Effect of Recycled Aggregate Concrete and Steel Fibers on the Fresh Properties of Self-Compacting Concrete

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Abstract. Globally, the amount of solid waste is constantly increasing, and its disposal is one of the critical issues in recent research studies. Concrete waste includes the rubble of demolished buildings, whether old buildings or those that have been subjected to earthquakes, etc. This research project aims to improve sustainability in the construction industry by recycling and reusing coarse aggregate that was previously used in concrete buildings. The objective is to utilize this recycled material to produce self-compacting concrete (SCC) and assess its performance in its fresh state. By finding new ways to repurpose materials that would otherwise go to waste, this research contributes to developing environmentally friendly practices and reducing the industry's carbon footprint. Furthermore, evaluating the performance of the recycled coarse aggregate in SCC will provide insights into its potential for future use in construction projects, which could ultimately lead to cost savings and improved efficiency in the industry. Recycled coarse aggregate (RCA) was used as a substitute for the natural coarse aggregate (NCA) with volume ratios of 0, 25, 50, 75, and 100%, and steel fibers (SF) were added to the concrete with different volumes ratios (0, 0.5, and 1 %). Workability tests such as slump flow, V-funnel, and L-box tests were carried out for the mixtures in their fresh state. In general, the results of the experimental work showed that the fresh properties indicated that almost all SCC mixtures were within the specified range, as stated in EFNARC requirements.

Keywords: solid waste; concrete; self-compacting concrete; recycled coarse aggregate; workability; steel fibers.

1. INTRODUCTION

Concrete is the basic building material used more than any other material in the world to construct buildings and infrastructures [1, 2]. Because of the growing population, the demand for unconventional concrete with certain specifications, particularly those used in the construction of tall buildings, has increased in recent years, the demand for unconventional concrete with certain specifications, particularly those used in the construction of tall buildings, has increased in recent years [3]. As a solution to the phenomenon of concrete segregation when concrete is thrown from high places or its easy flow in places dense with reinforcing steel, the so-called self-compacting concrete (SCC) has been produced, which is concrete capable of flowing smoothly under the influence of its weight and is also capable of able to fill the molds even in the heavy reinforcement's regions, while maintaining homogeneity and perfectly [4–6]. In parallel with the high production of concrete, the concrete production process has raised environmental concerns, as it can produce thousands of tons of solid waste annually and worldwide [7]. This represents a real problem and requires a more sustainable strategy to preserve the environment by conserving natural resources and reducing the amount of waste that constitutes an additional burden in how to dispose of it. Since aggregate is one of the most important natural resources, the increased demand for concrete construction puts pressure on the environment and the limited and accessible resources. As a result, the need has emerged to focus on the production of sustainable resources that contribute to the production of concrete and, at the same time, be environmentally friendly, with a focus on non-traditional and new applications used in the recycling and use of materials [8].

Kou and Poon [9] studied the properties of SCC made from recycled aggregates, where this type of concrete showed good performance. Different proportions of recycled fine and coarse aggregates were used, and recycled fine aggregate was the most effective. The study also proved that the use of fly ash from industrial facilities improved concrete properties. Grdic [10] evaluated different replacement ratios of coarse aggregate with recycled aggregate to produce self-compacting concrete. The results showed that the recycled coarse aggregate can be successfully used instead of the natural coarse aggregate. Tang [11] and Pereira-De-Oliveira [12] used recycled coarse aggregate (RCA) to improve the properties of SCC. The results showed that RCA can be substituted for natural coarse aggregate up to 100% without affecting the fresh properties of concrete. Sharubim [13] used RCA as an alternative to natural coarse aggregate (NCA) in SCC. They observed that RCA improves the flow ability of

SCC without altering its basic properties. Nili [14] proved that adding steel fibers to SCC contributes to improving the strength properties despite its negative impact on its fresh properties. The results of the study conducted by Abed [15] showed that recycled concrete aggregate (RCA) does not have a negative effect on the new properties of self-compacting high-strength concrete (SCHSC) and that the use of RCA can improve the mechanical properties of concrete that containing recycled aggregate. Kapoor [16] used RCA in the SCC mix, in addition to the addition of fly ash (FA). The study found that when natural aggregates are replaced with RCA, the workability of SCC mixtures will decrease. However, this paper, a part of a study, investigated the effect of combined steel fibers and RCA on the fresh and hardened properties of SCC. This study aims to investigate the effect of steel fibers and RCA on the fresh properties of SCC.

