recorded. The mixtures with crushed ceramics the flexural strength more than mixtures with crushed red brick by 0.7% was observed.

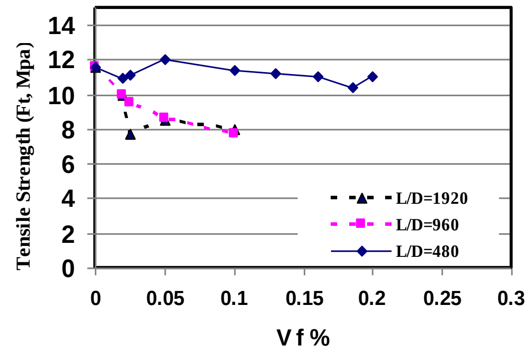

Figure (16.a) Crushed Ceramic Aggregate.

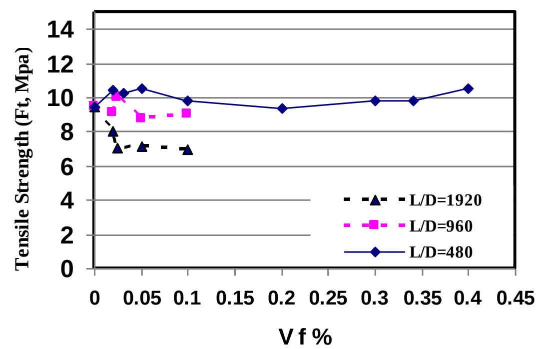

Figure (16.b) Crushed Red Brick Aggregate.
Figure (16) Effect of Glass Volume Fraction on the Tensile Strength for the Mixes with Crushed Ceramic Aggregate.

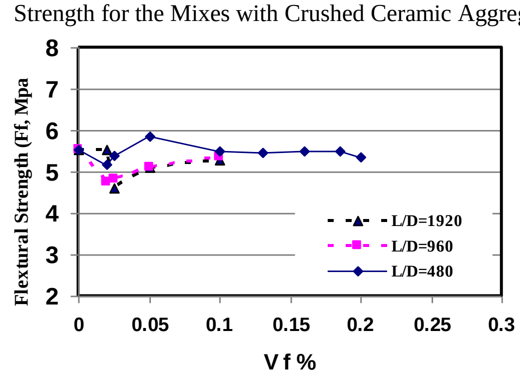

Figure (17.a) Crushed Ceramic Aggregate

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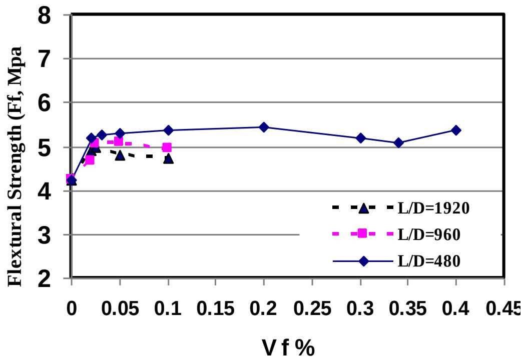

Figure (17.b) Crushed Red Brick Aggregate.
Figure (17) Effect of Glass Volume Fraction on the Flextural Strength for the Mixes with Crushed Ceramic Aggregate.

At different percentages of recycled material, fresh properties for GRSCC were evaluated at the optimum volume fraction for glass fibers with aspect ratio 480. The different percentages of recycled aggregated were (25%, 50%, 75% and 100%) as a replacement of coarse aggregate (dolomite). The optimum volume fraction for glass fiber was 0.05% for crushed red brick and crushed ceramic respectively. Figures (18 and 19) show the relationship between the flow diameter and the T50cm for slump test with the percentage of recycling material. Figure (18) represents that for GRSCC mixes; as the percentage of recycled aggregate increases as the flow diameter decreases while the opposite behavior is noticed for the RSCC.

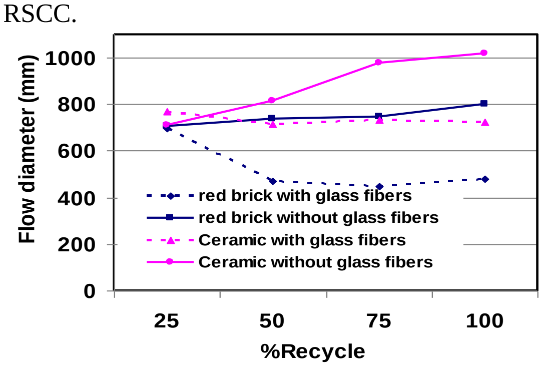

Figure (18) Flow Diameter and % Recycling Relationship for Slump Test.

Also the flow diameter for the mixes without glass fiber was higher than that with glass fiber. This duo to the amount of glass fibers as well as higher internal resistance of the glass fibers in fresh concrete mixtures. T_{50cm} for these mixes was illustrated in figure (19). Clearly, as the percentage of recycled aggregate increases as the T_{50cm} decreases for the GRSCC and increases for the RSCC. Moreover, the T_{50cm} for the mixes with glass fibers was lower than that without glass fibers. From these results, the flow diameter for mixes GRSCC with crushed ceramics meet the requirements of SCC [22] while the opposite for the GRSCC with red brick except the mixes with 25% replacement of coarse aggregate.

