Mechanical Performance Of Sustainable Concrete Including Recycled Fine And Coarse Aggregate Improved By Silica Fume

Hemin G. Ahmed, Khaleel H. Younis, Shelan M. Maruf

Abstract: In this investigational research, the performance of recycled aggregate concrete (RAC) has been tackled. The research studies the impact of the use of recycled fine and coarse aggregates on fresh and hardened properties of recycled aggregate concrete (RAC). Workability, compressive strength and flexural strength are examined in this paper. The effect of the use of silica fume (SF) as a method to enhance the behavior of RAC was studied. SF was used to replace the cement at contents (by mass) of 5%, 10% and 15%. Six mixtures were investigated. The mixtures made with recycled fine (RF) aggregate (at content of 50%) and natural coarse aggregate were four; these mixes made with 0%, 5%, 10%, 15% of silica fume. One mix was made with 50% RF aggregates and 100% recycled coarse aggregate. Also, a reference mix which includes natural fine and coarse aggregates was prepared for comparison purpose. It was concluded that using RF aggregates diminish the workability and strength of RAC. The use of SF decreases the workability of RAC though it enhances the compressive and flexural strength of RAC. If SF is used at contents within 10% to 15% of cement mass in RAC, its strength can be significantly enhanced.

Index Terms: Silica fume, Recycled fine aggregates, recycled concrete, compressive strength, flexural strength.

1. INTRODUCTION

There is no doubt that concrete is the most common used constructional material in the construction industry [1]. This can be attributed to the fact that concrete is versatile, cost-effective and can be formed in different shapes. Nonetheless, the large quantities of CO2 that emit during manufacturing of cement and extracting the raw materials, cause serious environmental concerns and sustainability concerns [1][2]. Beside the emission of CO2, the industry of construction is also accused of the accrual of vast amounts of construction and demolition waste (CDW) which also causes real environmental issues. Issues and concerns such as the depletion of landfills and diminution of the natural resources of aggregates extraction and cement manufacturing raw materials, are among the main environmental issues. The harmful effect of such issues can be mitigated through different methodologies[3][4]. One method is the use of cementitous supplementary materials such as Silica fume (SF) in the manufacture of concrete. SF is a by-product material that can be used to replace OPC [5]. SF can significantly contribute in minimizing the use of cement which in turn may greatly help in mitigating the aforementioned environmental issues[6]. Reusing/recycling of CDW (as aggregates in concrete) is another approach that can be used to reduce the environmental-related issue of concrete [7]. Recycled aggregate concrete (RAC) usually contains recycled fine (RF) and coarse (RC) aggregates. It is obvious to say that utilizing RF and RC aggregates in the production of RAC is useful in mitigating the impacts of the environmental issues though its performance cannot reach that of the natural aggregate concrete (NAC)[4]. Previous studies[4][6][8] have stated that the performance of RAC is inferior to that of NAC. The use of RF and RC aggregates affects the behavior of RCA in both states of concrete (fresh and hardened). Both RF and RC aggregates diminish the workability of concrete reduce the mechanical characteristics of concrete [9][10]. Reduction up to 45%, 30% and 25% in compressive strength, splitting tensile strength and flexural strength, respectively, compared to NAC have been reported in the previous studies [2][4]. The lower quality of RAC has been attributed to the properties of the RF and RC aggregates as stated in the previous studies. RF and RC aggregates are composed of natural aggregate and attached paste. The attached paste is known for its porous nature and contains micro-cracks caused by the crushing process during the production of recycled aggregates [6][11]. Such properties lead to a poor structure of aggregates with in the concrete. It results in high porosity and water absorption. Indeed, such properties cause low workability of RAC when compared to NAC[8][12].

It is observed, in the previous studies conducted to examine the effect of using SF in NAC, SF can improve the performance of NCA through its pozzolanic characteristic. Due to such reaction, SF can enhance both mechanical properties and improve the durability behavior of NAC through filling ability and enhancing the micro-structure of NAC [12].

