International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

Pre-Wetting of Recycled Concrete as Alternative of Chemical, Natural and Industrial Waste Additives

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Abstract: ***Destructive infrastructure is increasing day by day due to the successive wars in the Arab region and this led to the formation of large volumes of demolished concrete, which produces a lot of waste materials and visual pollution in the spaces. Meanwhile, environmental protection has become a challenge, not an option. As well as, reusing of demolished concrete in new structures is necessary to preserve the raw resources of aggregate away from attrition. Seventy-two specimens of (100 x 100 x 100 mm) were prepared with water to cement (W/C) ratio of 0.4, where have replaced the different proportions of natural aggregate (NA) (0%, 30%, 45%, and 60%) by recycled concrete aggregate (RCA), and then were added 2.5% super plasticizer (SP) in place of cement to other specimens according to previous replacement proportion of RCA to determine the optimum percentage of RCA and to investigate the effectiveness of using Super Plasticizer. The replacement proportion of RCA were 45% of NA. sixty six cubes of 45% - RCA were prepared with a different proportions of 0, 10, 15, and 20 % of instead of a fine aggregate for each the Iron Filler (IF) and Al-Qawirah Silica Sand (QSS), it is natural Silica was got from the quarry of AL-Qawirah, Jordan. The use of this type of silica as a substitute for fine aggregate with RCA is the first use in Jordan. The final stage of research was the pre-wetting of RCA by 0%, 2.5%, 5%, and 7.5% as percentage of W/C, it is an extra water added to the 45%-RCA mixtures before an hour from mix process, thirty-six cubes were casted with different proportions of extra water. The results displayed that the workability was reduced by increasing the RCA, while the workability was increase as ratios of W/C increase. The analytical study shows a considerable enhancement of the compressive strength of 2.5% pre-wetting of RCA with 45%-RCA relative to the SP, IF, and NA, where the increase in the compressive strength was 64% and 28% at 2.5% pre-wetting of RCA relative to SP-45% RCA and NA, respectively.***

Keywords: Natural Silica, Aggregate Pre-wetting, Iron Filler, Recycled Aggregate

I. INTRODUCTION

The use of RCA as coarse aggregate has been started so as to dispose of the waste concrete materials [18, 14]. As well as the excavation of ground to get rocks and preparation of the gravel, sand and filler causes significant ecological damage [17].

Revised Manuscript Received on October 30, 2019.
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In the US consumption of NA is estimated to rise extra of 2.5 billion tons / year by 2020 [8]. As for carbon emissions, the production of 1 ton of RCA is emitted about half of what is emitted it when production 1 ton of NA (RCA produces 0.0024 million ton of carbon emission) [22].

Therefore, the safeguard of the environment is considered as a basic factor, where the human survival is directly associated with it [12]. Concert is essentially for development and infrastructures construction all over the world [16].

The countries experiencing wars, natural disasters or deficiency raw resources, where utilizing RCA in civil engineering projects is a first step in sustainability [9]. The RCA are considered highly heterogeneous as well have a high absorption of water caused by old mortar attached to the aggregate surface and lower toughness caused by crushing of waste concrete and have a lower density is produced by the existence of the remaining mortar surrounding old NA [23]. In general, concrete strength should be high to accommodate overloading in extreme loading situations [7]. Water is necessary in order to accelerate hydration reaction of cement and safe a certain fluidity when manufacturing concrete [24]. Old mortar collected the water in its voids. Accordingly, the amount of water needed for cement hydration would not be satisfactory, as a result effects greatly fresh property of concrete. Consequently, it is essential to wet the RCA earlier before mixing them with cement so as to don't influence the workability and the hardened concrete properties. An adjustment of additional water content is required to retain the same ratio of W/C [21].

The RCA usually have poor properties related to NA, there are several techniques to enhance the properties of RCA such as, mixing methods, pozzolanic materials and surface treatments. In Pozzolanic materials increases the strength of RCA by filling voids and also by increasing the bond between cement paste and motor [5]. Chemical additives may be added to mixes of concrete to improve their performances. Many researches have been used super SP to increase the workability and concrete strength. SP is a great plasticizing influence on concrete as well it is decrease the ratio of W/C necessary for concrete, without affecting concrete consistency, this result in increased the concrete strength with the same workability level[1]. Ngo and other in 2017[10] studied the effects of SP on the properties of concrete mixtures, they added RCA with different quantities 15, 30, 70, and 100% of NA, the results indicated that mixtures made using SP had a higher value of compressive strength of concrete than those without SP.

