Exprimental effect of using silica fume and fly ash on mechanical properties of recycled concretes

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Abstract— **This paper presents the results of a laboratory study on the mechanical performance of recycled concretes prepared with incorporation of two mineral admixtures including silica fume (SF) and fly ash (FA). The recycled aggregates concrete (RAC) was prepared by using 0, 25, 50 and 100% coarse aggregate replacement. The compressive strength, splitting tensile strength (SPT) and ultrasonic pulse velocity (UPV) of concrete mixes were completed. The results showed that the pozzolanic materials cannot have a significant effect on compressive strength loss trend. In contrast, the ultimate compressive strength of recycled concretes strongly effected by pozzolanic materials. The SPT and UPV test results showed that compare with FA, the use of SF reduced the negative effect of high replaced percentage of recycled aggregates.**

Index Terms— **Fly Ash (FA), Silica Fume (SF), Mechanical Properties, Recycled Coarse Aggregate, Recycled Concrete.**

I. INTRODUCTION

In last decades, the use of recycled aggregate (RA)in concrete production is more considerate because of environmental protection, conservation of natural aggregate resources, shortage of waste disposal land and increasing cost of waste treatment prior to disposal [1]. Although much information is already available on the effect of RA on the mechanical properties [2-4], but due to the dependence of the mechanical response of recycled concretes on aggregates quality [5], standards allows limited extends of replacing of recycled aggregates with natural aggregates [6-8]. A bit of change in mechanical properties of recycled concretes have been observed [9, 10]. Most of researchers reported that significant losses in mechanical and durability properties of recycled concretes in high replacement level [11-15].

Several factors has been suggested for the use of RA, which have a significant influence on the compressive strength of concrete, including recycled aggregate replacement level [16], recycled aggregate moisture content [17], Quality of the original material [18], Water to cement ratio [19] and chemical admixtures [20]. Some researchers have tried to modify the weakness of mechanical properties of recycled concretes by adding supplementary cementitious materials (SCM) [21-24]. Kou and Poon [25] tried different levels of cement replacement using FA and suggested 50% replacement on natural aggregates (NA) and 25% of FA as an optimum mix proportion for recycled concretes. Kou et al. [24] studied the effect of adding diffrent mineral admixtures and showed a nearly 10% strength increase for all concrete mixes when 10% SF was added. They suggested that increasing the replacement level of NA with RA has no effect on the SF content required to achieve an increase in strength.

In this study, the influence of two dosages of pozzolanic materials (i.e., 10% SF and 25% FA) were studied. The main reason of choosing this specific dosage of SCMs was their successful application in previous studies [24, 25]. This paper tries to investigate and compare the mechanical properties of recycled concretes made with two types of pozzolans with the same mix proportion. The effect of replacing 10% SF and 25% FA by ordinary Portland cement (OPC) on mechanical properties such as 7 and 28 days compressive strength (F_c), splitting tensile strength (SPT) and ultrasonic pulse velocity (UPV) were investigated.

II. EXPERIMENTAL PROGRAM

In this investigation four levels of coarse aggregate replacement, i.e., 0, 25, 50 and 100% along 10% SF and 25% FA were used. The percentage of recycled coarse aggregates (RCA) replacement were calculated based on total aggregates weight. The mix design was done according to the Iranian Concrete Code (ICC) [26] which targeted a compressive strength of 40 MPa at 28 days. The compressive strength test was done at the age of 7 and 28 days using a total of 48 cubic specimens as 150 x 150 x 150 mm. The SPT and UPV at 28 days were performed on sets of 3 cylinder specimens as 150 x 300 mm for each replacement level. All specimens were casted in ambient conditions and demolded at 24 ± 2 hours after mixing and then were fully submerged in water at temperature 25 ± 2°C until the age of testing according with ASTM C192 [27].

III. MATERIALS

A. Binbers

The cementitious materials (CM) is used in this study were OPC according to ASTM type I, SF obtained from Ferro silica plant and FA type C. The chemical composition of binders are given in Table 1.