Thus, this research aims to investigate the influence of employing SF as cement replacement on the behavior of RAC. SF was used at various ratios to replace cement in this research. The RAC mixtures include both RF and RC aggregates. The sand is partially (50%) replaced with RF aggregate and in one mix the natural gravel was fully replaced with RC aggregates obtained from old concrete structures. Workability and mechanical properties such as compressive strength and flexural strength are examined in this research.

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2 EXPERIMENTAL WORK

2.1 Materials

The first binder employed in this research is cement (OPC) type CEM I as per BS EN 197. In Table 1, the chemical constituents and some physical characteristics of the OPC, as provided by the supplier, are illustrated. As mineral admixtures, Silica fume (SF) is the second binder used in the current research to partially replace the cement (see Table 1).

***TABLE 1**.*
CHEMICAL COMPOSITION OF BINDERS.

Material	SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	Na2O	K2O
OPC	21.04	4.83	3.01	66.5	0.76	2.65	0.35	0.52
SF	93.4	0.8	1.5	0.8	0.2	-	0.72	0.70

Two kind of coarse aggregate were utilized in this research. Natural river gravel brought from the area of Klak in Erbil governance was the first type, see Figure 1. While, the second type recycled aggregate extracted from crushing the rubbles of old concrete structures. The first one is characterized with a rounded shape; whereas the second one had an angular shape. Both type had a maximum size of 20mm. Table 3 shows the physical characteristics of these two types of aggregates.

***FIG. 1**. Natural and recycled aggregates used in the study.*

Similarly, two types of fine aggregate employed in this research; the first one was river sand brought from the same area (Klak) and the second one was recycled fine (RF) aggregate obtained from the crushing process of large lumps of concrete extracted from the rubbles of concrete structures. Both types had the same maximum size of 4.75 mm. See Table for the physical properties of both types.

***TABLE 2**.*
PHYSICAL CHARACTERISTICS OF AGGREGATES.

Type of aggregate	Characteristic			
	Shape	Surface texture	Specific gravity (SSD)	Water absorption (%)
Natural (fine)	Rounded	Smooth	2.67	1.1
Recycled (fine)	Angular	Rough	2.40	6.1
Natural (coarse)	Rounded	Smooth	2.65	1.0
Recycled (coarse)	Angular	Rough	2.44	3.2

To reach to a required workability, chemical compounds known as superplasticizer was utilized in preparing all concrete mixtures. It was a chemical solution includes polymers calledpoly-carboxylate ether.

2.2 Mix proportioning, mixing and specimens preparation
Six mixtures were investigated in this research as can be seen in Table 3. The table contains information regarding the code of mixes and ingredients all mixes. The ratio of water/cement (w/c) was constant in all mixtures and was equal to 0.49. The added quantity of the superplasticizer was the same in all mixtures and was equal to 0.35% of cement mass.

TABLE 3.
DETAILS OF MIXTURES.

Mix	Code	C*	SF	CA		FA	
				N	RC	N	RF
1	NFSF0	340	0	1112	0	750	0
2	RFSF0	340	0	1112	0	375	375
3	RFSF5	323	17	1112	0	375	375
4	RFSF10	305	35	1112	0	375	375
5	RFSF15	289	51	1112	0	375	375
6	RFCSF15	289	51	0	1112	375	375

* C= Cement, SF= Silica fume, CA= Coarse Agg., N= Natural, r=Recycled, FA=Fine Agg.

