International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-4, Issue-3, March 2017

Investigation on Mechanical Properties of Recycled Concrete Containing Natural Zeolite

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Abstract— **In this study, the effect of various dosages of natural zeolite (NZ) on the mechanical properties of recycled coarse aggregates concrete (RC) was presented. The RC was prepared by using 0, 25, 50 and 100% coarse aggregate replacement and sourced from demolished concrete piles and building projects. Three dosages of NZ i.e. 10, 20 and 30% were replaced with cement. Mechanical properties as compressive strength, splitting tensile strength, modulus of elasticity and ultrasonic pulse velocity were evaluated. The test results demonstrated that although compared with other NZ dosages, the use of 10% of NZ as a conservative dosage of NZ, lead to more mechanical properties, but a combination of 25% of RA replacement and 20% of NZ replacement can produce RC with mechanical properties close to RC made with 10 of NZ.**

Index Terms— **Recycled Concrete, Recycled Aggregates, Natural Zeolite, Mechanical Properties.**

I. Introduction

Urbanization and satisfaction of human needs in developing countries are the most important reasons for excessive natural resource consumption. Constriction industry plays a significant role in the use of natural resources and construction waste generation. The use of recycled aggregates (RA) in construction industry constitutes a significant step towards a more sustainable society. As an alternative to depositing them in landfills, the use of RA creates new market opportunities to be exploited, which are also favorable to the environment. The preliminary studies on application of RA were focused on the compressive strength and their economic feasibility [1-4]. Despite the increasing in mechanical and durability related researches in this field, some standards [5-7] due to the durability-related problems, allows limited extended of replacing of RA. In recent years, many researchers used supplementary cementitious materials (SCM) as fly ash, silica fume and ground granular blast slag to achieve durable concrete and reduce the negative effect of high replacement of RA [8-10].

Natural Zeolite (NZ) is one of the popular pozzolans which has been used in the construction industry since ancient times and has used in the manufacture of blended cements from the first decades of twentieth-century [11] NZ is volcanic or volcano-sediment material with a three-dimensional frame structure and is classified as a hydrated aluminosilicate of alkali and alkaline earth cations [12]. NZ has a cryptocrystalline structure, and like other pozzolans, it undergoes pozzolanic activity due to its high quantity of reactive SiO2 and Al2O3, which combines with $Ca(OH)_2$ to form additional C–S–H gel [13]. The most common types of NZ are clinoptilolite, heulandite, analcime, chabazite, and mordenite.

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Using thermo-gravimetric and X-ray powder diffraction analysis (XRD) have shown that the pozzolanic reaction in concretes and cementitious pastes containing NZ specially, clinoptilolite type considerably reduced the calcium hydroxide content [14] so recently many researchers focus on using the clinoptilolite type of NZ of concrete application such as porcelain, aggregate and dimension stone [15-17]. Generally, the pozzolanic activity of NZ leads to improvement in mechanical properties and durability of concretes [18-20] but there is no general consensus on the early or later effect of NZ on mechanical properties of concretes [21,22].

While numerous studies have investigated the effectiveness of SCMs on mechanical properties of recycled concrete, the role of the NZ on these properties has not been widely considered. This paper establishes the feasibility use of NZ as pozzolanic material to improve mechanical properties of RC. For this purpose, different levels of recycled coarse aggregates (RCA) (0%, 25%, 50% and 100%) to produce RC were used. To improve the mechanical properties of concretes, three dosages of NZ (10%, 20% and 30%) were used. Mechanical properties in terms of 7 and 28-day compressive strength, splitting tensile strength (SPT), modulus of elasticity (Ec) 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 three levels of NZ, i.e., 10, 20 and 30% were used. The percentages of RCA replacement were calculated based on total aggregate's weight. The mix design was done according to the Iranian Concrete Code [23] 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 72 cubic specimens as 150 x 150 x 150 mm. The Ec, 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 cast 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 [24].

III. Materials

A. Binders

The cementitious materials (CM) are used in this study were OPC according to ASTM type I, and NZ. The chemical compositions of binders are given in Table 1.

Table 1. Chemical composition of cementitious materials (%)

Composition	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	LOI
NZ	68	1.5	11.5	2.5	-	-	12.2
Cement	21.28	3.7	6.1	64.34	2.1	2.13	2.2

B. *Aggregates*

River sand with a maximum size (MSA) of 2 mm as fine aggregate and crushed aggregate with a MSA of 19 mm were used in the concrete mixes. For this study the NA were replaced with RCA as MSA of 19 mm. The RCA were consisted of demolished concrete piles and building projects.

C. *Water and Superplasticizer*

To obtain a proper workability, a poly carboxyl-based superplasticizer (SP) with density 1.1±0.02 g/cm^3 was used. The maximum use of 1% of CM weight showed the required workability.