2. EXPERIMENTAL PROGRAM

A total of fifteen SCC mixtures were prepared as follows: five coarse aggregate replacement ratios of (0%, 25%, 50%, 75%, and 100%) and three steel fiber (SF) percentages of (0%, 0.5%, and 1%). Self-compacting concrete tests were conducted for concrete in its fresh state.

2.1 Materials Characteristics

All concrete mixtures were prepared to utilize Ordinary Portland Cement (ASTM type I) with a fineness of 295 m^2/kg and a specific gravity of 3.15. Silica fume (SF) and fly ash (FA) (type F) were used in the concrete mixtures as binder additives to satisfy the SCC requirements. The chemical compositions of cement, silica fume, and fly ash were inserted in Table 1.

Table 1: Chemical composition and specific gravity of cement, silica fume, and fly ash.

Oxide (%)	Cement	Silica fume	Fly ash
SiO_2	19.11	93.2	55.67
Fe_2O_3	3.37	1.5	12.96
CaO	66.26	0.4	5.11
Al_2O_3	6.42	0.7	20.73
MgO	1.45	0.1	2.65
SO_3	2.31	0.1	0.34
Na_2O+ K_2O	1.08	1.4	2.54
Specific gravity	3.15	2.2	2.10

The natural fine aggregates (NFA) and the natural coarse aggregates (NCA) used in all mixtures were locally available (from the same source) that are river aggregates with a specific gravity of 2.65 and 2.60, have water absorptions of 3.80% and 1.52%, respectively. The maximum coarse aggregate size was 11mm. The physical properties and sieve analysis for fine and coarse aggregate were listed in Tables 2 and 3. On the other hand, the recycled coarse aggregate (RCA) was produced by the residual concrete block, and locally available from concrete block factories was collected. A vibrating sieve was used to obtain particle sizes greater than 4.75 mm. The recycled aggregate has a specific gravity of 2.52, water absorptions of 5.0%, and was used in different percentages to replace coarse aggregate. The physical properties and sieve analysis of recycled coarse aggregate are presented in Table 3.

Table 2: Sieve analysis of natural fine aggregate (NFA).

Sieve Size (mm)	Percentage passing (%)	ASTM C136-06 limits (%)
4.75	100	95-100
2.36	92	80-100
1.18	79	50-85
0.6	45	25-60
0.3	23	10-30
0.15	4	0-10

Table 3: Sieve analysis of NCA and RCA.

Sieve Size (mm)	Percentage passing (%)		ASTM C136-06 limits (%)
	NCA	RCA	
12	100	100	90-100
9.5	61	46	40-70
4.75	14	11	0-15
Pan	0	0	0

Steel fibers (SF) have produced fiber-reinforced self-compacting concrete (FR-SCC). Micro-corrugated steel fibers with an aspect ratio of 65 were used and taken into account, adding different proportions and affecting the fresh and hardened properties of the FR-SCC. The properties of the SF utilized in the present study are shown in

Table 4. To obtain self-compacting concrete conforming to the specifications, a super-plasticizer (SP) with a 1.5% percentage was added to increase the flow ability of the concrete mixtures.

Table 4**:** Properties of steel fiber (SF) used in the present study.

Steel Fibers	
Material	Low steel wire, copper-coated
Diameter	0.2 mm
Length	12-14 mm
Tensile strength	≥2850 MPa
Feature	Excellent tensile, bending, and shearing strength, resistance against cracking, impact, and fatigue

2.2 Mix Proportions

The preparations of SCC differ from those of conventional concrete due to the difference in placing and filling. To obtain the desired properties of SCC, it is required to fulfill three essential criteria, namely the passing and the filling ability without using vibration as well as segregation resistance. Hence, basic experiments such as slump flow, V-funnel, and L-box are performed to measure the fresh properties of the concrete used. In this study, these experiments are conducted in accordance with BS EN 12350-part 9-11 or ASTM C. Therefore, several mixing ratios were tested to obtain self-compacting concrete that conforms to the specifications with target strength up to 40 MPa with an age of 7 days. This mixture was dependent on a reference mixture. Then, the replacement proportions of the natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) were (0, 25, 50, 75, and 100%). Considering the addition of three different percentages of steel fibers (0, 0.5, and 1.0%) to each concrete mixture, as indicated in Table 5.