Th The mixer which used in this study tp prepare the concrete mixtures had a capacity of 100 liter. The mixing conducted in a number of steps. In the first step, both fine and coarse aggregates were added to the mixer pan and the dry aggregates were mixed for 1 minute. In the second step, the amount of the water required for aggregates (both natural and recycled) to reach the state of saturated surface dry (SSD) was added to the mixer and further mixing was performed for one more minute. The ingredients were left in the mixer pan for 15 minutes to allow the aggregates to absorb water and reach the SSD state. In the third step, the binders (cemnt and SF) were put in the mixer and the materials were mixed for two minutes. In the fourth step, the water and the super-plasticizer were added to the mixer and mixing resumed for three minutes. Afterwards, the fresh concrete was assessed for its workability, and then, the concrete was poured in the molds and compacted using a vibrating table. The molds used to cast the concrete were : 3 of 100 mm cubes, 3 of cylinders with dimensions of 100×200 mm and 3 prisms of 100×100×500 mm were cast for each mix. After casting, the molds were covered with plastic sheets and kept for 24 h. Thereafter, the samples were stripped off and moved into water container to cure for further 27 days.

2.2 Tests

Workability
With the help of slump test, the workability of all mixtures was examined. the slump test was undertaken as per the BS EN 12350-2 [13].

Compressive strength
Following the guidelines of BS EN 12390-3 [14], the compressive strength of the concrete cubes were assessed at the age 28. A compression machine with a hydraulic mechanism and capacity of 2000 KN was employed in this

test.

Flexural strength
The guidelines of the standard of BS EN 12390-5 [15]was followed to evaluate the flexural strength of all mixtures. At age 28 days, the concrete prisms were examined for flexural strength. Figure 5 shows the bending test machine that has a capacity of 100KN and used in this study.

3 RESULTS AND DISCUSSION

3.1 Workability
The fresh concrete was evaluated for it workability through slump test. Results of the slump test obtained in (mm) of the six mixes are illustrated in Table 4 and also depicted in Figure 2. For comparison purpose, the normalized workability (slump) of all mixes are also shown in Table 4. The normalized values represent (slump value of a mix with respect to the slump value of the reference mix (mix number 1).

TABLE 4.
RESULTS OF WORKABILITY AND COMPRESSIVE STRENGTH TESTS.

Mix	Code	Slump		Compressive Strength	
		Value (mm)	Normalized	Value (MPa)	Normalized
1	NFSF0	115	1	36.1	0
2	RFSF0	90	0.74	28.6	0.79
3	RFSF5	80	0.70	30.2	0.84
4	RFSF10	70	0.61	33.7	0.93
5	RFSF15	60	0.52	35.5	0.98
6	RFCSF15	40	0.35	31.2	0.86

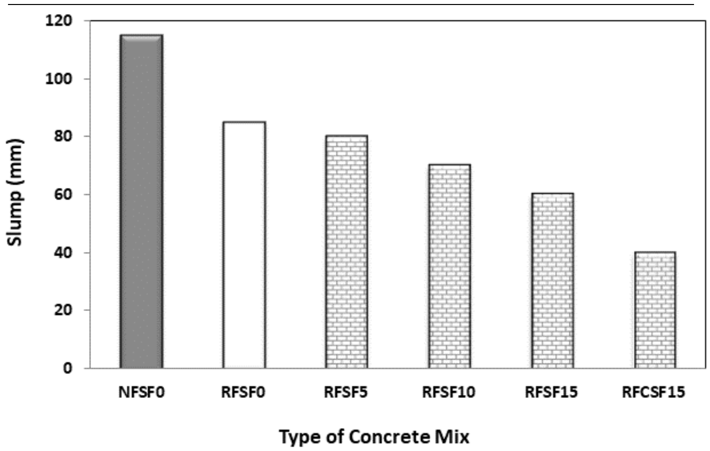

***FIG. 2**. Results of slum test.*

It can be seen that when sand is replaced with RF aggregate, the workability of concrete reduces (see table 4).The slump value dropped to 90 mm for mix RFSF0 compared to 115 mm of the reference mix (mix number 1) (see Figure 6); this represents a reduction of 16% in workability as indicated by the normalized values in Table 4. This can be attributed to the high absorption capacity of recycled fine aggregates. Such diminish in workability due to addition of RF was also observed by [4][16]. Lower workability was observed when SF was added at different ratios. In comparison to the slump value of the reference, mixes RFSF5, RFSF10 and RFSF15 showed lower values by 30%, 39% and 48%, respectively. Such trend can be related to high surface area of SF particles. When the gravel was fully replaced with recycled coarse (RC) aggregates, more reduction in the workability was recorded (see Figure 2). For mix RFCSF0, the reduction reached 75% compared to the reference mix. This is due to the high absorption and the rough surface of the RC aggregates particles.