Table 1. Chemical composition of cementitious materials (%)

Composition	SiO2	Fe2O3	Al2O3	CaO	MgO	SO3
Micro Silica	94.73	0.87	1.32	0.49	0.97	0.1
Fly Ash	56.7	5.3	28.2	2.8	5.2	0.68
Cement	21.28	3.7	6.1	64.34	2.1	2.13

B. Aggregates

River sand with maximum size (MSA) of 2 mm as fine aggregate and crushed aggregate with a MSA of 19 mm were

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used in the concrete mixes. For this study the NA were replaced with RCA with MSA of 19 mm. The RCA were consist of demolished concrete piles and building projects.

C. *Water and Superplastisizer*

To obtain a proper workability, a poly carboxyl-based superplasticizer (SP) with density 1.1±0.02 g/cm3 was used. The maximum use of 1% of CM weight showed the proper workability and consistency.

IV. IXM REPRATIONP

Two concrete mixes were produced namely, conventional concrete (CC) and recycled coarse aggregate concrete (RC). The CC was prepared with 100% natural aggregates mixes and the RC mixes prepared with 25, 50 and 100% RCA replacement. The recycled concretes containing SF and FA were designed RC-SF and RC-FA, respectively. All mixes were made with constant W/B ratio as 0.36 and 420 kg/m3 CM content. The mixes were prepared in a laboratory mixer 150 L based on fallowing method; first, all of coarse aggregates, 1/3 of water and 1/2 of pozzolanic material were mixed for 1 min. The main objective of this method was based on two stage mixing method (TSMA) [28] to ensure complete penetration of pozzolanic slurry in the voids of RA and fill them and produce a thin layer of CM on attached mortar to improve adhesion of old and new mortars (See Fig.1). Secondly, 1/2 of natural sand, 1/2 of cement and 1/3 of water were mixed for 2 min. Lastly, the remained materials (1/2 of natural sand, 1/2 of pozzolanic material and 1/3 of water) were added with remained cement and mixed for 6 min. Further details are given in Table 2.

Table 2. Mix proportion

Mixture	Constituents (kg/m^3) R(%)	W	SP	C	SF	FA	S	NCA	RCA
CC-SF	0	150	4.2	378	42	0	888	815	0
RC-SF25	25	150	4.2	378	42	0	888	570	245
RC-SF50	50	150	4.2	378	42	0	888	408	405
RC-SF100	100	150	4.2	378	42	0	888	0	815
CC-FA	0	150	4.2	315	0	105	888	815	0
RC-FA25	25	150	4.2	315	0	105	888	570	245
RC-FA50	50	150	4.2	315	0	105	888	408	408
RC-FA100	100	150	4.2	315	0	105	888	0	815

R: Replacement; W: Water; SP: Superplasticizer; C: Cement; SF: Micro silica; FA: Fly Ash; S: Sand; NCA: Natural Coarse Aggregate; RCA: Recycled Coarse Aggregate

V. EXPERIMENTAL RESULTS AND DISCUSSION

A. *Compressive Strength*

a. *Influence of Recycled Coarse Aggregate Replacement*

7-day Compressive strength

The compressive strength was applied using a hydraulic press with a maximum capacity of 200 kN, which was set at a rate of 0.5 MPa/s. The compressive strength was applied according to ASTM C109 [29] using three cubes specimens with the dimension of 150 mm x150 mm x 150 mm to obtain an average value at 7 days. Table 3 and Fig. 2 show the results for the compressive strength of the made concrete.

The descending slope of graphs in Fig. 2 shows reduction in compressive strength of both concretes containing SF and FA with increase of RA replacement at 7 days. The average results of maximum compressive strength of CC at the age of 7 days shows 44.8 and 28.7 MPa for concretes containing SF and FA, respectively. The average results of 7-day compressive strength for recycled concretes containing SF were, 46.2, 44.6 and 40.5 MPa for RC-SF25, RC-SF50 and RC-SF100, respectively. In concretes containing SF, incorporation of 25%, 50% and 100% RA resulting in an average increase of approximately 3% and decrease of 0.5% and 9.5% at 7 days compressive strength, respectively.

In recycled concretes containing FA, compared to CC with FA, the 6%, 12% and 22% loss of 7 days compressive strength were observed for 25%, 50% and 100% RCA, respectively. In general, the descending slope of both graphs in Fig. 2 for concretes containing SF and FA shows similar trend at 7-day compressive strength.