Another research has stated that a dosage from 0.75% to 2.2% by cement weight may be added for a normal concert, and may be reached to 3% by cement weight for high strength [2]. Ngwenya and Franklin, 2015[11], replaced a five proportions of RCA; 0%, 25%, 50%, 75%, and 100% at W/C of 0.45 and 0.5. Tests stated that slump and compressive strength of concrete reduced by increasing the proportion of replacement of RCA and by increasing the ratio of W/C. Adnan et al., 2007 prepared the specimens by 0%, 25%, 50%, 75%, and 100% RCA at different ratio of W/C (0.4, 0.5, and 0.6). Tiwari and Nateriya., 2008[20]
revealed that the compressive strength value of concrete was reduced by increasing RCA replacement, where replacement ratios were 0%, 50% and 100%. According to Guerzou and other in 2018 [21] study, they replaced NA by RCA at proportions of 0%, 50% and 100%. The aggregates saturated initially before 24 hours from mixing process and introducing them in concrete mixes. The research stated that by substituting 50% of saturated RCA have presented satisfactory results on mechanical strengths and workability, attained results were comparable to those of control concrete mixes casted with 100% NA.
As for the use of silica Al Tijani., 2016[1] conducted his experiments by utilizing a different amounts of RCA (0%, 25%, 50%, and 75%) with a changed percentages of micro-silica (MS) 0%, 5%, 15%, 20% by cement weight, the results shown that 50% of RCA is optimum percent, as revealed that added 15% of MS to 50%-RCA mixtures increase the compressive concrete strength value to 26.2 % in compare to the control mixtures. . Kou SC and other in 2011 presented an investigational study on the performance of RCA by adding Silica Fumes (SF), the results proven that the adding of SF to concrete mixtures of the RCA have a higher value of compressive strength than that to the NA mixtures. Compressive strength value of concrete can be improved by using iron filler (IF) to the mixtures, Alzaed., 2014[3] prepared cylinders and cubes specimens by 0%, 10%, 20% and 30% of IF in place fine aggregates, he demonstrated that, compressive strength value increase as IF increase.
In this research, laboratory investigations were conducted on the concrete mixtures of RCA with or without an additives to define a hardened and fresh of concrete properties of RCA. QSS used by 0%, 10%, 15% and 20% of the total fines as a replacement. Furthermore, 2.5 % SP was used as a replacement percentage of cement, and IF was added to RCA mixes as a replacement of fine aggregate with 0%, 10%, 15% and 20%, to increase the concrete quality, and then the last stage was to pre-wetting of RCA with a W/C ratio 0%, 2.5%, 5%, and 7.5% before an hour from a mix process to achieve a comparative analysis between improved concrete mixtures with control concrete mixtures which set by NA.

II. MATERIAL AND METHODOLOGY OF THE STUDY

A. *Cement and Aggregates.*

1) Ordinary Portland Cement (Type I). It is a local cement produced by company of Alshemalia Cement, Jordan.
2) Fine and coarse NA. Natural aggregate (NA) were transported from quarry of Wadi Alkarak to laboratory. The NA gradation was chosen according to a Jordanian standard, Table1 shown this specifications.

Table-1: Gradation of a coarse and fine aggregate.

Sieve size	% Passing *Fine Aggregate*	% Passing *Coarse Aggregate*
1 inch	100	100
3/4 inch	100	97.24
1/2 inch	100	60.65
3/8 inch	100	33.59
#4	99	2.88
#8	86	0.57
#16	50	0
#30	30	0
#50	16	0
Fine > #200 (75mc)	7	0

Coarse of RCA: One of local demolished residential structure are used as the main resource of coarse RCA. Manually process was used to prepare the crushed aggregate by a hummer up until obtain a required size of RCA to be added to concrete mixtures.
Specific gravity, water absorption, and abrasion values of NA and RCA were determined as revealed in the Table 2. Higher value of water absorption and abrasion may be as a result of an old attached mortar that covered coarse aggregate, the old attached mortar contains a high porosity. The standard specifications of abrasion, Specific gravity, and water absorption are 15-30% Max, 2.4 – 2.9, and 0.8 – 3.7% Max respectively [11, 12].