3.2 Compressive strength
The results of the compression test are presented in Table 4. These results are the average of testing three cubes at the age of 28 days. For comparison purpose, the normalized Compressive strength of all mixes is also shown in Figure 3. The normalized values represent (compressive strength value of a mix with respect to the compressive strength value of the reference mix RFSF0.

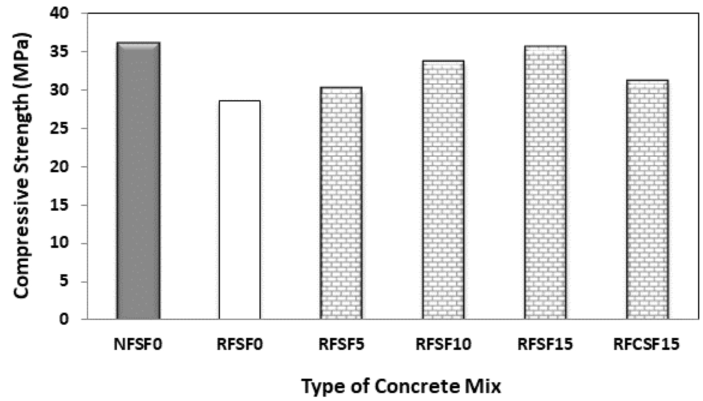

***FIG. 3**. Results of compressive strength.*

The replacement of sand with RF aggregates had a negative impact on the compressive strength of concrete as can be seen Table 4. The strength of mix RFSF0 reduced to 28.6MPa compared to 36.1MPa for the reference mix; this denotes a decrease of 21% in compressive strength as point out by the normalized values in Table 4. The low quality of RF aggregates; represented in that RF particles are light, porous, and weak; thus resulting in concrete with low compressive strength[3][17]. When SF used a s replacement to the cement, the 28 days compressive strength of the mixes made with RF aggregates increased. The ratio of SF directly affects this strength improvement; as the strength increases with the increase of the ratio of SF as shown in Figure 3. For instance, when the SF was added at contents 5%, 10% and 15%, the compressive strength of the mixes (RFSF5, RFSF10 and RFSF15) showed strength of 30.2, 33.7 and 35.5 respectively. These values are higher than the value of the mix RFSF0 made with no SF but lower than that of the reference mix (NFSF0). These results, in comparison to mix RFSF0, denotes strength enhancement of 6%, 18% and 24% for the mixes RFSF5, RFSF10, RFSF15, respectively. This means that if the cement is replaced with SF at content of 15%, the strength of the mixes made with RF aggregates can be improved up to 24% and can reach to comparable strength to that of the mix made with naturals fine aggregates (see Table 4). A reduction of 4.3MPa in the compressive strength was observed when the gravel was replaced with RC aggregates. Such strength improvement due to the addition of SF was also stated by [3][12]. The pozzolanic reaction and the filling ability of the SF particles are the prime reasons for increase in the strength of the mixes made with RF aggregates [5].

3.3 Flexural strength

The results of the bending test are presented in Figure 4. These results are the average of testing three prisms at the age of 28 days. For comparison purpose, the normalized flexural strength of all mixes is also shown in Figure 5. The normalized values represent (flexural strength value of a mix with respect to the flexural strength value of the reference mix RFSF0.

