# Mechanical Performance Of Self-Compacting Concrete Incorporating Recycled Aggregate: A Review

**Khaleel H. Younis, Shkar Latif**

**Abstract:** The construction of huge concrete structures with gradually complex designed forms that have congested reinforcement has been increased. Therefore, the need to improve the current practices of concrete technology to introduce new kinds of concrete with superior properties has attracted the researchers to conduct more studies in this regard. As a result, the researchers achieved their goal and developed a new kind of concrete which is known as self-compacting concrete (SCC). Meanwhile, one of the biggest challenges facing the industry of the civil engineering is how to be eco-friendly. One way is by using the natural resources judiciously in construction practices. Another way is by utilization of recycled materials in the production of concrete. The amount of the destructed and demolished waste that has been increased due to the great request of materials of construction in current years put an enormous pressure on nature. So, this has made the use of recycled aggregate in concrete a vital step towards eliminating the depletion of the natural resources of aggregate, sustainability enhancement and protecting the environment. This paper presents a review on the effect of recycled concrete aggregate (RCA) on the mechanical properties of self-compacting. Despite the reduction in its mechanical properties, SCC made with RCA can be easily used in constructing structural elements and help in enhancing the sustainability of concrete.

**Index Terms:** Compressive strength, Construction waste, Modulus of elasticity, Self-compacting concrete, Recycled aggregate, Tensile strength,

## 1. INTRODUCTION

Urbanization has lead the need for constructing large concrete structures that characterized with complicated designed shapes and congested reinforcements a necessity. Thus, encourages the investigators attempt to enhance the current concrete technology practices and develop new modern concrete. A new kind of concrete has been invented by the Japanese researchers in 1980 which’s called self-compacting concrete. SCC is a kind of concrete that preserves its homogeneity and flows under its particular weight in its state of plastic during filling any form even surrounding the congested reinforcement of the framework, attaining compaction without vibrating mechanically. The construction generation and waste of demolition has been growing each year around the world beside inventing this type of concrete. Each year in sites of construction, a large amount of waste of construction is produced from demolition sites, material factories, construction sites, natural disasters, earthquakes and construction materials[1],[2],[3]. A significant problem is caused due to lack of disposal sites as there is no place for disposing and eliminating the wastes specifically around huge cities. On the other hand, the activity of construction is urged due to urbanization; hence use of natural aggregate in concrete is increased extremely. Also, construction of sustainable concrete must be considered to overcome this issue in industry of construction. To attain these, discovering another technique is method to utilize the waste of demolition and construction efficiently in production of a new type of concrete [2],[4],[5]. There is an enormous importance of using and recycling of waste of concretes in protection of nature, because protects the nature by minimizing the use of resources of natural aggregate and it can decrease the pollution of environment [2],[6],[7]. In the next sections, a comprehensive review about the mechanical properties of self-compacting concrete incorporating recycled concrete coarse aggregate (RCA) is presented. The review includes the compressive strength, tensile strength and modulus of elasticity.


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## 2 LITERATURE REVIEW

The recycled concrete aggregate that attained from the wastes of concrete has been used in producing new concrete as a substitute to natural aggregate in past few years[9]. RCA can be used in many applications of concrete as an alternative to NAC including demanding and popular applications like self-compacting concrete. The application of using recycled concrete aggregate as partial substitute for fine and coarse aggregate in self-compacting concrete is established by the scholars[10]. The properties of SCC prepared with coarse RCA without mineral admixtures has been studied and proved that for producing self-compacting concrete RCA can be used successfully [11] .

### 2.1 Compressive strength

Salesa, et al. [12] investigated the physio-mechanical properties of SCC made with precast concrete rejects. Different concretes (Control, RC1, RC2 and RC3) compressive strength data were compared for different days (2, 7 and 28 days). The normality assumption of concrete parameters under investigation was checked by Shapiro-Wilk test in this study by using the t-tests compared after verifying the parametric behaviour. P-values below 0.05 are considered as statically important and all tests are two tailed. Table 1 shows the results.

**TABLE 1**.
RESULTS OF STUDENT'S T-TEST COMPRESSIVE STRENGTH AND SHAPIRO-WILK TEST [12].

| Tested Age (days) | Concrete type 1 | Concrete type 2 | Shapiro-Wilk test | | | Student's *t*-test | |
|---|---|---|---|---|---|---|---|
| | | | *p*-value Concrete Type 1 | *p*-value Concrete Type 2 | Normal Distribution | *p*-value | Statistical significant Differences |
| 2 | RC1 | Control | 0.059 | 0.817 | Yes | <0.0001 | Yes |
| | RC2 | Control | 0.256 | 0.817 | Yes | <0.0001 | Yes |
| | RC3 | Control | 0.389 | 0.817 | Yes | <0.0001 | Yes |
| | RC2 | RC1 | 0.256 | 0.059 | Yes | 0.0012 | Yes |
| | RC3 | RC1 | 0.389 | 0.059 | Yes | 0.0021 | Yes |
| | RC3 | RC2 | 0.389 | 0.256 | Yes | 0.1675 | No |
| 7 | RC1 | Control | 0.919 | 0.710 | Yes | <0.0001 | Yes |
| | RC2 | Control | 0.247 | 0.710 | Yes | <0.0001 | Yes |
| | RC3 | Control | 0.239 | 0.710 | Yes | 0.0002 | Yes |
| | RC2 | RC1 | 0.247 | 0.919 | Yes | <0.0001 | Yes |
| | RC3 | RC1 | 0.239 | 0.919 | Yes | 0.0252 | Yes |
| | RC3 | RC2 | 0.239 | 0.247 | Yes | 0.2716 | No |
| 28 | RC1 | Control | 0.159 | 0.404 | Yes | <0.0001 | Yes |
| | RC2 | Control | 0.249 | 0.404 | Yes | <0.0001 | Yes |
| | RC3 | Control | 0.338 | 0.404 | Yes | <0.0001 | Yes |
| | RC2 | RC1 | 0.249 | 0.159 | Yes | 0.0079 | Yes |
| | RC3 | RC1 | 0.338 | 0.159 | Yes | 0.0240 | Yes |
| | RC3 | RC2 | 0.338 | 0.249 | Yes | 0.2587 | No |

