Experimental study on performance of recycled aggregate concrete: Effect of reactive mineral admixtures

Article *in* International Journal of Civil Engineering and Technology · February 2019

4 authors:


Khaleel Younis
Erbil polytechnic university


Firas F. Jirjees
Erbil polytechnic university


Ganjeena Medhat
Erbil polytechnic university


Barham Ali
Gaziantep University

International Journal of Civil Engineering and Technology (IJCIET)
Volume 10, Issue 01, January 2019, pp. 2566–2576, Article ID: IJCIET_10_01_229
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType=1
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

EXPERIMENTAL STUDY ON PERFORMANCE OF RECYCLED AGGREGATE CONCRETE: EFFECT OF REACTIVE MINERAL ADMIXTURES

Khaleel H. Younis
Road Construction Department, Erbil Polytechnic University, Erbil, Iraq
Environmental Engineering Department, Knowledge University, Erbil, Iraq

Firas F. Jirjees
Road Construction Department, Erbil Polytechnic University, Erbil, Iraq

Ganjeena Khoshnaw
Road Construction Department, Erbil Polytechnic University, Erbil, Iraq
Civil Engineering Department, Tishk International University, Erbil, Iraq

Barham Haidar Ali
Civil Engineering Department, Tishk International University, Erbil, Iraq

ABSTRACT

This paper presents an experimental study on the performance of recycled aggregate concrete (RAC) that includes recycled coarse aggregate (RCA). This study investigates the effect of replacing the natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) on the workability and mechanical properties of concrete. The effect of using reactive mineral admixtures such as fly ash (FA) and silica fume (SF) as cement replacement on these properties of RAC is also examined and compared to the results of natural aggregate concrete (NAC). The mechanical properties include: compressive strength, tensile strength and flexural strength. Various reactive mineral admixtures replacement ratios were used including (20% FA or 20% SF or a combination of 10% FA + 10% SF). In total, five mixes were investigated. The results show that reactive mineral admixtures do not have negative effect on the workability of the RAC. Also, SF leads to better strength improvement of RAC than FA. The combination of both SF and FA can enhance the strength of RAC.

Key words: Recycled aggregate concrete, mechanical properties, reactive mineral admixtures, silica fume, fly ash.

Cite this Article: Khaleel H. Younis, Firas F. Jirjees, Ganjeena Khoshnaw, Barham Haidar Ali, Experimental Study on Performance of Recycled Aggregate Concrete: Effect of Reactive Mineral Admixtures, *International Journal of Civil Engineering and Technology (IJCIET)* 10(1), 2019, pp. 2566–2576.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=1

1. INTRODUCTION

One of the sustainability issues and environmental concerns that are globally recognized is the accumulation of huge amounts of waste materials and particularly the waste from construction and demolition activities. If such massive volume of waste materials is disposed of, the world will face serious environmental problems such as the depletion of limited landfills area [1,2]. In addition, the decline in the natural recourses of aggregates used in the production of concrete is another sustainability issue. Also, it is well-known that the manufacturing of Portland cement is responsible for the emission of significant amount of CO_2 to the environment. Hence, the utilization of reactive mineral admixtures by-product such as fly ash (FA) and silica fume (SF) to reduce the use of cement in the production of concrete can considerably help in mitigating the environmental impacts caused by the emission of CO_2 [3,4]. If the use of such mineral admixtures is coupled with the use of recycled aggregate instead of natural aggregate in the production of concrete, a great enhancement to the sustainability of concrete can be achieved. Inorganic residual products like crushed concrete are used as recycled aggregates in concrete. Further, cement can be partially replaced with by product reactive mineral admixtures like fly ash, silica fume in producing concrete.

The performance of RAC has been studied by many researchers [2-12]. These studies in have shown that the use of recycled aggregate leads to low quality concrete. The use of recycled aggregate reduces the mechanical properties and decreases the workability of concrete. Studies have shown that compressive strength, splitting tensile strength and flexural strength of RAC are lower than that of NAC by up to 40%, 20% and 15%, respectively. This is attributed to the weakness of recycled aggregate which has properties such as high porosity, low density and high water absorption. These properties, particularly high porosity and water absorption, are also the reason behind the low workability of the concrete incorporated recycled aggregate [4].