Table -2: RCA and NA properties.

Test	NA	RCA
L. A. Abrasion Test Mass Loss (ASTM C131 – 81)	25.4 %	42.3 %
Specific Gravity (ASTM C127 (2012a))	2.61	2.29
Water Absorption ASTM C127 (2012a)	1.41 %	7.3%

B. *Additives:*

1) SP: (AdCon SP 500) is used in this research has specifications shown below in Table 3, where was added at percent 2.5% by cement weight to develop the workability of RCA mixtures. This percent has been credited according to the several recommendations of researchers, as mentioned in the introduction.

Table-3: AdCon SP 500 properties [4].

Appearance	Specific gravity	PH	Chloride content	Air entrai-ment
Brown liquid	1.195± 0.01@25°C	7-8	Almost nil to BS5075	Less than 2%

2) QSS: Virgin silica has a purity approximately 96%, since the AL-Qawirah quarry, Jordan considered a good and available resource. QSS was used as a modifier instead of a fines natural aggregate. The size of QSS is < 1 mm and > 0.1 mm. The percentages of QSS at 0%, 10%, 15%, and 20% of the entire fines.

3) IF: is a waste industrials materials consisting of very small pieces of metal which has size < 0.1 mm. it was got from one of the local iron workshops, and then added as a replacement percentage of fine aggregates to RCA mixtures.

C. *Pre-wetting of Recycled Concrete*

To achieve a required level of concrete workability, a certain ratio of W/C added to dried RCA to wetting them before an hour of mixing and adding them as a constituent in concrete mixes. The use of this technique is due to the addition of free water throughout the concrete mixing process have produced a segregations and bleedings. The extra water amount used in this research are 0%, 2.5%, 5%, and 7.5% of W/C ratio used for a control mixes made without adding water.

D. *Concrete Mixture*

Ninety concrete cubes of (10 x 10 x 10 cm) were casted at RCA percentages of 0%, 30%, 45%, and 60% in place NA, where the coarse aggregates is the one that has been replaced, and then the SP was added at 0% and 2.5% of cement content for these mixtures. Three specimens for a percentage of RCA at W/C of 0.4. SSQ and IF at the ratios 0, 10, 15, and 20% were used as an additives instead of fine aggregate at a replacement percentage 45% of RCA, which is optimum percent which are determined according to this research results. Hardened and fresh properties of concrete were studied to define the compressive strength of concrete and the effectiveness of adding RCA on workability. All of these mixtures have examined after curing in the water bath 7, 14 and 28 days. Sixty six cubes made for QSS and IF-Twenty seven cubes are made to the concrete mixes with pre-wetting of RCA before the mixing them, where the extra water of 0, 2.5, 5, and 7.5 % of W/C (0.4).

E. *Experimental Investigations*

Accordance to ASTM C39-05 the compressive strength of concrete has determine after 7, 14 and 28 days of curing. Cement content is 400 kg/m3, compressive strength value of concrete was defined to reach 50 -60 MPa (After immersion in water for 28 days). Slump test accomplished according to ASTM C143-78 standards.

III. RESULTS AND DISCUSSION

A. *Determine the optimum ratio of RCA*

Table 4 summarizes the tests conducted to obtain the compressive strength values of concrete after immersion of the samples in the water bath for a period of 7, 14 and 28 days. Each value of this table represents the arithmetic mean of three sample tests. The compressive strength has higher value at 2.5% SP related to 0% SP for any RCA proportion, and also maximum compressive at the curing period of 28 days. The preceding results indicate that compressive strength value of concrete decline as the RCA proportion increase as shown in the Fig. 1, the same behavior for 7, 14 days of curing. High values for water absorption may be the cause of this behavior, the same results were obtained by Tiwari and Nateriya, 2008[20] and Adnan et al., 2007

Table 4: Compressive strength of concrete after 7, 14, and 28 days of curing at 0% and 2.5% SP.