The compressive strength of normal concrete is lower than concretes with recycled aggregate at all ages as shown by T-test. There are no significant differences between RC3 and RC2 (p-values below 0.05) among RCAs, but there is difference among RC3, RC2 AND RC1. Fig 1 shows the declarations in the boxplots of compressive strength, where establishes the compressive strength boxplots from all investigated concretes. An improving linear tendency is observed in all concrete compressive strengths, the difference among all groups are shown in identical way in all phases [12].

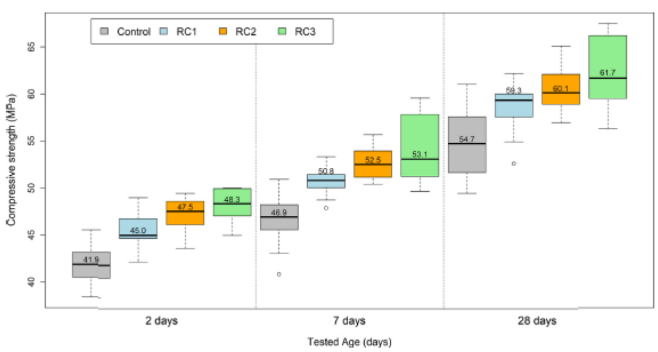



***FIG. 1.*** *Boxplots of compressive strength [12].*

Normal concrete's superior strength that compared with recycled concrete aggregate is noted graphically, however the difference is less between the recycled concretes, specifically among RC3 and RC2. Recycled concretes compressive resistance increments are 7.7%, 10.9% and 13.8% for RC1, RC2 and RC3 individually as shown in Fig 2. The compressive strength of RC1 is lower than RC2 and RC3, although the difference between RC2 and RC3 is small and cannot be confirmed statistically that both concretes are different (p-values >0.05) [12].

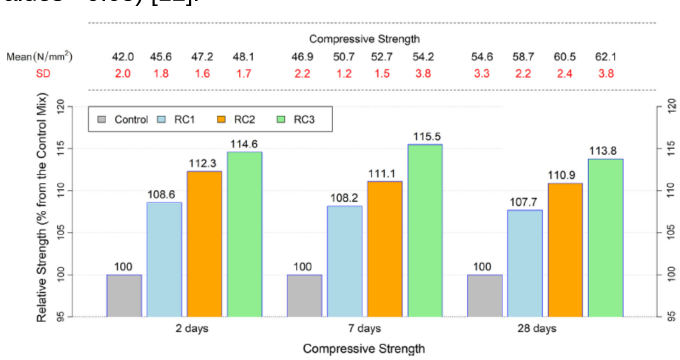


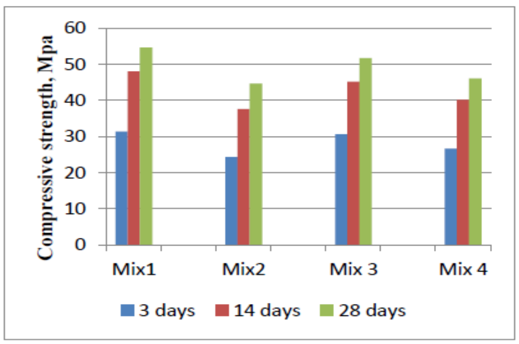

***FIG. 2.*** *Different concrete mixes' relative compressive*

strengths (mean values) [12]. In an experiment conducted by Kou and Poon [10], the researchers evaluated the self-compacting concrete's fresh and hardened properties that made with recycled aggregate as both fine and coarse aggregate. Three mixes of self-compacting concrete with 100% coarse recycled aggregate (CRA) has been prepared and to replace river sand different levels of fine recycled aggregate (FRA) has been used. For all mixtures of the concretes the concrete content was kept constant. The mixtures of the SSC were prepared with, 25, 50, 75 and 100% FRA, the equivalent ratio of water-to-binder in Series I and II for the SSC mixes were 0.53 and 0.44. For Series III, SCC mixtures were prepared with 100% recycled aggregate (both fine and coarse), but three different ratios of W/B (0.44, 0.40 and 0.35) were used. Table 2 presents the results of compressive strength of the RA-SCC mixtures in Series I, II and III. Each presented value is the average of three measurements. Replacement of combination of 25% and 50% of FRA and RCA respectively, showed no significant effect on the compressive strength of Series I in SSC mixes at 28 days. However, compressive strength at early ages of (1, 4 and 7-day) was reduced slightly as replacement of FRA increased 50 to 100%). The compressive strength in Series I of the RA-SCC mixes prepared with 75% and 100% was nearly 10% lesser than that of the control-1 at late ages of curing (28 and 90-day) [10].