Table. 3 Mechanical properties of recycled coarse concretes

Notation	Compressive strength (MPa) 7 days	28 days	Strength Gain (%)	SPT (MPa)	UPV (Km/s)
CC-SF	44.8	57.4	1.28	4.4	4.96
RC-SF 25	46.2	53.8	1.16	5.5	4.69
RC-SF 50	44.6	52	1.17	5.4	4.67
RC-SF 100	40.5	51.7	1.28	3.6	4.45
CC-FA	28.7	35.2	1.23	2.7	4.47
RC-FA 25	26.9	32.4	1.20	2.58	4.31
RC-FA 50	25.3	30.8	1.22	2.3	3.76
RC-FA 100	22.4	32.5	1.45	1.94	3.71

The impressive distinguish between 7-day compressive strength of two types of concrete may be as a result of early age effect of SF in compressive strength gain compered to FA where there is 56% differences in 7-day compressive of conventional concretes compose with SF and FA. This gap lead to increase with increase in recycled coarse aggregates replacement where 71%, 76% and 81% were observed for 25%, 50% and 100% replacement, respectively. It can be concluded that increase in RA replacement level can lead to higher 7-day compressive strength differences between recycled concretes containing SF and FA.

a)fly ash b) silica fume

Fig 1. Presoaking of recycled aggregates in a) fly ash slurry b) silica fume slurry

28-day Compressive Strength

The average results of 28-day compressive strength of concretes are shown in Table 3 and Fig. 3. After 28 days, the compressive strength of CC-SF found 57.4 MPa, whereas it was obtained for RC-SF25, RC-SF50 and RC-SF100 as 53.8, 52 and 51.7 MPa, with reduction of 6%, 9% and 10%, respectively. For concrete containing FA the conventional concrete 28-day compressive strength had 35.2 MPa and the compressive strengths of 32.4, 31.8 and 32.5 MPa were observed for RC-FA25, RC-FA50 and RC-FA100, with reduction of 8%, 10% and 8%, respectively.

Although the compressive strength of concretes containing SF were higher than that of FA concretes, but they had similar trend. As can be seen from Fig. 3 the CC-SF have 63% compressive strength higher than that of CC-FA. Unlike the 7-day compressive strength, increases in recycled aggregates replacement lead to less differences between compressive strength of concretes containing SF and FA where 66%, 64% and 59% differences in compressive strength of two pozzolanic recycled concretes was found for 25%, 50% and 100% RA replacement, respectively.

In duration of 7 to 28 days, the compressive strength differences between two pozzolanic recycled concrete lead to decrease where the average of 76% gap among compressive strength of 7-day of SF and FA containing recycled concretes lead to 63% at 28-day. This might be duo to the dilatory effect of FA [25]. In addition, it can deduced that the trend of 28-day compressive strength losses due to the increase of recycled aggregate is not effected by pozzolanic types. In contrast, the ultimate compressive strength of recycled concretes is strongly effected by pozzolanic materials where the RC-SF100 had 28-day compressive strength as 51.7 MPa compared with RC-FA100 as 32.5 MPa.

b. Influence of Replacement

Fig. 4 illustrates the compressive strength gain for recycled concretes containing SF and FA. Compared to 7 days, the 28-day compressive strength improvement of CC-SF was 28% where changed from 44.8 to 57.4 MPa. The incorporation of RA in concretes containing SF lead to 28-day compressive strength as 53.8, 52 and 51.7 MPa for RC-SF25, RC-SF50 and RC-SF100, with 16%, 17% and 28% strength gain compared to 7-day compressive strength, respectively. Similar trend was found for recycled concrete containing FA where 28-day compressive strength of 0%, 25%, 50% and 100% replacement of RCA were done by 23%, 20%, 26% and 45% strength gain compared to 7-day compressive strength.

As it can be seen from the Fig. 4, in concrete containing pozzolans, the higher compressive strength gain was belong to 100% RCA replacement. Compared to CC, the higher strength gain in recycled concrete might be due to the fact that pre-saturation of RCA in pozzolanic slurry in TSMA method fill the pores of RCA and improved the microstructure of the interfacial transition zone (ITZ) and increased the bond strength between the new cement paste and the old aggregates after continuous hydration. Although the 28-day compressive strength of recycled concretes containing FA were lower than that of recycled concretes containing SF, but the higher strength gain for this types of concretes were observed in this period.