It is well known that reactive mineral admixtures such as fly ash and silica fume possess important pozzolanic characteristic. The use of such materials leads to improvement of the mechanical properties and enhancement of the durability performance of concrete. These improvements is due to the pozzolanic reaction that leads to the production of more of calcium silicate hydrate (C-S-H) which is known as the product of cement hydration that is responsible of the strength of cement paste and concrete. The effect of using FA on the properties of concrete has been studied by [7-9].

It is reported that FA can increase the strength of RAC at ages after 28 days [8,10]. Similarly, the use of SF improves the strength of the concrete with recycled aggregate [7].

There are few studies that tackle the effect of combining both FA and SF on the properties of the concrete with recycle aggregate. Therefore, this paper examines the effect of using FA and SF separately and combined on the performance of concrete that includes 100% RCA. The following sections describe the experimental work, results, discussion and conclusions.

2. EXPERIMENTAL PROGRAMME

2.1. Materials

2.1.1. Cement

In this study, Portland cement type CEM I was used. It meets the requirements of BS EN 197. Table 1 shows the chemical analysis of the cement (as given by the supplier).

Table 1 Chemical analysis of the Portland cement, fly ash and silica fume

Material	SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	Na2O	K2O	Na2Oeq
CEM I	20.94	4.96	2.92	65.9	0.78	2.8	0.25	0.42	0.52
FA	54.6	27.8	9.2	3.2	2.0	-	0.21	0.58	-
SF	92.8	0.6	1.3	0.4	0.2	-	0.82	0.77	-

2.1.2. Reactive mineral admixtures

Reactive mineral admixtures such as fly ash (FA) and silica fume (SF) were used in this study. The chemical composition and some physical properties of these materials (as provided by the supplier) are shown in Table 2.

Table 2 Physical and mechanical properties of the Portland cement, fly ash and silica fume

Property	CEM I	FA	SF
Specific gravity	3.15	2.15	2.2
Fineness (m2/kg)	438	460	16300
Initial setting time (min)	100	-	-
Compressive strength (MPa)	52.1	-	-

2.1.3. Aggregates

Local river sand from Khabat district in Erbil city-Iraq was used as fine aggregate in this study. The fine aggregate had a maximum size of < 4.75 mm. Two types of coarse aggregate (natural and recycled) were used in current study (shown in Figure 1). The first one was natural rounded river aggregate. The second one was coarse recycled aggregate derived from old concrete portions generated by the demolishing of old concrete buildings. Both types of coarse aggregates had the same maximum size of < 19.5 mm. the properties of coarse aggregates used in this study are presented in Table 3.

Table 3 Physical properties of coarse aggregates (CA)

Property	Type of CA	
	NCA	RCA
Shape	Rounded	Angular
Surface texture	Smooth	Rough
Specific gravity (SSD)	2.65	2.49
Water absorption %	1.3	4.8

Figure 1 a- Natural coarse aggregate, b- Recycled coarse aggregate.

2.1.4. Superplastisizers

To achieve concrete with a desirable workability, superplasticizers were used. The workability was assessed using slump test. An aqueous solution incorporating polycarboxylate ether (PCE) polymers was used as superpalstizer in this study.

2.2. Mix proportions and experimental work

In total, five different mixes were prepared and investigated. Details of the mixes including variables of the study and code of mixes are presented in Table 4. Table 4 also shows the mix proportions for all mixes. The mixes had the same water/cement (w/c) ratio (0.5). Superplasticizers were added to all mixes with a content of 0.3% of cement mass to achieve workability of 60-100 mm slump.

Table 4 Code of mixes, variables of study and mix proportions (kg/ m3)

Mix	Mix	% of	Cement	Fly	Silica	Water	Coarse	Coarse Agg.	Fine
M1	NAC	0	350	-	-	175	1065	0	752
M2	RAC	0	350	-	-	175	-	1065	752
M3	RACFA20	20	280	70	-	175	-	1065	752
M4	RACSF20	20	280	-	70	175	-	1065	752
M5	RACFA10SF10	20	280	35	35	175	-	1065	752

[a] By concrete mass

A pan mixer with capacity of 0.08 m^3 was used to mix the concrete ingredients. The concrete mixtures were compacted using internal vibrator. For each mix: three 100 mm cubes, three cylinders 100×200 mm and three prisms 100×100×400 mm were prepared. After casting, specimens were covered by plastic sheets and allowed to cure for 24 hours before being demoulded. Then, they were kept in water tanks for 27 days.