**TABLE 2**.
RA-SCC mixtures in Series I, II and III 's Compressive strengths [10].

| Mix code | Recycled agg. fine (%) | W/B | Compressive strength (MPa) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1-day | 4-day | 7-day | 28-day | 90-day |
| *Series I* | | | | | | | |
| Control-1 | 0 | | 10.3 | 26.8 | 32.9 | 44.3 | 56.5 |
| RF25 | 25 | | 11.2 | 29.0 | 34.0 | 44.5 | 54.7 |
| RF50 | 50 | 0.53 | 8.8 | 25.3 | 31.1 | 43.4 | 55.7 |
| RF75 | 75 | | 9.4 | 26.0 | 29.7 | 41.3 | 50.8 |
| RF100 | 100 | | 9.8 | 23.6 | 29.2 | 38.7 | 50.1 |
| *Series II* | | | | | | | |
| Control-2 | 0 | | 11.1 | 30.3 | 36.8 | 53.7 | 78.9 |
| RF25 | 25 | | 13.8 | 38.3 | 43.9 | 64.3 | 82.6 |
| RF50 | 50 | 0.44 | 17.5 | 38.4 | 42.1 | 62.3 | 81.4 |
| RF75 | 75 | | 13.8 | 32.3 | 40.9 | 56.3 | 75.3 |
| RF100 | 100 | | 15.1 | 29.2 | 38.3 | 53.2 | 71.7 |
| *Series III* | | | | | | | |
| RF100A | 100 | 0.44 | 15.1 | 29.2 | 38.3 | 53.2 | 71.7 |
| RF100B | 100 | 0.40 | 15.6 | 33.1 | 44.0 | 59.1 | 77.0 |
| RF100C | 100 | 0.35 | 16.6 | 39.8 | 43.8 | 64.2 | 81.8 |

The compressive strength of mixture of Series I SCC was different from Series II. Due to the minimized ratio of water-to-binder of Series II SCC mixes the compressive strength of Series I SCC was lower than Series II SCC mixtures. Compressive strength of the control-2 was lower than RA-SCC mixes at early ages age (1, 4 and 7-day) as shown in table 2. Increase of compressive strength of RA-SCC mixes was clearer for the sand replacement mixtures of (25 and 50%). Additionally, the compressive strengths of the control-2 at the later ages (28 and 90 days) was lower than the RA-SCC mixtures prepared with 25% and 50% fine recycled aggregates as shown in Table 2. Compressive strengths at the 28 and 90-day of the SCC mixes prepared with 75% and 100% fine recycled aggregates strengths were close to those of the control-2, excluding compressive strength of the concrete mixtures with 100% fine recycled aggregate at 90-day. The compressive strength of Series III in RA-SCC mixtures prepared by using 100% fine recycled aggregate as the fine aggregate is presented in table 2. As anticipated as the W/B ratio reduced the compressive strength improved at all the test ages [10]. Bommareddy [13] conducted an experimental study on the effect of RCA on self-compacting concrete's fresh and mechanical propertied and durability behavior of 20 mixtures of concrete. Based on the recycled concrete aggregate content: 0, 25, 50, 75, the mixes were separated to five groups, with constant ratio of 0.38 of water-to-cementitious material, and 100% of coarse aggregate replaced by RCA. Normal concrete mixes of each group designed with 100% Portland cement, whereas the other mixes were prepared with 50% of portland cement replaced by a mixture of additional cementitious materials (SCMs) such as granulated blast furnace slag and class C fly ash. Figures 3 and 4 demonstrate the impact of adding of SCMs to the mixtures of SCC concrete including, slag, fly ash and together slag and fly ash. Compressive strength at 3, 14 and 28-days decreased as a result of adding of S and FA. Although compressive strength's decrease was higher in the mixes with FA than the mixes with FA and S or S. Figure 3 shows that the compressive strength at 28 days for mixes 2,3, and 4 were fewer than control mix by 18.32, 5.3, and 15.6%, respectively.

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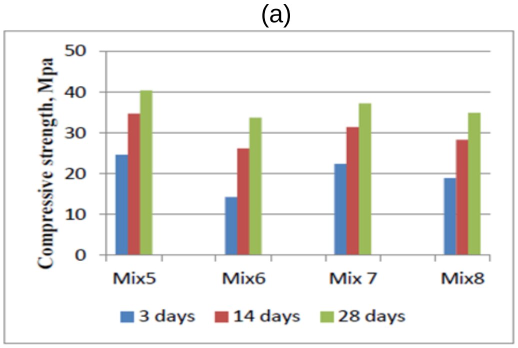


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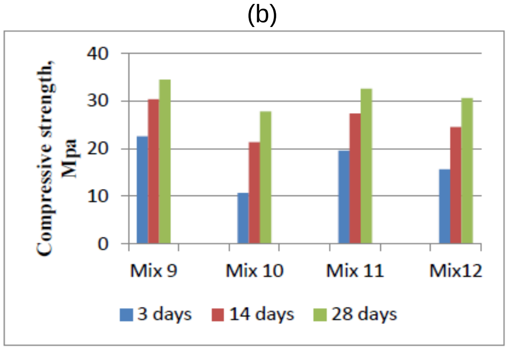


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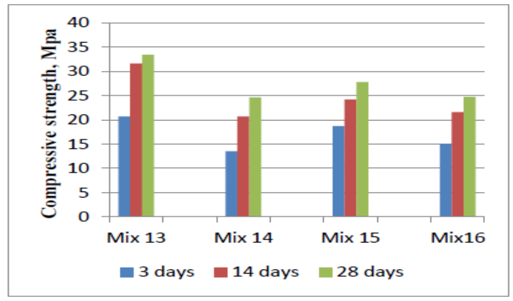