Table 5: Mix design proportion in unit kg/m^3.

Mix Code*	**OPC**	**FA**	**SC**	**Water**	**w/c**	**w/b**	**NFA**	**NCA**	**RCA**	**SP**
RC00SF#	350	100	50	200	0.57	0.4	730	900	0	1.5%
RC25SF#								675	230	
RC50SF#								450	460	
RC75SF#								225	654	
RC100SF#								0	873	

* # means each mix contains three percentages of SF (0, 0.5, 1.0%).

2.3 Mixture Preparation and Casting

According to the mix preparation given in Table 5, the quantities of materials required for one batch were calculated. Fine aggregate and coarse aggregate with steel fibers were first mixed for two minutes in a concrete mixer with the addition of about 20% of the mixture water. Then, cement, fly ash, and silica fume binder materials were added with 60% of the water mixture. Then the remaining water was mixed with the super-plasticizer and added to the mixture. To ensure that the mixture is homogeneous and that the fibers do not clump, the mixture is rotated for 4–5 minutes. After the mixing procedure is completed, the required experiments of the mixture in its fresh state are performed to determine the fresh properties of the SCC mixture.

2.4 Testing Procedures of Fresh Properties

The fresh properties of the present study mixtures were measured using slump flow, V-funnel, and L-box tests, as shown in Figures 1 and 2. The test results for the fresh properties of these mixtures are listed in Table 6. In general, the Slump flow and L-box test results for all mixtures were within the range recommended by EFNARC [2]. To some extent, the flow results of the SCC's V-funnel were within the mentioned specification's limits, except for some mixtures that exceeded the EFNARC limits because they contained steel fibers. The reason for this may be attributed to the fact that the proposed EFNARC limits are for normal SCC. In general, and as expected, the presence of fibers had a negative effect on the workability and thus increased flow time as well as slow flow of concrete.

3. RESULTS AND DISCUSSION

The experimental results reached in this study will be reviewed, and the fresh properties of SCC mixtures will be discussed. The SCC mixtures should satisfy the requirements of the European Union of National Associations Representing Concrete (EFNARC) [2]. After many attempts to prepare SCC mixes by finding tests for fresh concrete, such as measuring slump flow diameter, slump flow time, V-funnel time, and L-box. According to EFNARC requirements, the SCC must meet workability criteria. The slump flow diameter should be approximately 550 to 800 mm, and the slump flow time T500 should be between 2 and 5 seconds. While the flow time through the V-funnel must be less than or equal to 10 seconds, and the L-box ratio (h_2/h_1) must be greater than or equal to 0.75 [3]. As shown in Table 5, the slump flow diameter of all mixtures in the fresh state ranged between 580 and 740 mm. In most tests, the time to achieve a diameter of 500 mm (T500) is less than 5 seconds. The time of the V-funnel flow is between 4 and 10 seconds, which is identical to the EFNARC limitations. Finally, the ratios between height at the beginning and end of the flow in the L-box test ranged between 0.80 and 1.0. In general, as shown in Table 6, the obtained results conform to the EFNARC limitations.