2.3. Tests

2.3.1. Workability "Slump Test"

Standard slump test was conducted for all mixes to assess workability of these mixes. The test carried out following the BS EN 12350-2 [13], see Figure 2.

Figure 2 Slump test

2.3.2. Compressive strength test

After 28 days of curing and by following the BS EN 12390-3 [14] standard test, the cube specimens were tested for compression. Figure 3 shows the machine used for the compressive strength test.

Figure 3 Compressive strength test machine

2.3.3. Splitting tensile strength test

After 28 days of curing and by following the BS EN 12390-6 [15] standard test, the 100×200 mm cylinders specimens were tested for splitting tensile. Figure 4 shows the machine used for the splitting tensile strength test.

Figure 4 Splitting tensile strength test machine

2.3.4. Flexural strength test

After 28 days of curing and by following the BS EN 12390-6 [16] standard test, the (100×100×400) mm prisms specimens were tested for flexural strength. The prisms were tested in two-point loading over a length of 300 mm as can be seen in Figure 5.

Figure 5 Flexural strength test machine (a) during testing (b) after testing

3. RESULTS AND DISCUSSION

3.1. Fresh properties "Slump Test"

The trial mixes of the mixtures with RCA revealed a decrease in the workability of these mixes compared to the mix with NCA. Hence, the decision was to add superplasticizer to all mixes in order to get workability (slump test) of (60-100 mm).

Table 5 & Figure 6 present the results of the slump test in mm for all mixes. The table also shows the change in slump (compared to that of NAC mix and RAC mix).

Table 5 Results of concrete slump test with the change in slump values (+ increase or - decrease) compared to NAC[1] and RAC[2]

Mix	Workability "Slump Test"		
	Slump mm	**Slump Change (%)[1]**	**Slump Change (%)[2]**
M1	100	0.0	-
M2	70	-30.0	0.0
M3	80	-20.0	+14.3
M4	60	-40.0	-14.3
M5	70	-30.0	0.0

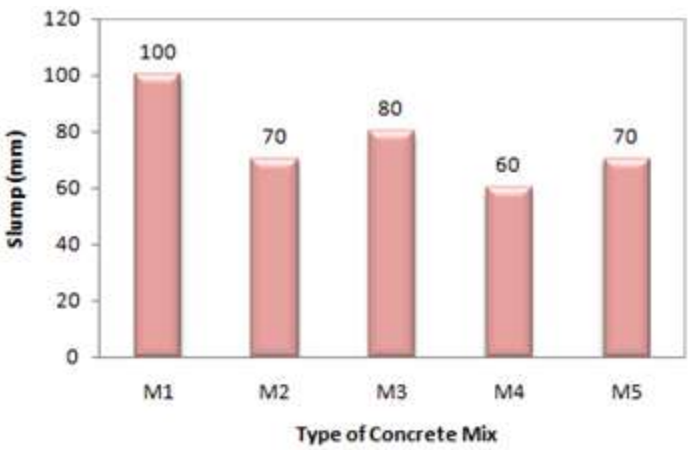

Figure 6 Effect of FA, SF and combination of FA & SF in RAC slump values

It can be seen that replacing NCA with RCA reduced the workability by 30%. This is due the fact that RCA have higher absorption capacity caused by the heterogeneous nature of RCA particles. The replacing of 20% of the cement with FA resulted in slump value of 80 mm which is comparable to the workability of the RAC mix without FA (70 mm). It is expected that FA reduces the workability due its high surface area compared to that of the cement [4]. On the other hand, the rounded particles of the FA may reduce the friction between the aggregate particles leading to better workability (higher slump values) [4]. It seems that the two opposite mechanisms worked together and lead to the result of 80 mm slump value. The mix with the SF showed a slump of 60 mm which is the lowest value of all mixes. In this case, it seems that the first mechanism (high surface area of the SF) had more effect than the second mechanism (less friction between the aggregate particles) and led to that result. The slump value of the mix with both FA and SF is 70 mm which is similar to that of the mix without these materials. This could be due to the combined effect of the two above mentioned mechanisms.

3.2. Compressive strength

Table 6 and Figure 7 show the results of the 28 days compressive strength of all mixes. The result of each mix is the average of 3 specimens. The table also shows the change in strength (compared to that of NAC mix and RAC mix).