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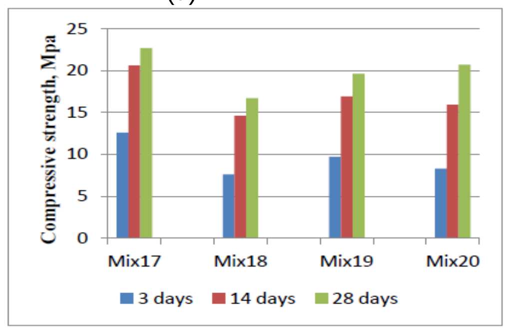
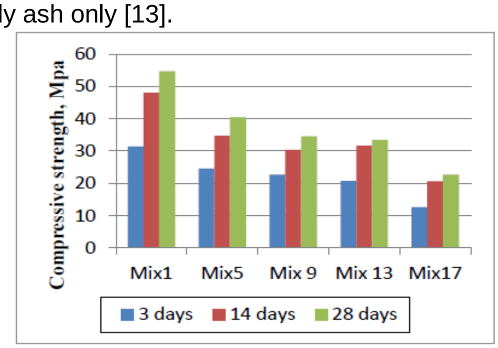



(e)

***FIG. 3.*** *compressive strength of self-compacting concrete : a) 0 % RCA content, b) 25 % RCA content, c) 50 % RCA content, d) 75% RCA content, e) 100% RCA content [13].*

Similar trend was observed for mixtures with 25, 50, 75, and 100% RCA. The 3, 14, and 28-days compressive strength were affected minimally by the addition of slag. Compressive strength of the control mixture at 3-days was more than mixtures with RCA by 2.55%, while compressive strength at 14 and 28-days was more by 5.833% and 5.3%, correspondingly. Though for the mixtures with flay ash recorded the minimum compressive strength between all mixtures, that the decrease was 22.61, 21.7, and 18.32% after 3, 14, and 28 days correspondingly as compared to the normal mixtures. The same trend was investigated at 3, 14, and 28 days mixtures for the cases of 25, 50, 75, and 100% RCA. As revealed in figure 4 mixtures with both 25% slag and 25% fly ash had an intermediate strength between those with 50 % slag and 50% fly ash only [13].

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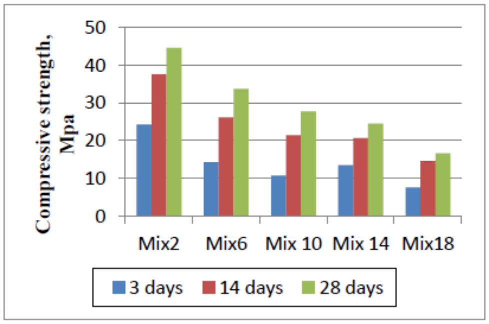


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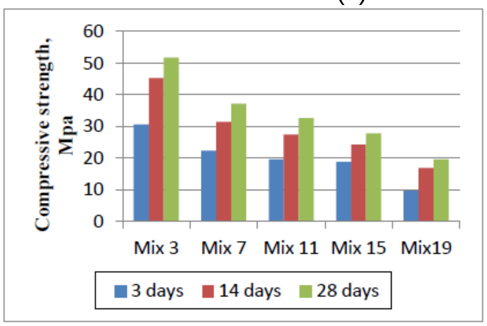


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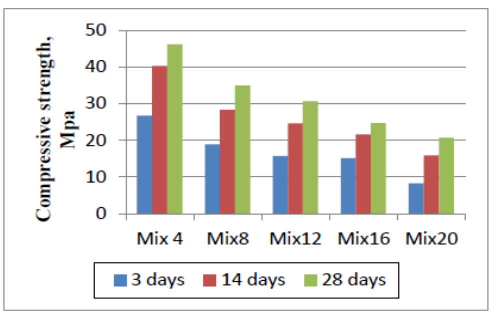


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***FIG. 4** compressive strength of self-compacting concrete: a) SCC-control, b) SCC-fly ash, c) SCC-slag, d) SCC-fly ash & slag [13].*

In another investigation [8], the durability and performance of SCC with natural pozzolan and RCA was studied. Figure 5 presents the results of (NSCC and RSCC)'s compressive strength. With increasing the amount of natural pozzolan the NSSC strength reduced as it is obviously seen in Fig 5. Likewise, the strength for all ages reduced for RSCC, though for higher content of natural pozzolan the strength improved slightly at later ages (120 days). This may be because of the pozzolanic activity of natural pozzolan that has a high SiO2 amount [8].