RCA %	7 Day		14 Day		28 Day	
	0 % SP	2.5% SP	0 % SP	2.5% SP	0 % SP	2.5% SP
0	31.2	49.6	38.1	48.8	51.8	54
15	29.1	44.2	35.3	44.2	48.4	49.8
30	26.6	35.9	31	39.1	44.1	44.3
45	24.2	35	29	37.1	39.7	40.6
60	20.4	31	24	30.2	34.1	38.7

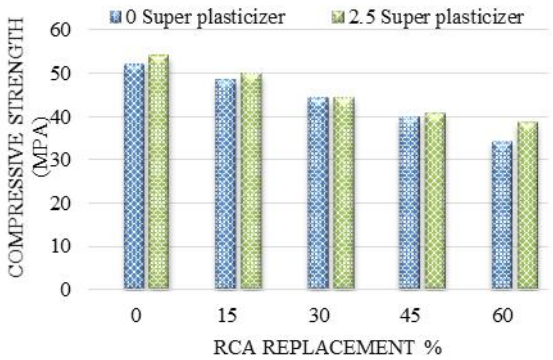

Fig. 1 Compressive strength value; after 28 days of curing.

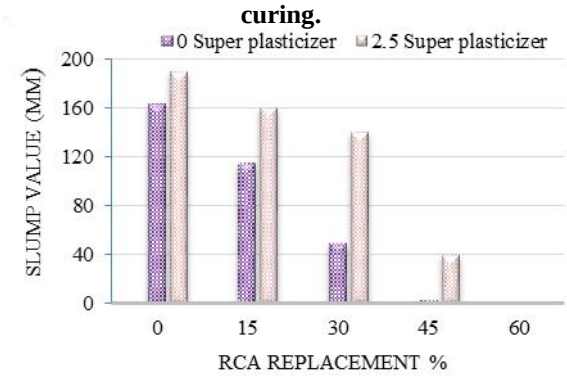

Fig. 2 Slump values vs RCA replacement

A 45% of RCA had been selected as a replacement proportion in place of NA according to standard compressive strength of concrete and economy, where the compressive strength was about 41 MPa. The standards value of compressive concrete strength can be classified as a concrete with low compressive strength if its strength < 20 N/mm2, a concrete with medium compressive strength if its strength was > 20 N/mm2 and < 40 N/mm2, a concrete with high compressive strength if its strength > 40 N/mm2 [15]. As for the cost, a 45% of RCA is better economically than 30%. In addition, at 45% of RCA, slump value was 40 mm as shown in the Fig. 2. However, compared with standard values, they can use these mixtures for a light reinforcement footings, highway vibrated with manually operated apparatuses according to standards values [15]. At 0, 2.5% SP, the slump test results prove that the concrete workability value decrease as RCA proportion increased, this is what Ngo et al., 2017[10] have reached.

B. *Per-Wetting of 45%-RCA Mixes with Pre-Wetting of 45%-RCA.*

1) Slump Value

The results showed that any increase in the ratio of W/C (resulting from pre-wetting RCA before an hour of design mix) leads to increase the slump values, where the slump values were 0, 4, 45, and 85 mm for 0%, 2.5%, 5.0%, and 7.5% respectively as exhibited in the Fig. 3.

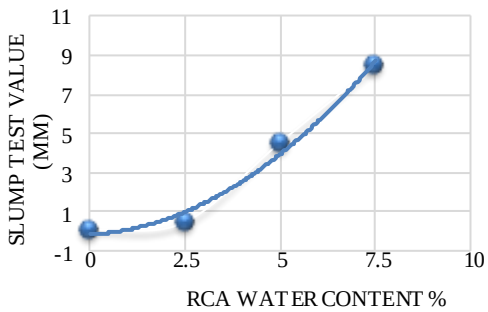

Fig. 3 Slump values vs extra W/C

The increase in slump values may be due to the increase in the proportion of W/C added to RCA, and as a result the best concrete workability because of the access to the desired water content which voids in the old cement mortar has been filled by. The slump values at 2.5% of W/C were 0 may be recommended for produce slabs of precast concrete pavement [13, 15]. There is an inverse association between strengths and workability of concretes after 2.5% of W/C.