Table 6 Results of compressive strength with the change in strength (+ increase or - decrease) compared to NAC[1] and RAC[2]

Mix	Compressive strength		
	Strength MPa	Strength Change (%)[1]	Strength Change (%)[2]
M1	35.4	0	-
M2	26.8	-24.3	0
M3	24.7	-30.2	-7.8
M4	36.3	+2.5	+35.4
M5	32.9	-7.1	+22.8

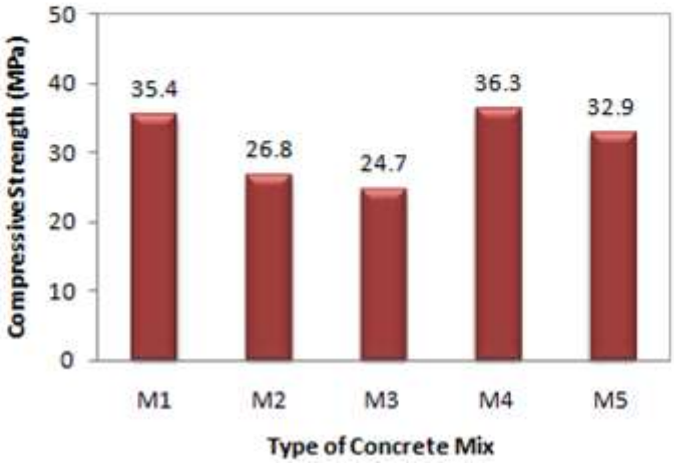

Figure 7 Effect of FA, SF and combination of FA & SF in RAC compressive strength

It can be seen that the RAC mix showed lower strength than that of the NAC mix. The strength loss due to the use of recycled coarse aggregate is about 24% (see table). This reduction is expected as the as the quality of RCA is lower than that of NCA. This is due to the attached mortar exist on the surface of the RCA which is characterized with low density and high porosity leading to a weaker concrete [4,12,17]. The use of 20% FA had a negative effect on the strength (at age of 28 day) of the RAC. The reduction is about 8% compared to the RAC without FA and 30.2% compared the NAC mix. This could be due to the fact that the pozzolanic reaction of the FA takes time and it becomes more effective at later ages [12]. On the other hand, the use of SF had a positive effect on the strength of RAC mix. This mix showed a strength increase of 35.4% compared to that of RAC without SF and it even reached the strength of the NAC mix with a marginal increase of 2.5%. This behavior can be attributed to the positive effect of the pozzolanic reaction of the SF which results in more calcium-silicate- hydrate (C-S-H) (the product responsible of the strength of the cement paste) in the structure of the concrete [7]. Hence, the addition of 20% of SF can significantly improve the strength of RAC. Similar strength enhancement was observed when 10% of FA and 10% of SF are used in the RAC as can be seen for (Mix5) in Figure 7. This mix showed strength improvement of 22.8% compared with RAC mix, but it showed 7.1% reduction compared to that of NAC mix.

3.3. Splitting tensile strength

The results of splitting tensile strength at the age of 28 days are shown in Table 7 and Figure 8. The result of each mix is the average of 3 specimens. The table also shows the change in strength (compared to that of NAC mix and RAC mix).

Table 7 Results of splitting tensile strength with the change in strength (+ increase or - decrease) compared to NAC[1] and RAC[2]

Mix	Splitting tensile strength		
	Strength MPa	**Strength Change (%)[1]**	**Strength Change (%)[2]**
M1	2.8	-	-
M2	2.5	-10.7	0.0
M3	2.4	-14.3	- 4.0
M4	3.0	+7.1	+20.0
M5	2.7	- 3.6	+ 8.0

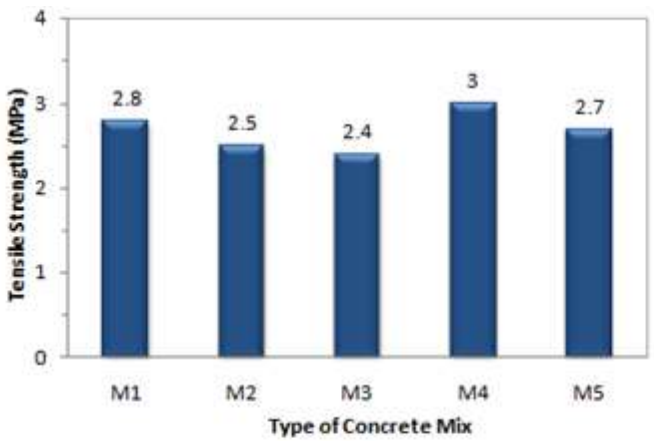

Figure 8 Effect of FA, SF and combination of FA & SF in RAC splitting tensile strength