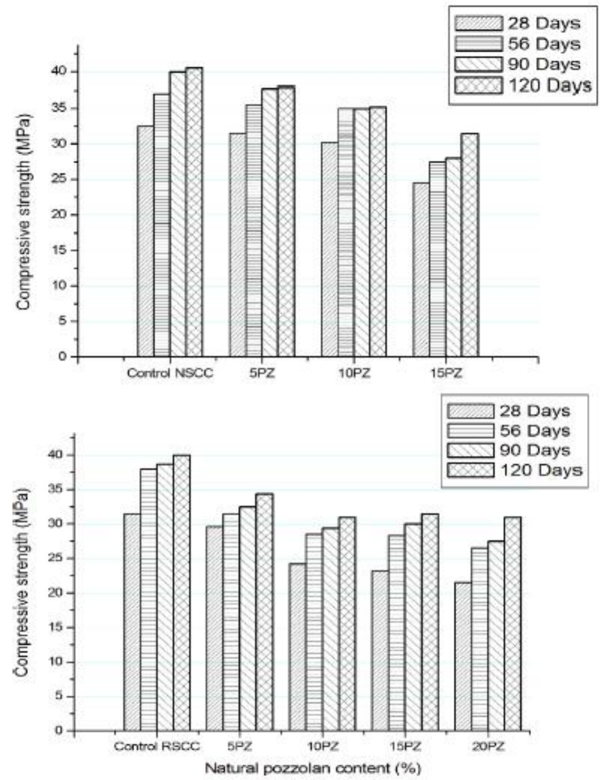



***FIG. 5**. RSCC and NSCC Compressive strength vs natural pozzolan content (%) [8].*

In an investigation, the impact of using RA on SCC's fresh and hardened properties was observed by [1]. The potential of using the RA attained from waste of crushed demolition for SCC production was investigated in this research. Table 3 presents the compressive strength for all mixtures of concretes at 7 and 28 days. It's obvious that decrease of the compressive strength as compared to NASCC is marginal up to 50 % substitution of NA with RA. When compared with NASCC the compressive strength of RASCC 75 and RASCC 100 mixes is decreased around 10–20 % [1].

**TABLE 3.**

HARDENED PROPERTIES OF VARIOUS SCC MIXES [1].

| S. No. | Mix designation | Compressive strength, N/mm$^2$ | | Split tensile strength, N/mm$^2$ | Flexural strength, N/mm$^2$ |
|---|---|---|---|---|---|
| | | at 7 days | at 28 days | | |
| 1 | NASCC | 22.6 | 36.2 | 3.50 | 5.29 |
| 2 | RASCC 25 | 21.5 | 35.4 | 2.91 | 3.52 |
| 3 | RASCC 50 | 20.4 | 34.7 | 2.33 | 3.02 |
| 4 | RASCC 75 | 17.9 | 32.8 | 1.95 | 2.58 |
| 5 | RASCC 100 | 16.4 | 30.3 | 1.45 | 2.89 |

Designing and characterizing steel-fibre-reinforced self-compacting concrete using recycled aggregates (SFR-SCC-RA) is studied in an experiment. As shown in Table 4, six different dosages of concrete were designed, two physical and mechanical characterization programs were also used. The concrete with natural aggregate NA/SC 12 recorded scientifically a higher compressive strength than the concrete with recycled aggregate. The difference for concrete plant is as high as 6.1% (7 d) and 5.7% (28 d), whereas the ranges are 44.1% (7 d) and 39.0% (28 d) for procedures of laboratories. Though the compressive strength that attained in concrete plants are, on average, 16.9% (7 d) and 8.3% (28 d) lesser than those attained in laboratory [14]. According to the others scholar's results [15], the difference among the concrete produced with recycled aggregate and the concrete produced with natural aggregate for concretes produced with water-to-cement ratio close to 0-40 can reach 25%. For cement content of 325 kg/m3 and water-to-cement ratio of 0.50 a 20%–25%, a decrease in compressive strength is found by Etxeberria, et al. [10], in those cases which the coarse aggregate was totally substituted by recycled aggregate utilizing a pre-saturation of the aggregate process [14].On the other hand, the compressive strength of normal concrete is comparable to that of concretes made with recycled aggregate with water-to-cement ratio > 0.55, even up to 100% of replacement[11]. Due to pozzolanic reactions combined with an internal curing process caused by the reservation of absorbed water during concrete manufacturing, Gonzalez-Corominas and Etxeberria [12] attribute this favorable strength behavior of recycled ceramic aggregate to a certain binding capacity [14].

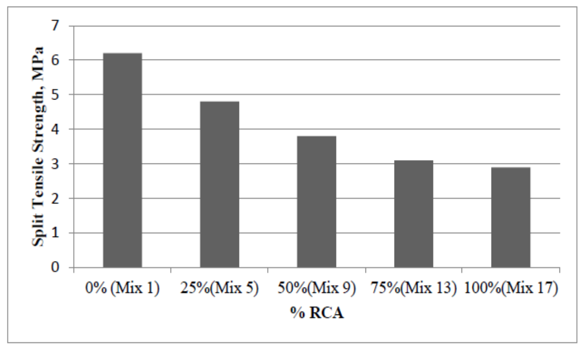
**TABLE 4.**
Average characteristic fck and compressive strength fcm of test specimens (CV in %) at 7 and 28 d[14].

| Dosage | $f_c$ (7 d) | | | | $f_c$ (28 d) | | | |
|---|---|---|---|---|---|---|---|---|
| | Plant | | Laboratory | | Plant | | Laboratory | |
| | $f_{cm}$ (N/mm$^2$) | $f_{ck}$ (N/mm$^2$) | $f_{cm}$ (N/mm$^2$) | $f_{ck}$ (N/mm$^2$) | $f_{cm}$ (N/mm$^2$) | $f_{ck}$ (N/mm$^2$) | $f_{cm}$ (N/mm$^2$) | $f_{ck}$ (N/mm$^2$) |
| NA/SC 12 | 26.21 (2.44) | 25.16 | 52.31 (4.14) | 48.76 | 35.03 (6.02) | 31.57 | 61.48 (1.88) | 59.58 |
| RA/SC 12 | 24.62 (3.13) | 23.36 | 29.58 (7.12) | 26.13 | 33.16 (2.53) | 31.78 | 37.48 (2.26) | 36.09 |
| RA/SC 20 | 26.10 (3.49) | 24.61 | 36.29 (8.03) | 31.51 | 35.03 (4.48) | 32.46 | 42.22 (7.22) | 37.22 |
| RA/SC 20+I | 27.08 (2.84) | 25.82 | 32.31 (6.24) | 29.00 | 33.06 (2.27) | 31.83 | 39.57 (0.57) | 39.20 |
| FRC-RA/SC 12–35 | 30.32 (1.68) | 29.48 | 29.23 (9.31) | 24.77 | 37.33 (0.56) | 36.99 | 38.09 (7.29) | 33.54 |
| FRC-RA/SC 20–50 | 34.60 (4.25) | 32.19 | 38.01 (2.98) | 36.71 | 44.28 (1.90) | 42.90 | 38.20 (1.77) | 37.09 |