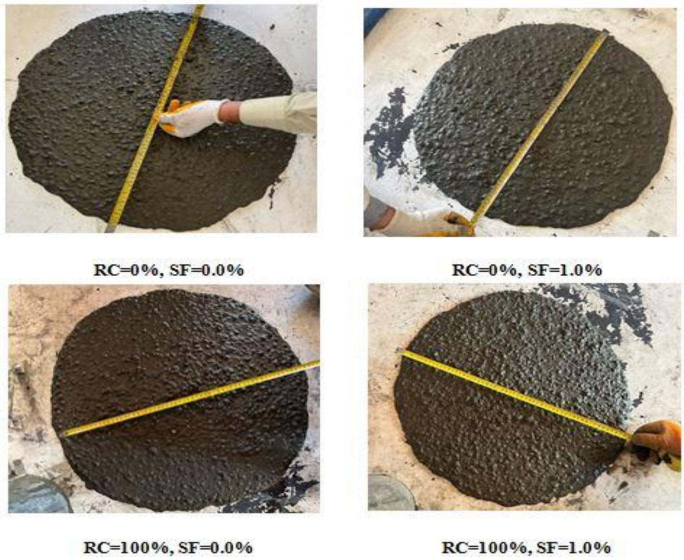

Figure 1: Effect of RCA% and SF% on the slump flow shapes of different mixtures.

Figure 2: V-funnel and L-box experiments of study mixtures.

Table 6: The fresh properties result of FR-SCC mixtures used.

SF%	RCA%	Mix code	Filling ability			Passing ability
			T50 slump (sec.)	Slump (mm)	V-funnel (sec.)	L-box
0.00%	0%	RC00SF00	1.80	740	3.83	0.94
	25%	RC25SF00	2.83	690	5.33	0.90
	50%	RC50SF00	3.73	675	9.65	0.86
	75%	RC75SF00	2.17	685	6.50	0.89
	100%	RC100SF00	3.06	590	9.08	0.91
0.50%	0%	RC00SF05	2.18	720	4.39	0.92
	25%	RC25SF05	3.03	680	6.13	0.88
	50%	RC50SF05	4.75	670	11.1	0.83
	75%	RC75SF05	2.79	660	7.71	0.86
	100%	RC100SF05	3.42	595	9.48	0.89
1.00%	0%	RC00SF10	3.31	700	4.60	0.88
	25%	RC25SF10	3.65	630	7.56	0.84
	50%	RC50SF10	5.40	610	12.75	0.81
	75%	RC75SF10	3.51	585	9.88	0.85
	100%	RC100SF10	3.76	625	10.20	0.87

3.1 Effect of Recycle Coarse Aggregate (RCA)

In general, the recycled coarse aggregate had a clear effect on the fresh properties of SCC. This effect varied with the different replacement proportions of this aggregate with the natural coarse aggregate. To some extent, the values of the fresh concrete tests for all replacement ratios were within the limits of EFNRAC. There was a significant decrease in the values of the slump flow diameter as an increase in the percentage of replacing normal aggregate with recycled aggregate. As can be seen, the flow diameter decreased from 740 to 580 when all the normal aggregate was replaced with recycled aggregate in the concrete mixture, as shown in Table 6 and Figure 3. On the other hand, the slump flow time (T500) ranged from 2 to 6 seconds for all concrete mixtures, and these values are within the EFNARC limitation. As shown in Figure 4, it was noted that the highest flow time was at a 50% replacement rate for all steel fiber ratios. The reason might be due to the increased porosity of the mixture and, thus, increased water absorption, which negatively affects the workability of the concrete mixture [16].

On the other hand, the V-funnel flow time was less than 10 seconds for all concrete mixes, which is within the range of acceptance according to EFNARC specifications and guidelines. As shown in Figure 5, the flow time increased at a 50% replacement ratio, which can be attributed to the same reason above. In the L-box test, the percentage (h_2/h_1) ranged between 0.81 and 1 for all concrete mixtures, and it conforms to the specifications and guidelines of EFNARC. It is noted from Figure 6 that the L-box SCC flow rate recorded the lowest values when replacing 50% of the normal aggregate with recycled aggregate and for all proportions of steel fibers. The reason for this can be attributed to the reduction in coherence between the granules of the coarse aggregate, which contributes to slowing down the flow of the concrete mixture as well as its agglomeration at the L-box opening, which leads to an increase in the difference between the height values (h_1, h_2).

