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# The Improvement of 28-day Compressive Strength of Self Compacting Concrete Made by Different Percentages of Recycled Concrete Aggregates using Nano-Silica

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***Abstract*—**In this study two series of self compacting concrete mixtures were prepared with 100% coarse recycled concrete aggregates and different percentages of 0%, 20%, 40%, 60%, 80% and 100% fine recycled concrete aggregates. In series I and II the water to binder ratios were 0.50 and 0.45, respectively. The cement content was kept 350 $\frac{kg}{m^3}$ for those mixtures that don't have any Nano-Silica. To improve the compressive strength of samples, Nano-Silica replaced with 10% of cement weight in concrete mixtures. By doing the tests, the results showed that, adding Nano-silica to the samples with less percentage of fine recycled concrete aggregates, lead to more increase on the compressive strength.

***Keywords*—**Compressive Strength, Nano-Silica, Recycled Concrete Aggregates, Self Compacting Concrete.

## I. INTRODUCTION

SELF Compacting Concrete (S.C.C.) is one of new advances in concrete technology that does not require any vibration during the placing process even in congested reinforcement, because it can be able to flow easily, fill the formwork and make a full compaction under its own weight [1]. Beside improved concrete surface in S.C.C., eliminating the vibration process leads to improve the environmental consideration and reduction of the exposure of workers to noise and vibration which have a positive effect in health and safety of workers. In general the materials for S.C.C. are the same as those used in conventional concrete like cement, aggregates and water but the additives are different. The most important basic principle for flowing the S.C.C. is the use of superplasticizer combined with a relatively high content of powder materials in terms of Portland cement, mineral additions, ground filler or very fine sands [2]. Now days because of environmental considerations, economical crisis and the growing trend in reduction of natural aggregates resources, paying attention to use recycled concrete aggregates in concrete (as aggregates) can be helpful. Recycled aggregates can be prepared in demolition of concrete structures. The coarse and fine portions of recycled aggregates can be used instead of natural coarse and fine aggregates. Noori and Salkhordeh reported that when natural coarse aggregates in S.C.C. were replaced by 100% of coarse recycled concrete aggregates and natural fine aggregates replaced by 0%, 20%, 40%, 60%, 80% and 100% of fine recycled concrete aggregates, the 28-day compressive strength of S.C.C. decreases [3].

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## II. MATERIALS

Zanjan Portland cement (type I-425), flay ash and Nano-Silica were used as the cementations materials in S.C.C. mixtures while limestone powder was used as filler. Zanjan Portland cement has the final setting time of 160 minutes and 28-days compressive strengths of 610 kg/cm2, the chemical properties of the cement is shown in Table 1.

To do the tests, the coarse and fine recycled aggregates used from local construction and demolition wastes in Zanjan. The normal size of the coarse recycled concrete aggregates were 20 mm and 10 mm. River sand with fineness modulus of 2.17 was used as the fine natural aggregates while the recycled aggregates with particle size of <5 mm and fineness modulus of 2.62 was used as fine recycled concrete aggregates. Particle size distributions of fine aggregates are shown in Table 2. The density of materials are shown in Table 3. Zanjan potable water is used to mix the concrete materials. The chemical admixtures were superplasticizer (Premia 196) and viscosity agent.

TABLE I
CHEMICAL PROPERTIES OF ZANJAN PORTLAND CEMENT

| $SiO_2$ % | $Al_2O_3$ % | $Fe_2O_3$ % | $TiO_2$ % | CaO % | MgO % | $SO_3$ % | $K_2O$ % | $Na_2O$ % | L.O.I % | Cl % |
|---|---|---|---|---|---|---|---|---|---|---|
| 22.20 | 5.50 | 3.20 | - | 64.90 | 1.50 | 1.40 | 0.70 | 0.30 | 0.50 | 0.008 |

TABLE II
PARTICLE SIZE DISTRIBUTION OF FINE AGGREGATES

| Size of BS Test Sieve (mm) | 5 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---|---|---|---|---|---|---|---|
| River Sand | 100 | 97 | 85 | 68 | 30 | 3 | 0.1 |
| Fine Recycled Concrete Aggregates | 100 | 82 | 65 | 50 | 33.5 | 7.5 | 3 |

TABLE III
DENSITY OF MATERIALS

| Density | Cement | River Sand | Flay ash | Limestone powder | Recycled Aggregates | | |
|---|---|---|---|---|---|---|---|
| | | | | | Coarse | | Fine |
| $\frac{kg}{m^3}$ | | | | | 10 mm | 20 mm | <5 mm |
| | 3075 | 2600 | 2170 | 2750 | 2510 | 2600 | 2350 |

## III. MIX DESIGNS

To do the tests, two series of S.C.C. mixtures with different fine recycled concrete aggregates and water to binder ratios were prepared. In mix designs with no Nano-Silica, the cement content and fly ash were kept respectively 350 and 210 $\frac{kg}{m^3}$. 100% of all coarse aggregates in mix designs were used from recycled concrete aggregates. In series I, twelve different mix designs of S.C.C. were prepared. In these twelve mix designs water to binder ratio of 0.50 was used. No fly ash was added to mixtures. Nano-silica was added with the 10% of cement weight instead of cement in the concrete mixtures. The fine recycled concrete aggregates of 0%, 20%, 40%, 60%, 80% and 100% replaced (by volume) instead of river sand. Mix designs of series I is shown in Table IV.