At the end of this part, it can be concluded that using recycled aggregate in SCC has positive influence on its compressive strength. At all ages of the tests the compressive strength of normal concrete is lower than concretes with recycled aggregate. An improving linear tendency is observed in all concrete compressive strengths, the difference among all groups are shown in identical way in all phases. The W/B ratio reduced the compressive strength improved at all the test ages. Compressive strength of the control mixture at 3-days was more than mixtures with RCA by 2.55%, while compressive strength at 14 and 28-days was more by 5.833% and 5.3%, correspondingly. For the mixtures with flay ash recorded the minimum compressive strength between all mixtures, that the decrease was 22.61, 21.7, and 18.32% after 3, 14, and 28 days correspondingly as compared to the normal mixtures. 4 mixtures with both 25% slag and 25% fly ash had an intermediate strength between those with 50 % slag and 50% fly ash only. the difference among the concrete produced with recycled aggregate and the concrete produced with natural aggregate for concretes produced with water-to-cement ratio close to 0-40 can reach 25%. On the other hand, the compressive strength of normal concrete is comparable to that of concretes made with recycled aggregate with water-to-cement ratio > 0.55, even up to 100% of replacement.

## 2.2 Tensile strength

In the same study of Bommareddy [13] that used 20 samples of concrete tensile strength also investigated. The tensile strength for all samples at 28 days are shown in Fig 6. The results are organized to demonstrate the impact of substitution of CA by different amounts of SCC-fly ash, RCA SCC-normal, SCC-fly ash & slag, and SCC-slag as presented in Figure 7a-d individually. The tensile strength of all samples reduced as the content of RCA increased from 0 to 100%. The lowest recorded was 1.8 MPa (261 psi) which corresponds to (Mix 18) of 100% RCA and 50% fly ash, whereas the highest tensile strength recorded was 6.2 MPa (899 psi) which corresponds to the normal sample (Mix1) of 0% RCA and 100% cement. The tensile strength for all different RCA contents improved by substituting the cement by 50% slag compared to substituting it by 25% slag and 25% fly ash and 50% fly ash [13].

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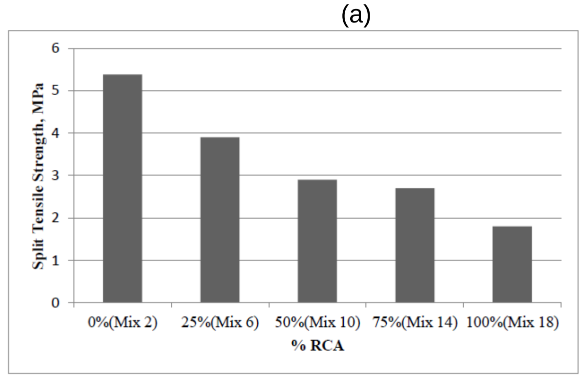


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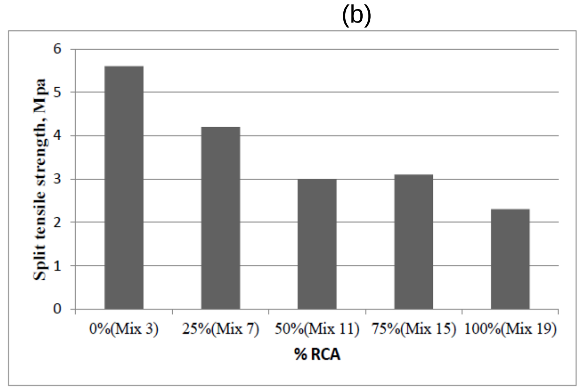


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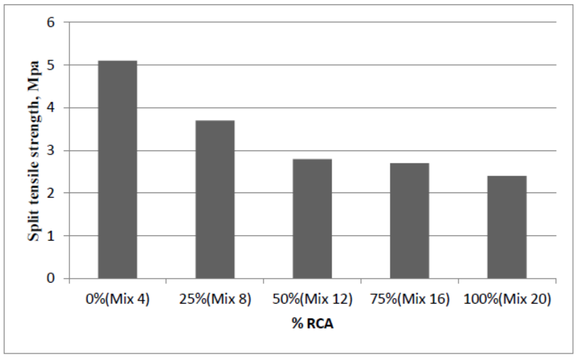


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***FIG. 7.*** *Split tensile strength of SCC: a) SCC-control, b) SCC-fly ash, c) SCC-slag , d) SCC-fly ash & slag [13]*

In the same experiment of p. By conducting the bending test, the tensile strength of self-compacting concrete samples at 28 days demonstrated. For all substitution amounts of Ra, the tensile strength of NASCC is higher than RASCC. The microstructures of RAC mixtures are the causes of this decrease of tensile strength. RA has two components: cement paste and natural aggregate, as compared to natural aggregate, that bounds to RA and decreased the quality to a certain level. The reason of lesser compressive and tensile strength, higher absorption capacity, lesser abrasion resistance, and minor density is the old cement paste[1]. In another research, the scholars studied the impact of 2 kinds of superplasticizers on the mechanical performance of the concrete mixtures with FRA. Figure 8 shows the results of the tensile strength. Fig 9 presents as function of ratio of substitution of aggregate and the relative differences. The relative variations as a function of the superplasticizer used (DWS) for each FRA incorporation value and as a function of the FRA combination ratio (DFRA) for a given superplasticizer is given along the absolute value[19].