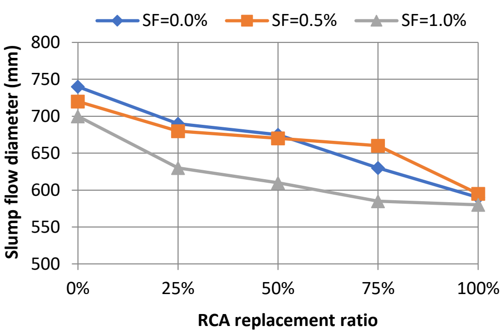

Figure 3: Effect of RCA on slump flow diameter.

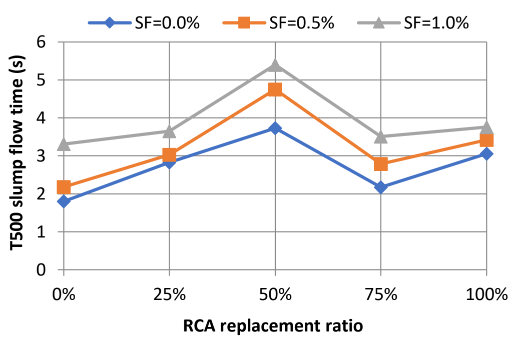

Figure 4: Effect of RCA on slump flow time.

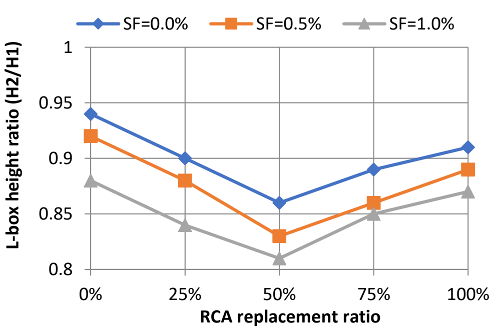

Figure 5: Effect of RCA on V-funnel flow time**.**

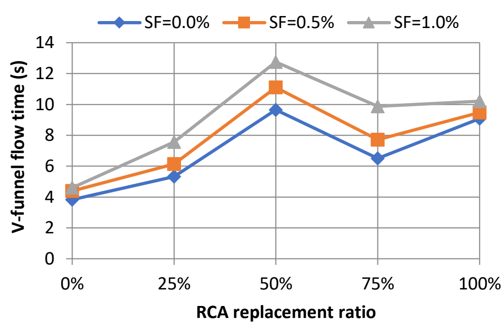

Figure 6: Effect of RCA on L-box ratio.

3.2 Effect of Steel Fibers

In general, the results showed that when the percentage of SF is increased, this will negatively affect the homogeneity of the concrete mixture, as reported by other researchers [17, 18]. Table 6 and Figure 7 represent the effect of using steel fiber (SF) in three different proportions, 0%, 0.5%, and 1%, on the fresh properties of SCC. As shown in Figure 8, the slump flow time (T500) increased, as well as the flow diameter decreased as the percentage of steel fibers increased and for all coarse aggregate replacement ratios. As shown in Figure 9, the time taken for concrete to flow from the V-funnel increases as the SF percentage increases, and this is probably due to the contribution of steel fibers to the heterogeneity of the mixture and, thus, the decrease in the bonding between the components of the concrete mixture. Figure 10 shows that the ratios (h_2 / h_1) also decreased with the increase in the SF ratios, as the steel fibers contribute to the agglomeration of the concrete and it's non-flowing, which helps in increase the difference between the level of concrete at the beginning and end of the L-box.

Overall, the addition of steel fibers to the concrete mixture had a negative effect on the fresh properties of SCC [19]. It is noted that the steel fibers help the agglomeration of the concrete mixture, which reduces its flow and makes it flow more clearly. An increase in this percentage may contribute to the non-coherence of the components of the concrete mixture and the non-fulfillment of the requirements of EFNARC.

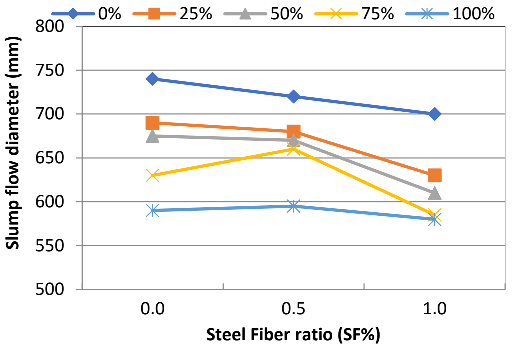

Figure 7. Effect of SF% on slump flow diameter.