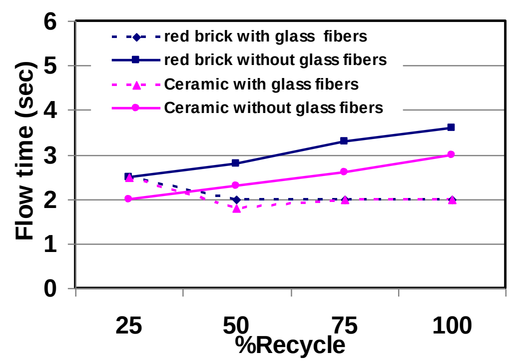

Figure (19) Flow Time and % Recycling Relationship for Slump Test.

Figures (20) and (21) show the relationship between the flow diameter and the H_2-H_1 with the percentage of recycled aggregate for J-ring test. The same trend was observed as found from slump test.

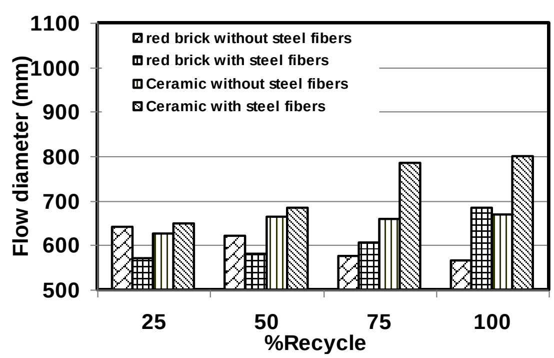

Figure (20) Flow Diameter and % Recycling Relationship for J-Ring Test.

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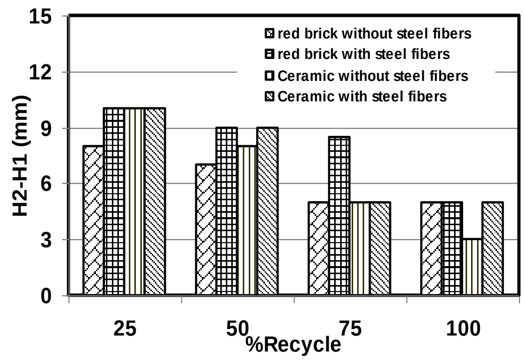

Figure (21) Flow Time and % Recycling Relationship for J-Ring Test.

Figure (22) presents the compressive strength for the GRSCC 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 figure (23).

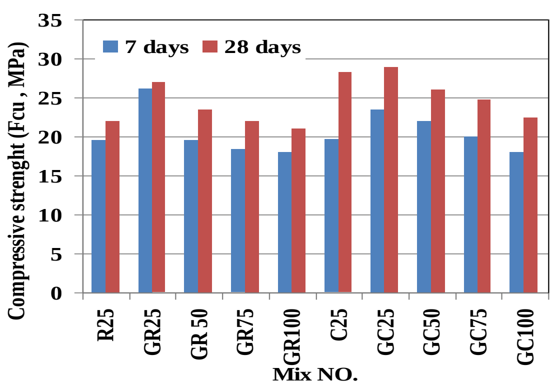

Figure (22) Compressive Strength of GRSCC

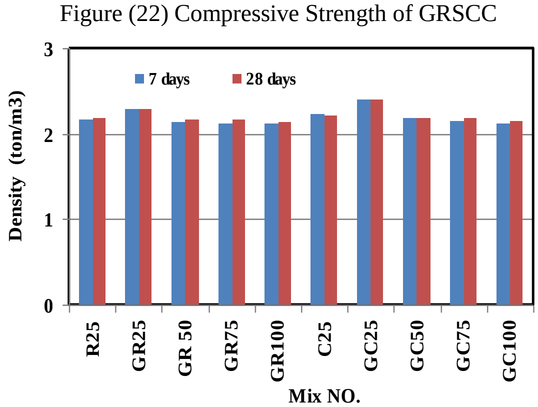

Figure (23) Density of GRSCC.

6. CONCLUSIONS

Based on the test results, the following conclusions can be drawn:

1. The concrete mixtures with crushed ceramic as a recycled aggregate having glass fiber volume fraction more than 0.025%, 0.05% and 0.19% show no passing ability at 1920, 960 and 480 aspect ratio respectively. These mixtures up to 0.025%, 0.05% and 0.19% of glass fibers volume fractions at 1920, 960 and 480 aspect ratio respectively behave as GRSCC.

2. The concrete mixtures with crushed red brick as a recycled aggregate having glass fiber volume fraction more than 0.02%, 0.05% and 0.34% show no passing ability at 1920, 960 and 480 aspect ratio respectively. These mixtures up to 0.02%, 0.05% and 0.34% of glass fibers volume fractions at 1920, 960 and 480 aspect ratio respectively behave as GRSCC.

3. Using glass fiber with the aspect ratio equal 480 get the best requirements of SCC for GRSCC mixes.

4. The optimum content for glass fiber volume fraction was 0.05% for the GRSCC with crushed ceramic and crushed red brick as a recycled aggregate respectively.

5. As the percentage of recycled aggregate increases as the flow diameter decreases for the GRSCC mixes.

6. GRSCC with crushed ceramic, compressive strength increased 25%, 31% and 33.6% at 480, 960 and 1920 aspect ratios, respectively compared to RSCC mixes without fibers.

7. GRSCC with crushed red brick, compressive strength increased 24%, 21.8% and 19% at 480, 960 and 1920 aspect ratios, respectively compared to RSCC mixes without fibers.

8. GRSCC mixes with crushed ceramic yields to improve in the compressive strength by 1%, 9.2% and 14.6% at 480, 960, 1920 aspect ratios respectively compared to GRSCC mixes with crushed red brick as a recycled aggregate.

9. GRSCC mixes with crushed ceramic have the tensile and the flexural strength more than mixtures with crushed red brick by 3.7% and 0.7% respectively.

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