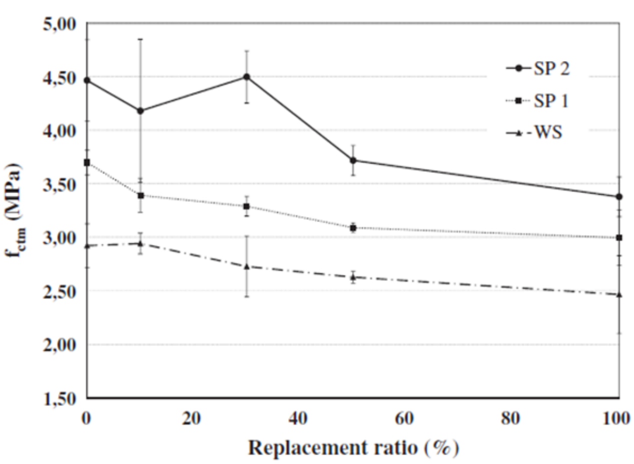


***FIGURE 8****. FNA/FRA replacement ratio and Splitting tensile strength at 28 days[19].*

The splitting tensile of the normal mixtures were of 2.9 MPa (without admixture), 3.7 MPa (SP 1) and 4.5 MPa (SP 2), while, when fine recycled aggregate was combined decreased by up to 15.6%, 19.0% and 24.3%. The tensile strength improved up to 26.6% and 52.8% when SP 1 and SP 2, correspondingly when superplasticizers added to the mixture. This means that the negative impacts of using fine recycled aggregate can be ignored by using superplasticizers[19].

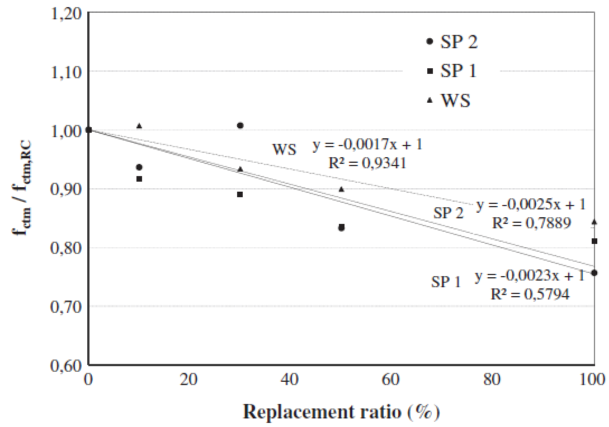


***FIG. 9****. FNA/FRCA replacement ratio and splitting tensile strength at 28-day of relative FRAC [19].*

By incorporating fine recycled aggregate either without superplasticizers or with them the tensile splitting strength decreases (from 15.6% to 24.3%); fine recycled aggregate concrete yield better with superplasticizers, absolute results (from 26.6% to 52.8%), the admixtures in fine recycled aggregate concrete is worse even within each studied family of concrete (i.e. comparing the enhancement in RC with that in FRAC)[19].In the same study that was done by Kou and Poon [4] the tensile splitting strength is also examined. Fig 10 determines the tensile strength at 28 days in Series I, II and III of the self-compacting concrete. It's obvious that 28-day tensile splitting strengths of the control-1 mix was somewhat higher than of the RA-SCC mixes in Series I. While tensile splitting strength of control-2 was lower than Series II mixtures, this is similar to the results of the compressive strength test.

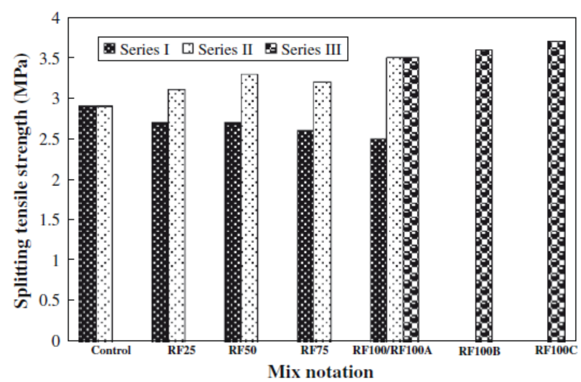


***FIG. 10****. RA-SCC Splitting tensile strength at 28 days in Series I, II, and III [10].*

By the end of this section, it can be decided that utilizing recycled aggregate in SCC has negative influence on its tensile strength as determined by most studies. For all substitution amounts of Ra, the tensile strength of NASCC is higher than RASCC. The reason of lesser compressive and tensile strength, higher absorption capacity, lesser abrasion resistance, and minor density is the old cement paste. The tensile strength for all different RCA contents improved by substituting the cement by 50% slag compared to substituting it by 25% slag and 25% fly ash and 50% fly ash. The lowest recorded was 1.8 MPa (261 psi) which corresponds to (Mix 18) of 100% RCA and 50% fly ash, whereas the highest tensile strength recorded was 6.2 MPa (899 psi) which corresponds to the normal sample (Mix1) of 0% RCA and 100% cement. Similar results were also observed in other studies [20], [21], [22], [23].