2) Compressive Strength of Concrete with Pre-Wetting of 45%-RCA

The maximum compressive strength value of concrete was at 2.5% extra W/C after 28 days of curing compared with the rest of the mixtures as exposed in the Fig. 4. At 0%, 5%, and 7.5% of extra W/C, the compressive strength after 7 or 14 days were approximately equal. An important difference was observed after 28 days of curing related to 7 and 14 day for 0%, 2.5%, 5% and 7%. These results confirm with found by related research, Guerzou and other in 2018 [21]. The pre-wetting RCA did not deplete the amount of water required for the hydration process of cement and this leads to developed mechanical strengths with pre-wetting of RCA. Based on preceding analysis, the 2.5% of extra W/C has a more workability compared to the 0% of extra W/C. Consequently, a percentage of 2.5 extra W/C with 45% - RCA can be adopted as the control mixes to compare it with the compressive strengths of modified concrete mixes. While other extra W/C (0, 5, 7.5%) can also be used for several other purposes discussed before.

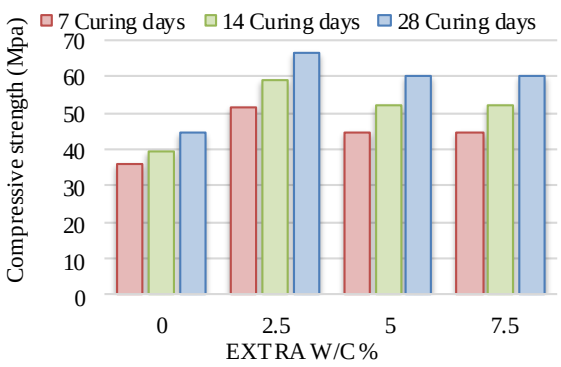

Fig. 4 Compressive strength vs extra W/C

C. *Modified Mixes.*

1) Adding of natural additives (QSS) with 45%-RCA to the concrete mix.

There is an improvement in the compressive strength value of 45%-RCA mixes as QQS % increase as presented in the Fig. 5, where the increase up to 68% at 20% of QSS compare with 0% of QSS after 28 of curing. It is clearly that the compressive strength is influenced by the number of days of water immersion. It is a result of close with the findings of Kou SC and other in 2011[6].

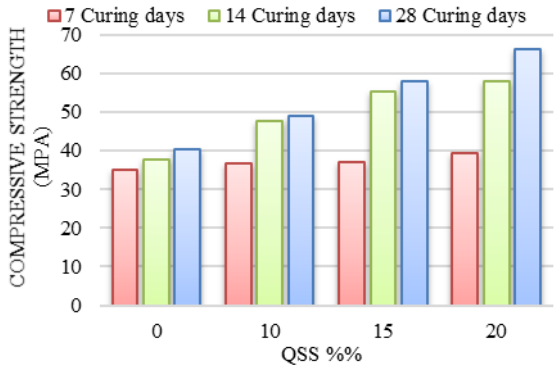

Fig. 5 Compressive strength of modified RCA mixes with QSS after 7, 14 and 28 days of curing

This improvement in the compressive strength may be due the increase the pozzalonic reaction resulting from increased effectiveness of hydration. The reaction between silica and lime leads to improved compressive strength, where the lime created during cement hydration. Additional calcium silicate hydrate are formed increasingly slowly and thus the formation of a very soft materials that helps cohesion and fill in the voids [13].

2) Adding of industrial additives (IF) with 45%-RCA to the concrete mix

The maximum compressive strength values of concrete were at 20% of IF after 28 of curing relating to those mixtures containing 10% and 15% of IF as showed in the Fig. 6. For the number of days of water immersion, the compressive strength of concrete at 20% of IF after 28 days increases by 9% and 21% more than 14 and 7 days of curing respectively. IF has a high toughness which gives higher values of compressive strength [13]. This is consistent with what Alzaed, A. N., 2014[3] got.