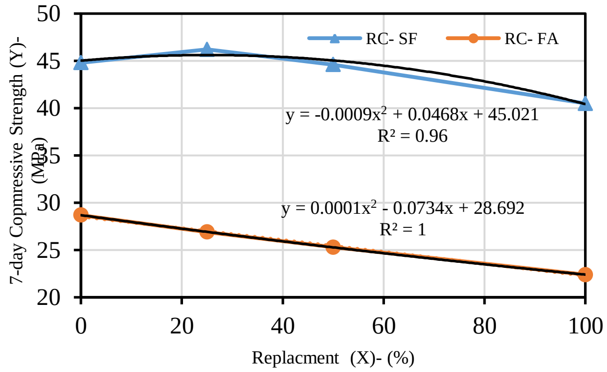

Fig 2. 7-day Compressive Strength of Specimens

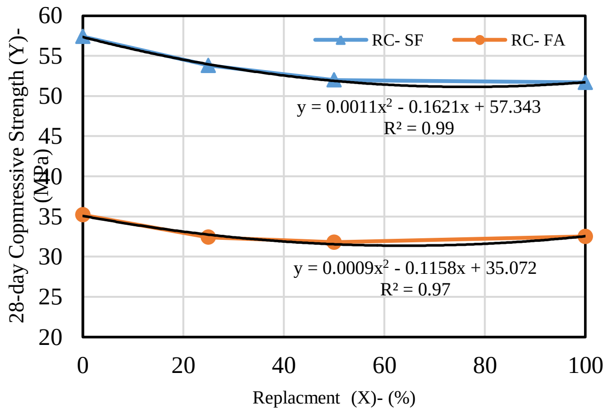

Fig. 3. 28-day Compressive Strength of Specimens

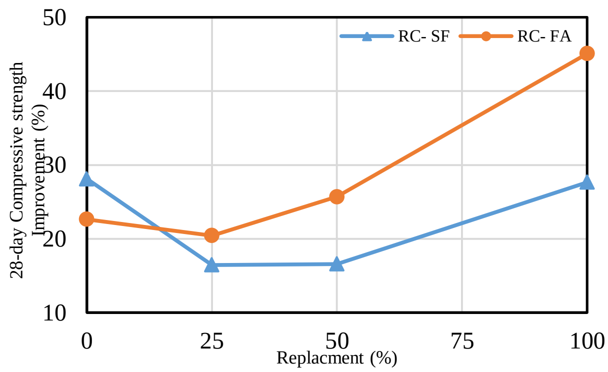

Fig4. Compressive strength gain of specimens at 28 days

B. Splitting Tensile Strength

The SPT for the mixes are given in Table 3 and Fig. 6. At 28 days, when compared to concretes containing FA, the concretes containing SF indicated significant improvement in SPT. Compared to CC-FA, the SPT of CC-SF was greater by 63%. The SPT value for RC-SF25 and RC-SF50 were as 5.5 and 5.4 MPa, respectively, which are higher than that of CC-SF. Meanwhile, compared to CC-SF the SPT of RC-SF100 was lower by 18%. The existing inverse relationship between RCA content and SPT was similar to RC-SF in RC-FA where 4%, 15% and 28% reduction were found for RC-FA25, RC-FA50 and RC-FA100, respectively. As expected, compared to the FA, due to the considerable effect of SF on early age mechanical properties of concrete, SPT of RC-SF was more than that of RC-FA. As it can be seen from Fig. 6, the SF reduced negative effect of high replaced percentage of RCA better than FA, where compared to CC-SF, 18% reduction of SPT for RC-SF100 and compared to CC-FA, 28% loss for RC-FA100 was found.