### 2.3 Modulus of Elasticity

Ortiz, et al. [12] studied the modulus of elasticity of SCC incorporating RCA. The average amounts of the modulus of elasticity that attained after the molded test specimens were tested during experimental phase of the laboratory is shown in Table 6. Three specimens of each dosage were tested for ages at 28 days and other three specimens at 365 days. Due to the granular skeleton configuration, the particle size, nature, and content of RA have a greater effect than other mechanical properties on value of modulus of elasticity.The modulus of elasticity of concrete mixes with RA's reduction is between 30% and 35%, the value for twelve dosages of RA/SC with similar value of compressive strength at 365 days approaches the predicted value for normal concrete. The reduction of elastic modulus of concrete mixes with 100 % replacement of recycled coarse aggregate as compared to normal concrete is also observed in this investigation [12].

**TABLE 6.**

Values of elastic modulus of the different dosages in the test specimens molded in the laboratory[12].

| Dosage | RA content (kg/m$^3$) | | | $E_{cm}$ (N/mm$^2$) | |
|---|---|---|---|---|---|
| | 4/12-T-R | 12/20-T-R | Total | 28 d | 365 d |
| NA/SC 12 | 0 | 0 | 0 | 35989 | 42343 |
| RA/SC 12 | 590 | - | 590 | 22973 | 25404 |
| RA/SC 20 | 180 | 360 | 540 | 25363 | 29182 |
| RA/SC 20+I | 200 | 390 | 590 | 24155 | 27317 |

Modulus of elasticity was also investigated by Á. Salesa, et.al. The dynamic and static elastic modulus of all manufactured mixes: recycled (RC1), multi-recycled (RC2 and RC3), and non-recycled (Control) are presented in Fig 11. As predicted the elastic modulus both static and dynamic of normal concrete is more than the mutli-recycled and recycled mixes of concretes. Additionally with each recycled cycle the elastic modulus is decreased[6].With respect to dynamic modulus of elasticity, the elastic modulus of normal concrete is also greater , 16.1%, 4.5%, and 8.1% correspondingly to RC3,RC1, and RC26. Concerning the static modulus of elasticity, the normal concrete has 34.1 GPa, that 17.2% bigger than RC3, and 11.2% larger than RC1 and RC2. [12].

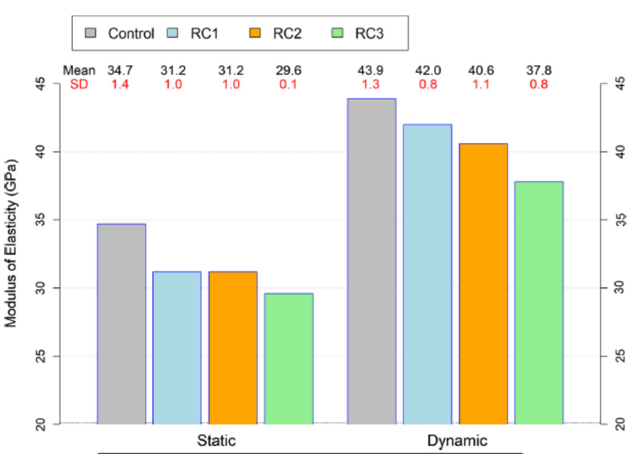


***FIG. 11**. dynamic and Static elastic modulus of different mixes [12].*

It can be decided at the end of this section that utilizing RA in self-compacting concrete has positive influence on its elastic modulus. The reduction of elastic modulus of concrete mixes with 100 % replacement of recycled coarse aggregate as compared to normal concrete. The modulus of elasticity of concrete mixes with RA's reduction is between 30% and 35%, the value for twelve dosages of RA/SC with similar value of compressive strength at 365 days approaches the predicted value for normal concrete. The elastic modulus both static and dynamic of normal concrete was more than the mutli-recycled and recycled mixes of concretes. Additionally, with each recycled cycle the elastic modulus was decreased. Comparable conclusions were drawn by other studies such as [24], [25].

## 4 CONCLUSION

This review paper is a collection of previous works on mechanical performance of self-compacting concrete with recycled aggregate of construction and demolition waste. The following conclusions can be drawn:

1. The compressive strength of normal concrete is generally lower than concretes with recycled aggregate. However, the compressive strength of RAC in most cases is sufficient to construct structural elements.
2. The reduction in the compressive strength depends on the replacing ratio on natural aggregate with the recycled one.
3. The difference among the concrete produced with recycled aggregate and the concrete produced with natural aggregate for concretes produced with water-to-cement ratio close to 0-40 can reach 25%. On the other hand, the compressive strength of normal concrete is comparable to that of concretes made with recycled aggregate with water-to-cement ratio > 0.55, even up to 100% of replacement.
4. Supplementary cementious materials such as fly ash, slag and silica fume can significantly help in improving the compressive strength of recycled aggregate concrete.
5. For all substitution amounts of recycled aggregate, the tensile strength of natural aggregate self-compacted concrete is higher than recycled aggregate self-compacting concrete.
6. The tensile strength for all different RCA contents improved by substituting the cement by 50% slag compared to substituting it by 25% slag and 25% fly ash and 50% fly ash.
7. The elastic modulus both static and dynamic of normal concrete is more than the mutli-recycled and recycled mixes of concretes. Additionally, with each recycled cycle the elastic modulus is decreased.
8. The reduction of elastic modulus of concrete mixes with fully (100 %) replacement of recycled coarse aggregate as compared to normal concrete is higher than partially replacement.

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