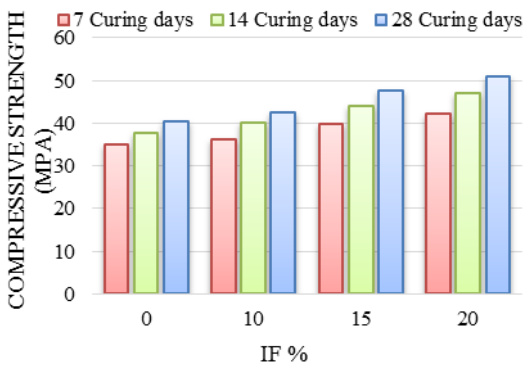

Fig. 6 Compressive strength of modified RCA mixes after 7, 14 and 28 days of curing

3) A comparative analysis between pre-wetting of RCA and 20% of SP, and 20% of QSS.

Fig. 7 shows the compressive strength values of pre-wetting of RCA, 20% of IF, 2.5% SP and 20% of QSS of the 45%-RCA concrete mixes after 7,14, and 28 days of the immersion in water. It can be reached to a good strength by pre-wetting of RCA without adding any additives (QSS, IF, and SP), where it reached up to 66.5 MPa.

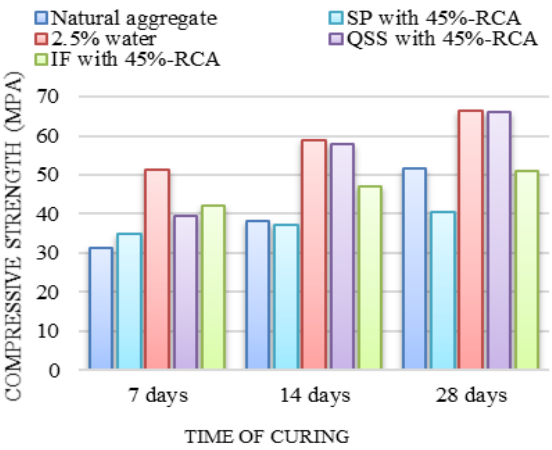

Fig. 7 Comparative analysis between pre-wetting of RCA, SP, IF, and QSS

The analytical study shows a considerable enhancement of the compressive strength of 2.5% pre-wetting of RCA with 45%-RCA relative to the SP, QSS, IF, where the increase in the compressive strength was 64% and 28% at 2.5% pre-wetting of RCA relative to SP-45% RCA and NA respectively. Approximate equivalence can be observed between both QSS-45% RCA and 2.5% pre-wetting of RCA, and also there is a steadily increasing in the compressive strength by increasing the water immersion time. As well as the effect of adding IF to the RCA is less than the addition of QSS. Finally, the addition of SP to RCA mixes seems somewhat weak compared to both QSS and IF.

IV. CONCLUSION

In this research, fresh and hardened characteristics of concrete mixtures made by pre-wetting of RCA or adding 20% of IF, 2.5% SP and 20% of QSS after 7, 14, and 28 days of the immersion in water were determined and can be summarized those results through the following.

1. Concrete mixes with 45%-RCA replacement and extra water of 2.5% of W/C have yielded satisfactory results so that they can be used in high-strength concrete where it reached 66.5 MPa after 28 days of the immersion in water after 28 days of the immersion in water, while other extra W/C can also be used for several other purposes of construction.
2. The increase in the compressive strength was 64% and 28% at 2.5% pre-wetting of RCA relative to SP-45% RCA and natural aggregate respectively.
3. Pre-wetting of RCA can give less than the cost of other mixtures that require greater cost and time wasted when preparing these mixes.
4. The addition of 20% of QSS to 45%-RCA mixes has an almost equal effect to pre-wetting RCA with 2.5% of extra W/C, where the compressive strength was also 66.2 MPa after 28 days of the immersion in water.
5. IF and SP can added to concrete mixes and give a good compressive strength and can used for pavement structure,
6. As RCA ratio used in the concrete mix reduced the compressive strength and workability of concrete improve.
7. The RCA have a greater water absorption than NA.

ACKNOWLEDGEMENTS

The authors are thankful to the Middle East University, Amman, Jordan for the financial support granted to cover the publication fee of this research article.

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