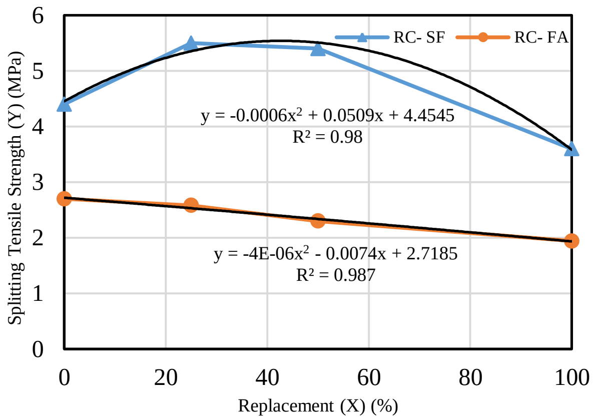

Fig5. Splittting tensile strength of specimens at 28 days

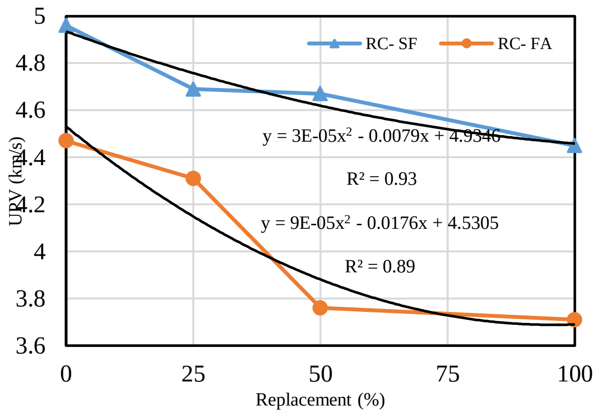

Fig6. Ultrasonic pulse velocity of specimens at 28 days

C. *Ultrasonic Pulse Velocity*

The cylindrical specimens of size 150 X 300 mm were used for the UPV test. The average UPV values were taken from three specimens obtained from each mixture using the Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT). The test was done in accordance ASTM C597 [30] in direct transmission state. All of the specimens were tested at the saturated condition, at the age of 28 days.

Fig. 7 and Table 3 present the conventional and recycled concrete UPV results. The descending slope of both graphs clearly demonstrate the inverse relationship between UPV value and aggregates replacement level. The CC-SF showed higher quality results with speed of 4.96 km/s. The highest UPV value for recycled concrete containing SF was assigned to the RC-SF25 with speed of 4.69 followed by 4.67 and 4.45 km/s for RC-SF50 and RC-SF100, respectively. All concrete specimens except RC-SF100 were classified in the range of "excellent" values according to the UPV values proposed by Whitehurst [31] which determined the quality of concretes with a density of 2400 kg/m3.

The UPV test results of concretes containing FA showed an average 14% loss than that of concretes containing SF. The UPV test value of CC-FA was observed as 4.47 and 4.31, 3.76, and 3.71 km/s were seen for RC-FA25, RC-FA50 and RC-FA100, respectively. The results of both types of pozzolanic concretes were in confirmation of previous researches that showed the UPV test values decrease with increase of aggregate replacement [32, 33]. Based on rating proposed by Malhotra [34], the specimens containing FA were classified in ''good'' condition as the UPV test value of all specimens were in the range of 3.71 to 4.47 km/s.

Although the increase of RA replacement lead to decrease in concrete quality and increase the pore spaces, but the RC-SF´s UPV test value still lie in "excellent" and RC-FAs lie in "good" level. It implies that SCMs had an extraordinary impact on filling RA voids and improved the negative effect of RA replacement and limited the development of large voids or cracks that would affects the structural integrity. Compared to FA, the better effect of SF on UPV test value of specimens lead to 10% loss for RC-SF100, meanwhile the 17% loss was observed for RC-FA100.

VI. Conclusion

Based on the results and discussions, the following conclusions can be drown:

1) Due to the early age effect of SF in gain strength, 56% differences in 7-day compressive strength of conventional concretes composed with SF and FA were shown. The increase in level of RCA replacement lead to increase in the gap.

2) The compressive strength differences between recycled concrete congaing SF and FA decreased during the time.

3) The pozzolanic materials cannot have a significant effect on compressive strength loss trend. In contrast, the ultimate compressive strength of recycled concretes strongly effected by pozzolanic materials where the RC-SF100 had 28-day strength of 51.7 MPa compared RC-FA100 as 31.8 MPa.

4) Although the 28-day compressive strength of recycled concretes containing FA were lower than that of recycled concretes containing SF, but the higher strength gain of the concretes were observed in this period.

5) 10% SF could reduce the negative effect of high replaced percentage of RCA more than 25% FA where 18% reduction of SPT value for RC-SF100 and 28% loss of RC-FA100 was found.

6) All results of recycled concretes UPV test values lie in "excellent" or "good" level. Compared to 25% FA, 10% SF had a significant effect on UPV test value where 10% loss for RC-SF100 UPV test value was shown, meanwhile the 17% loss was obtained for RC-FA100.

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