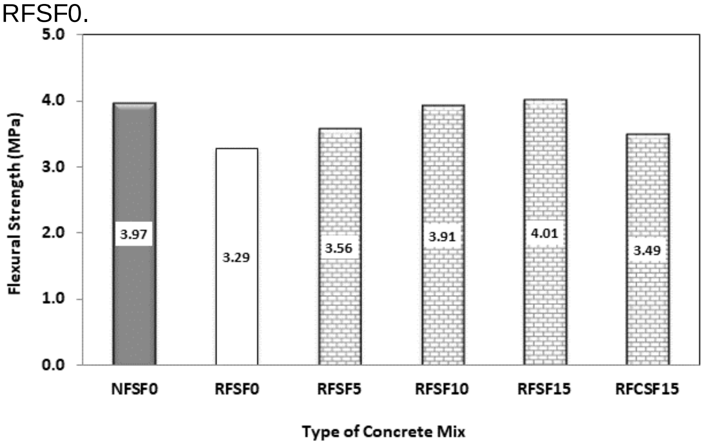

FIG. 4. *Results of flexural strength.*

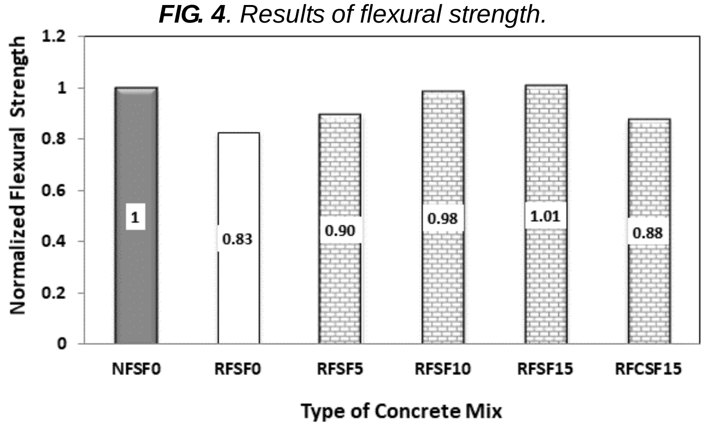

FIG. 5. *Results of normalized flexural strength.*

Figure 4 shows that generally the trend of the flexural strength is similar to that of the compressive strength. The flexural strength of mix NFSF was 3.9MPa while that of the mix RFSF0 was 3.29MPa, which represents a reduction of 17. The decay in the flexural strength can be related to the same weaknesses of the RF aggregates previously mentioned in section 3.2. Just as the trend of the compressive strength, the use of SF had a positive influence on the flexural strength of the mixes including RF aggregates. The strength improved from 3.29 MPa (for mix RFSF0) to 3.56, 3.91 and 4.01 when the SF replaced the cement by 5%, 10% and 15%, respectively. It can be said that the use of SF at contents of 5%, 10% and 15% can enhance the flexural strength by 8%, 19% and 22% respectively, compared to that of mix RFSF0 (see Figure 5). Additionally, comparable flexural strength to that of the reference mix (NFSF0) can be achieved if SF is used at a content between 10-20 % of the cement. Such improvement in the flexural strength of the mixes made with recycled fine aggregates can be related to the chemical pozzolanic reaction that results in producing more of the gel C-S-H which enhances the strength of the concrete [5].

4 CONCLUSION

The results of this experimental research can lead to the following conclusions:

-Utilization of recycled aggregates (fine and coarse) reduces the workability of concrete due to its high absorption capacity and rough surface. This decrease in the workability increases when silica fume is added to the mixtures. The decrease due to using recycled aggregates and silica fume may rise up to 65%.

-Both compressive and flexural strengths of concrete decline when 50% of the sand was replaced with recycled aggregates. The weak surface of the recycled aggregates (fine and coarse) is the key reason for such trend.

- In terms of strength, a beneficial impact was observed when the cement was replaced with silica. The chemical reaction caused by the pozzalnic nature of SF is the main prime reason to such strength improvement.