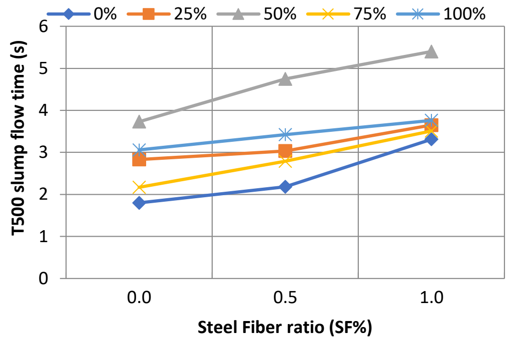

Figure 8. Effect of SF% on slump flow time.

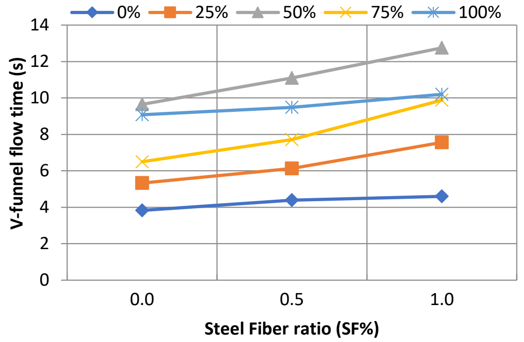

Figure 9: V-funnel flow time vs. steel fiber ratio.

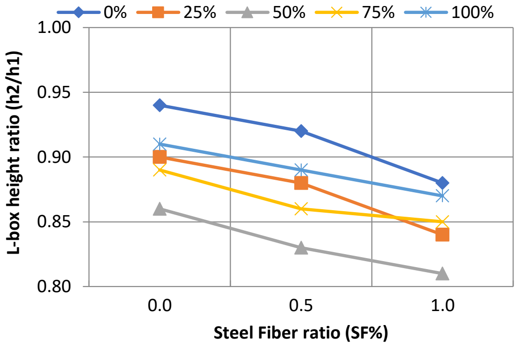

Figure 10: L-box height ratio vs. steel fiber ratio.

4. CONCLUSIONS

This research was conducted to study the effect of replacing natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) and the interaction of steel fiber addition (SF) on the fresh properties of SCC. The following conclusions were drawn from the results, and the fresh properties were discussed:

- The effect of RCA was negative on the properties of concrete in its fresh state, and this may be due to the high roughness of the surface as well as the high water absorption of RCA, which negatively affected the workability of concrete.
- In general, replacing the natural aggregate with recycled aggregate had a negative effect on the flowability of concrete, as the flow time of the SCC mixture increased, and the flow diameter decreased with increasing replacement rates. The reason could be the large porosity of RCA, which can absorb more water.
- V-funnel flow time was within the acceptance range per EFNARC specifications and guidelines, except for 50% RCA. This may be due to RCA's inconsistent and rough surface, which increases the flow time of suppressing V in SCC with increasing RCA.
- To an extent, the L-box flow is decreased by increasing RCA, indicating low possibility. This contributed to reducing the flow of fresh concrete from the mouth of the box. The reason may be attributed to the surface's roughness and the RCA's angular shape, which result in reduced mixture flow.
- The inclusion of steel fibers had a negative impact on the fresh properties of the SCC as a result of its shape, which contributes to a certain extent to isolating the concrete as well as reducing its flow.

REFERENCES

[1] Amran M, Huang S-S, Onaizi AM, Makul N, Hakim S. Abdelgader, Togay Ozbakkaloglu. Recent trends in ultra-high performance concrete (UHPC): Current status, challenges, and future prospects. Constr Build Mater [Internet]. 2022;352(1):129029.
Available from: https://www.sciencedirect.com/science/article/abs/pii/S0950061822026848

[2] Efnarc. Specification and Guidelines for the use of specialist products for Mechanised Tunnelling (TBM) in Soft Ground and Hard Rock. 2005;44(1):1–45.