The general trend of the results of the splitting tensile strength is similar to that of the compressive strength. It can be seen that the strength of the RAC (Mix2) is 2.5 MPa which is smaller than that of the NAC (2.8 MPa) by about 11%. This reduction in strength of RAC is due to the weakness of the recycled coarse aggregate which has lower density compared to the natural aggregate [10,12]. The use of 20% of FA did not help in improving the splitting tensile strength of RAC and showed strength of 2.4 MPa. Whereas, the use of 20% of SF increased the strength of the RAC by 7.1% comparing to NAC mix and 20% comparing to RAC without SF as can be seen in table 7. This is due to the pozzolanic reaction as explained in section1. The last mix which has 10% FA and 10% SF showed an increase of 8% in the splitting strength compared to the RAC (Mix2).

3.4. Flexural strength

The results of flexural strength at the age of 28 days are shown in Table 8 & Figure 9. The result of each mix is the average of 3 prisms. The table also shows the change in strength (compared to that of NAC mix and RAC mix).

Table 8 Results of flexural strength with the change in strength (+ increase or - decrease) compared to NAC[1] and RAC[2]

Mix	Flexural strength		
	Strength MPa	Strength Change (%)[1]	Strength Change (%)[2]
M1	3.1	0.0	-
M2	3.0	- 3.2	0.0
M3	2.9	- 6.5	- 3.3
M4	3.2	+ 3.2	+ 6.7
M5	3.2	+ 3.2	+ 6.7

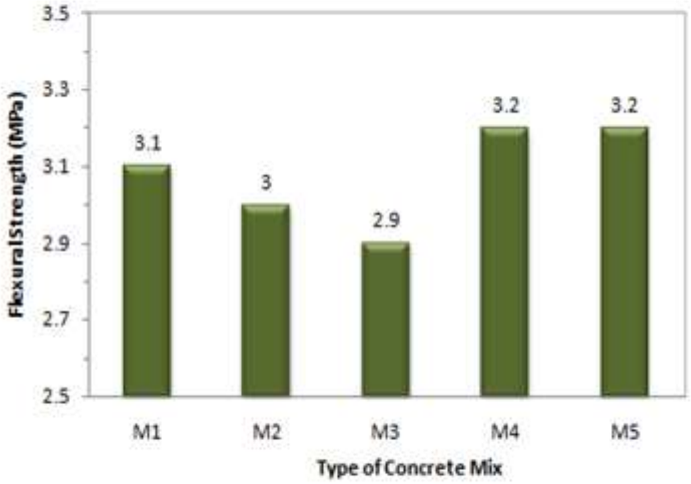

Figure 9 Effect of FA, SF and combination of FA & SF in RAC flexural strength

Figure 9 shows that the trend of the results of the flexural strength is generally similar to that of the compressive strength and splitting tensile strength. The flexural strength of the NAC (Mix1) is 3.1 MPa. The RAC mix (Mix2) showed lower strength than that of the NAC by 3.2%. This decline in flexural strength of RAC is mainly due to the attached mortar exist on the surface of the recycled aggregate leading a concrete of low density with low strength [3,10]. The use of 20% of FA did not improve the flexural strength of RAC and showed strength of 2.9 MPa. Whilst, the use of 20% of SF increased the strength of the RAC by 3.2% comparing to NAC mix and 6.7% comparing to RAC without SF as can be seen in table 8. The main reason behind the increase in strength is the pozzolanic reaction as explained in section 1. Using 10% FA and 10% SF (Mix5) showed an increase of 6.7% in the flexural strength compared to the RAC mix (Mix2).

4. CONCLUSIONS

Based on the experimental results, the following conclusions can be drawn:-

Recycled aggregate reduces the workability (slump) of concrete due to the high water absorption and the rough surface of recycled aggregate. The use of reactive microfiller such as FA and SF can have a negative effect on one side and a positive effect on the other side. The negative effect comes from fine size of these materials which demands high water content to keep normal workability. The positive effect is due to spherical shaped particles of such materials providing a lubricant effect and better workability.