In series II, twelve different mix designs of S.C.C. were prepared. In these twelve mix designs water to binder ratio of 0.45 was used. To increase the cementation content 70 $\frac{kg}{m^3}$ of fly ash was added to mixtures. Nano-silica was added with the 10% of cement weight instead of cement in the concrete mixtures. The fine recycled concrete aggregates of 0%, 20%, 40%, 60%, 80% and 100% replaced (by volume) instead of river sand. Mix designs of series II is shown in Table V.

## IV. COMPRESSIVE STRENGTH OF THE S.C.C

Compressive strength test is one of the most important and most common tests to know about the resistance of concrete. The compressive strength test was carried out on the concrete specimens according to BS 1881 part 116 [4].

### *A. Compressive strength of series I*

The results of tests conducted on samples of series I, is shown in Table 6. Each of the resulting numbers is the average results of three samples.

*The results in series I show that:*

1) Adding 20 and 40 percent of the fine recycled concrete aggregates have a little effect on the 28-day compressive strength.
2) By adding Nano-Silica the compressive strength increases in all mixtures.
3) The highest compressive strength among the samples with Nano-Silica is the one with 20 percent of the fine recycled concrete aggregates. This shows that the rate of increase is higher in samples with less percentage of fine recycled aggregates.
4) N-FRA (100) with 100% of coarse and fine recycled concrete aggregates can easily be replaced with FRA (20) with 20% of fine and 100% of coarse recycled concrete aggregates from compressive strength view point.

TABLE IV
MIX DESIGNS OF SERIES I

| M.C | R.F.A (%) | $\frac{w}{b}$ | W $\frac{kg}{m^3}$ | C $\frac{kg}{m^3}$ | N.S $\frac{kg}{m^3}$ | F.A $\frac{kg}{m^3}$ | L.P $\frac{kg}{m^3}$ | R.S $\frac{kg}{m^3}$ | F.R.A $\frac{kg}{m^3}$ | C.R.A $\frac{kg}{m^3}$ 10mm | 20mm | S.P $\frac{l}{m^3}$ | V.A $\frac{l}{m^3}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control I | 0 | 0.50 | 175 | 350 | 0 | 0 | 210 | 680 | 0 | 600 | 300 | 9 | 1.5 |
| N-Control I | 0 | 0.50 | 175 | 315 | 35 | 0 | 210 | 680 | 0 | 600 | 300 | 9 | 1.5 |
| FRA(20) | 20 | 0.50 | 175 | 350 | 0 | 0 | 210 | 544 | 122 | 600 | 300 | 9 | 2 |
| N-FRA(20) | 20 | 0.50 | 175 | 315 | 35 | 0 | 210 | 544 | 122 | 600 | 300 | 9 | 2 |
| FRA(40) | 40 | 0.50 | 175 | 350 | 0 | 0 | 210 | 408 | 245 | 600 | 300 | 9 | 2 |
| N-FRA(40) | 40 | 0.50 | 175 | 315 | 35 | 0 | 210 | 408 | 245 | 600 | 300 | 9 | 2 |
| FRA(60) | 60 | 0.50 | 175 | 350 | 0 | 0 | 210 | 272 | 368 | 600 | 300 | 9 | 2 |
| N-FRA(60) | 60 | 0.50 | 175 | 315 | 35 | 0 | 210 | 272 | 368 | 600 | 300 | 9 | 2 |
| FRA(80) | 80 | 0.50 | 175 | 350 | 0 | 0 | 210 | 136 | 490 | 600 | 300 | 9 | 2 |
| N-FRA(80) | 80 | 0.50 | 175 | 315 | 35 | 0 | 210 | 136 | 490 | 600 | 300 | 9 | 2 |
| FRA(100) | 100 | 0.50 | 175 | 350 | 0 | 0 | 210 | 0 | 613 | 600 | 300 | 9 | 2 |
| N-FRA(100) | 100 | 0.50 | 175 | 315 | 35 | 0 | 210 | 0 | 613 | 600 | 300 | 9 | 2 |

M.C: Mix Code, F.R.A: Fine Recycled Aggregate, w/b: water to binder, W: Water, C: Cement, N.S: Nano-Silica F.A: Fly Ash, L.P: Limestone Powder, R.S: River Sand, C.R.A: Coarse Recycled Aggregate, S.P: Superplasticizer, V.A: Viscosity Agent