-Adding silica fume at ratios between 10% to 15% can result in strength of concrete made with recycled aggregates, in particular fine aggregates, that is comparable to the strength of the mixture made with natural aggregates. Hence, Silica fume can be a way to increases the use of recycled aggregate in concrete.

ACKNOWLEDGMENT

The authors wish to thank Erbil Polytechnic University for the support during conducting this study.

REFERENCES

[1] Mehta KP, Monteiro PJM. Concrete structure, properties, and materials 1993.
[2] Younis KH, Latif S. Mechanical performance of self-compacting concrete incorporating recycled aggregate: A review. Int J Sci Technol Res 2019;8:560–7.
[3] Salahuddin H, Qureshi LA, Nawaz A, Raza SS. Effect of recycled fine aggregates on performance of Reactive Powder Concrete. Constr Build Mater 2020;243. doi:10.1016/j.conbuildmat.2020.118223.
[4] Younis KH. Restrained Shrinkage Behaviour of Concrete with Recycled Materials. The University of Sheffield, 2014. doi:http://etheses.whiterose.ac.uk/id/eprint/5966.
[5] Younis KH, Mustafa SM. Feasibility of Using Nanoparticles of SiO 2 to Improve the Performance of Recycled Aggregate Concrete. Adv Mater Sci Eng 2018;2018:1–11. doi:10.1155/2018/1512830.
[6] Tam VWY, Tam CM. Diversifying two-stage mixing approach (TSMA) for recycled aggregate concrete: TSMAs and TSMAsc. Constr Build Mater 2008;22:2068–77. doi:10.1016/j.conbuildmat.2007.07.024.
[7] Younis KH. Nano-Silica Modified Recycled Aggregate Concrete: Mechanical Properties and Microstructure. Eurasian J Sci Eng 2018;3:167. doi:doi: 10.23918/eajse.v3i3p167.

[8] Younis KH, Pilakoutas K. Strength prediction model and methods for improving recycled aggregate concrete. Constr Build Mater 2013;49:688–701. doi:10.1016/J.CONBUILDMAT.2013.09.003.
[9] de Brito J, Saikia N. Recycled Aggregate in Concrete. London: Springer London; 2013. doi:10.1007/978-1-4471-4540-0.
[10] Younis KH, Pilakoutas K, Guadagnini M, Angelakopoulos H. Feasibility of using recycled steel fibres to enhance the behaviour of recycled aggregate concrete. Am. Concr. Institute, ACI Spec. Publ., vol. 2014- July, 2014, p. 113–22.
[11] Tabsh SW, Abdelfatah AS. Influence of recycled concrete aggregates on strength properties of concrete. Constr Build Mater 2009;23:1163–7. doi:10.1016/j.conbuildmat.2008.06.007.
[12] Tam VWY, Soomro M, Evangelista ACJ. A review of recycled aggregate in concrete applications (2000–2017). Constr Build Mater 2018;172:272–92. doi:10.1016/J.CONBUILDMAT.2018.03.240.
[13] British Standard EN BS12350-2. Testing fresh concrete: Part 2: Slump-test 2009.
[14] British Standard 12390-3. BSI Testing hardened concrete Part 3: Compressive strength of test specimens. London; UK: British Standard Institution; 2009.
[15] British Standards Institution BSI EN B 12390-5. Testing hardened concrete–Part 5: flexural strength of test specimens. 2009.
[16] Tam VWY, Wang K, Tam CM. Assessing relationships among properties of demolished concrete, recycled aggregate and recycled aggregate concrete using regression analysis. J Hazard Mater 2008;152:703–14. doi:10.1016/j.jhazmat.2007.07.061.
[17] Xie J, Fang C, Lu Z, Li Z, Li L. Effects of the addition of silica fume and rubber particles on the compressive behaviour of recycled aggregate concrete with steel fibres. J Clean Prod 2018;197. doi:10.1016/j.jclepro.2018.06.237.