- The compressive strength, split tensile strength and flexural strength values of the RAC decreased by 24.3%, 10.7% and 3.2% respectively than the control mix (NAC mix). This decrease is due to the weakness of the recycled aggregate.
- The use of 20% of FA alone did not help in improving the strength of the RAC at age of 28. This is mainly due to the fact that pozzalnic reaction FA is more effective at later ages.
- In RAC mixes incorporating SF, all strengths were significantly improved. This is due to the pozzolanic reaction of the SF which starts at early ages and lead to better strength development.
- The mix with a combination of reactive mineral admixtures (10% FA & 10% SF) showed better strength than RAC mix and comparable strength to that of the NAC mix. Hence, the use of such mix as well as the RAC mix where 20% of the cement was replaced by SF can promote for the use of recycle aggregate and lead to more eco-friendly concrete.

REFERENCES

[1] Younis, K. H. and K. Pilakoutas, Strength prediction model and methods for improving recycled aggregate concrete. *Construction and Building Materials*, **49**(0), 2013, pp. 688-701.

[2] Maruf, S. M., Construction waste management in Kurdistan region. *Polytechnic Journal*, **7**(4), 2017, pp. 205-214,

[3] Younis, K.H., Restrained Shrinkage Behaviour of Concrete with Recycled Materials, PhD thesis in Civil and Structural Engineering. 2014, University of Sheffield: Sheffield, UK.

[4] Silva, R.V., Brito, J. de, Dhir, R.K., Fresh-state performance of recycled aggregate concrete: A review. *Construction and Building Materials,* **178**, 2018, pp. 19-31

[5] Khaleel, H.Y., et al., Feasibility of using recycled steel fibres to enhance the behaviour of recycled aggregate concrete. ACI Special Publication, 2017. 310: p. 113-123.

[6] Younis, K. H. and Mustafa, S. M, Feasibility of Using Nanoparticles of SiO 2 to Improve the Performance of Recycled Aggregate Concrete. *Advances in Materials Science and Engineering*, **3**, 2018, pp. 1-11,

[7] González-Fonteboa, B., & Martínez-Abella, F. Concretes with aggregates from demolition waste and silica fume. Materials and mechanical properties. *Building and Environment*, ***43***(4), 2008, pp. 429-437.

[8] A. Bilodeau, V. Sivasundaram, K.E. Painter, V.M. Malhotra **Durability of concrete incorporating high volumes of fly ash from sources in the U.S** *ACI Material Journal*, **91** (1), 1994, pp. 3-12

[9] Berndt, M. L. Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate. *Construction and building materials*, **23**(7), (2009) pp.2606-2613.

[10] Limbachiya, M., Meddah, M. S., & Ouchagour, Y. (2012). Use of recycled concrete aggregate in fly-ash concrete. *Construction and Building Materials*, *27*(1), 439-449.

[11] Lima, Carmine, et al. "Physical properties and mechanical behaviour of concrete made with recycled aggregates and fly ash .*Construction and Building Materials* **47,** 2013,pp. 547-559.

[12] Çakır, Ö. Experimental analysis of properties of recycled coarse aggregate (RCA) concrete with mineral additives. *Construction and Building Materials,* **68** ,2014,pp. 17-25.

[13] BS EN 12390-2:2009, Testing Fresh Concrete Part 2: Slump test, British Standards Institution, London, UK, 2009.

[14] BS EN 12390-3:2009, Testing Hardened Concrete Part 3: Compressive Strength of Test Specimens, British Standards Institution, London, UK, 2009.

[15] BS EN 12390-6:2009, Testing Hardened Concrete Part 6: Splitting tensile Strength of Test Specimens, British Standards Institution, London, UK, 2009.

[16] BS EN 12390-5:2009, Testing Hardened Concrete Part 5: Flexural Strength of Test Specimens, British Standards Institution, London, UK, 2009.

[17] Khaleel H. Younis and Shelan M. Mustafa, "Feasibility of Using Nanoparticles of SiO_2 to Improve the Performance of Recycled Aggregate Concrete," *Advances in Materials Science and Engineering*, vol. 2018, 11 pages,