TABLE V
MIX DESIGNS OF SERIES II

| M.C | R.F.A (%) | $\frac{w}{b}$ | W $\frac{kg}{m^3}$ | C $\frac{kg}{m^3}$ | N.S $\frac{kg}{m^3}$ | F.A $\frac{kg}{m^3}$ | L.P $\frac{kg}{m^3}$ | R.S $\frac{kg}{m^3}$ | F.R.A $\frac{kg}{m^3}$ | C.R.A $\frac{kg}{m^3}$ 10mm | 20mm | S.P $\frac{l}{m^3}$ | V.A $\frac{l}{m^3}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control I | 0 | 0.45 | 192 | 350 | 0 | 75 | 210 | 650 | 0 | 532 | 266 | 9 | - |
| N-Control I | 0 | 0.45 | 192 | 315 | 35 | 75 | 210 | 650 | 0 | 532 | 266 | 9 | - |
| FRA(20) | 20 | 0.45 | 192 | 350 | 0 | 75 | 210 | 520 | 118 | 532 | 266 | 9 | - |
| N-FRA(20) | 20 | 0.45 | 192 | 315 | 35 | 75 | 210 | 520 | 118 | 532 | 266 | 9 | - |
| FRA(40) | 40 | 0.45 | 192 | 350 | 0 | 75 | 210 | 390 | 235 | 532 | 266 | 9 | - |
| N-FRA(40) | 40 | 0.45 | 192 | 315 | 35 | 75 | 210 | 390 | 235 | 532 | 266 | 9 | - |
| FRA(60) | 60 | 0.45 | 192 | 350 | 0 | 75 | 210 | 260 | 353 | 532 | 266 | 9 | - |
| N-FRA(60) | 60 | 0.45 | 192 | 315 | 35 | 75 | 210 | 260 | 353 | 532 | 266 | 9 | - |
| FRA(80) | 80 | 0.45 | 192 | 350 | 0 | 75 | 210 | 130 | 470 | 532 | 266 | 9 | - |
| N-FRA(80) | 80 | 0.45 | 192 | 315 | 35 | 75 | 210 | 130 | 470 | 532 | 266 | 9 | - |
| FRA(100) | 100 | 0.45 | 192 | 350 | 0 | 75 | 210 | 0 | 588 | 532 | 266 | 9 | - |
| N-FRA(100) | 100 | 0.45 | 192 | 315 | 35 | 75 | 210 | 0 | 588 | 532 | 266 | 9 | - |

TABLE VI
COMPRESSIVE STRENGTH OF SERIES I SAMPLES (M.PA)

| M.C | 28-days |
|---|---|
| Control I | 45.60 |
| N-Control I | 72.90 |
| FRA(20) | 45.80 |
| N-FRA(20) | 71.70 |
| FRA(40) | 44.40 |
| N-FRA(40) | 66.20 |
| FRA(60) | 42.10 |
| N-FRA(60) | 57.1 |
| FRA(80) | 41 |
| N-FRA(80) | 50.65 |
| FRA(100) | 39.80 |
| N-FRA(100) | 45 |

### *B. Compressive strength of series II*

The results of tests conducted on samples of series II, is shown in Table 7. Each of the resulting numbers is the average results of three samples.

TABLE VII
COMPRESSIVE STRENGTH OF SERIES II SAMPLES (M.PA)

| M.C | 28-days |
|---|---|
| Control I | 55.20 |
| N-Control I | 91 |
| FRA(20) | 65.60 |
| N-FRA(20) | 106.2 |
| FRA(40) | 62.70 |
| N-FRA(40) | 96.55 |
| FRA(60) | 58.40 |
| N-FRA(60) | 82.20 |
| FRA(80) | 55.50 |
| N-FRA(80) | 72.50 |
| FRA(100) | 54 |
| N-FRA(100) | 66.40 |

*The results in series II show that:*

1) Adding 20 and 40 percent of the fine recycled concrete aggregates have a little effect on the 28-day compressive strength.
2) Samples with 20 and 40 percent of fine recycled concrete aggregates have a higher compressive strength than control sample in 28-days.
3) By adding Nano-Silica the compressive strength increases in all mixtures.

## V. CONCLUSION

From the findings of this laboratory investigation for self compacting concrete made by Nano-Silica and different percentages of fine recycled concrete aggregates, the following conclusions can be extracted:

1) Both coarse and fine natural aggregates can be replaced by recycled concrete aggregates.
2) Adding Nano-silica to the samples with less percentage of fine recycled concrete aggregates, lead to more increase on the compressive strength.
3) N-FRA (100) with 100% of coarse and fine recycled concrete aggregates can easily be replaced with FRA (20) with 20% of fine and 100% of coarse recycled concrete aggregates from compressive strength view point.
4) Because of environmental considerations, economical crisis and the growing trend in reduction of natural aggregates resources, the use of recycled concrete aggregates can be very helpful.

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