[3] Aslani F, Hou L, Nejadi S, Sun J, Abbasi S. Experimental analysis of fiber-reinforced recycled aggregate self-compacting concrete using waste recycled concrete aggregates, polypropylene, and steel fibers. Struct Concr. 2019;20(5):1670–83.

[4] Bester N. Concrete for high-rise buildings : Performance requirements, mix design and construction considerations design and construction considerations. Struct Concr Prop Pract. 2013.

[5] Rafat Siddique, Soheil Jahandari. Self-Compacting Concrete: Materials, Properties, and Applications. Nucl. Phys. 2019; 13(1): 104–116.

[6] Abdulhaleem K. Mechanical Behavior of Self-Compacting Fiber Reinforced Concrete at Elevated Temperatures. Ph.D. Thesis. 2018.

[7] Huang TY, Chuieh PT. Life Cycle Assessment of Reusing Fly Ash from Municipal Solid Waste Incineration. Procedia Eng. 2015;118(1): 984–91.

[8] Aslani F, Ma G, Yim Wan DL, Muselin G. Development of high-performance self-compacting concrete using waste recycled concrete aggregates and rubber granules. J Clean Prod [Internet]. 2018;182(1):553–66. Available from: https://doi.org/10.1016/j.jclepro.2018.02.074

[9] Kou SC, Poon CS. Properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates. Cem Concr Compos [Internet]. 2009;31(9):622–7. Available from: http://dx.doi.org/10.1016/j.cemconcomp.2009.06.005

[10] Grdic ZJ, Toplicic-Curcic GA, Despotovic IM, Ristic NS. Properties of self-compacting concrete prepared with coarse recycled concrete aggregate. Constr Build Mater [Internet]. 2010;24(7):1129–33. Available from: http://dx.doi.org/10.1016/j.conbuildmat.2009.12.029

[11] Tang W. Fresh properties of self-compacting concrete with coarse recycled aggregate. Adv Mater Res. 2013;602–604:938–42.

[12] Pereira-De-Oliveira LA, Nepomuceno MCS, Castro-Gomes JP, Vila MFC. Permeability properties of self-Compacting concrete with coarse recycled aggregates. Constr Build Mater [Internet]. 2014;51(1):113–20. Available from: http://dx.doi.org/10.1016/j.conbuildmat.2013.10.061

[13] Sharobim K, Hassan H, Ragheb S. Mechanical Properties of Self Compacting Recycled Aggregate Concrete. Port-Said Eng Res J. 2017;21(2):78–87.

[14] Nili M, Sasanipour H, Aslani F. The effect of fine and coarse recycled aggregates on fresh and mechanical properties of self-compacting concrete. Materials (Basel). 2019;12(7).

[15] Abed M, Nemes R, Tayeh BA. Properties of self-compacting high-strength concrete containing multiple use of recycled aggregate. J King Saud Univ - Eng Sci [Internet]. 2020;32(2):108–14. Available from: https://doi.org/10.1016/j.jksues.2018.12.002

[16] Kapoor K, Singh SP, Singh B, Singh P. Effect of recycled aggregates on fresh and hardened properties of self compacting concrete. Mater Today Proc [Internet]. 2020;32(1):600–7. Available from: https://doi.org/10.1016/j.matpr.2020.02.753

[17] Ahmad J, González-Lezcano RA, Majdi A, Ben Kahla N, Deifalla AF, El-Shorbagy MA. Glass Fibers Reinforced Concrete: Overview on Mechanical, Durability and Microstructure Analysis. Materials (Basel). 2022;15(15):1–23.

[18] Alrawashdeh A, Eren O. Mechanical and physical characterization of steel fibre reinforced self-compacting concrete: Different aspect ratios and volume fractions of fibres. Results Eng [Internet]. 2022;13(1):100335. Available from: https://doi.org/10.1016/j.rineng.2022.100335

[19] Farhad as, Gedeon R. Experimental investigation into the properties of self-compacting rubberised concrete incorporating polypropylene and steel fibers. Struct Concr [Internet]. 2018;20(1):267–81. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/suco.201800182