IV. Mix Proportion

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 RC containing NZ were designed RC-Z. All mixes were made with a constant W/B ratio as 0.36 and 420 kg/m3 CM content. The mixes were developed in a laboratory mixer 150 L based on following method; first, all of coarse aggregates, 1/3 of water and 1/2 of pozzolanic material were mixed for 1 minute. The main objective of this method was based on the two-stage mixing method (TSMA) [25] 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 cement, 1/2 of natural sand, 1/2 of pozzolanic material and 1/3 of water) were added to remaining cement and mixed for 6 min. Details are given in Table 2.

V. Exprimental Results and Discussion

A. *Compressive Strength*

a. *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 [26] using three cube specimens with the dimension of 150x150x150 mm to obtain an average value at 7 days. Table 3, Fig. 2 show the results for the compressive strength of the made concretes.

Fig 1. Presoaking of recycled aggregates in zeolite slurry

Table 2. Mix proportions of different mix designs

Constituents (Kg/m³)										
Mixture	R(%)	Z%	W	SP	CM	C	Z	S	NCA	RCA
CC-Z10	0	10	150	4.2	420	378	42	888	815	0
RC25-Z10	25	10	150	4.2	420	378	42	888	570	245
RC50-Z10	50	10	150	4.2	420	378	42	888	408	408
RC100-Z10	100	10	150	4.2	420	378	42	888	0	815
CC-Z20	0	20	150	4.2	420	336	84	888	815	0
RC25-Z20	25	20	150	4.2	420	336	84	888	570	245
RC50-Z20	50	20	150	4.2	420	336	84	888	408	408
RC100-Z20	100	20	150	4.2	420	336	84	888	0	815
CC-Z30	0	30	150	4.2	420	294	126	888	815	0
RC25-Z30	25	30	150	4.2	420	294	126	888	570	245
RC50-Z30	50	30	150	4.2	420	294	126	888	408	408
RC100-Z30	100	30	150	4.2	420	294	126	888	0	815

R: Replacement; Z: Zeolite; W: Water; SP: Superplasticizer; C: Cement; S: Sand; NCA: Natural Coarse Aggregate; RCA: Recycled Coarse Aggregate

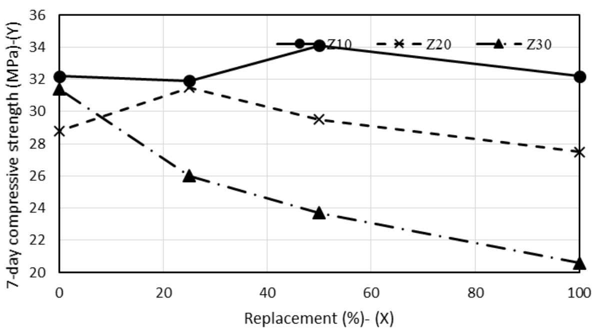

Fig 2. 7-day compressive strength of specimens

The general descending slope of graphs in Fig. 3 show reduction in compressive strength for all types of the mix designs at 7 days. The average results of maximum compressive strength of the CC at the age of 7 days shows 32.2, 28.8 and 31.4 MPa for concretes containing 10%, 20% and 30% of NZ, respectively. The average results of RC containing 10% NZ were 31.9, 34.1 and 32.2 for RC25-Z10, RC50-Z10 and RC100-Z10, respectively. The obtained results show that the use of 10% of NZ has no negative effect on 7- day compressive strength of RC and compare with CC-Z10, concretes containing 50% and 100% lead to more 7-day compressive strength. The average results of RC containing 20% NZ were 31.5, 29.5 and 27.5 MPa for concretes containing 25%, 50% and 100% RCA, respectively. The higher 7-day compressive strength of RC25-Z20 and RC50-Z20 and negligible reduction of RC100-Z20 than CC-Z20 show the negligible effect of 20% replacement of NZ on RC and its positive effect on 7-day compressive strength gain in more levels of RA replacement. In RC containing 30% of NZ, the average results of 7-day compressive strength were 26, 23.7 and 20.6 MPa for RC25-Z30, RC50-Z30 and RC100-Z30, respectively. Compared to CC-30, the 17%, 25% and 34% losses of 7-day compressive strength were observed for concretes containing 25%, 50% and 100% RCA, respectively. The descending slope of these types of concretes clearly shows the adverse effect of 30% of NZ on the 7-day compressive strength of RC.

As it can be seen from the Fig. 2, the 11% distinguish between 7-day compressive strength of CC´s containing 10%, 20% and 30% of NZ is inconsiderable. But this gap leads to increase with the increase in RCA replacement where 18%, 30% and 36% were observed for 25%, 50% and 100% RCA replacement, respectively. It can be concluded that for higher level of RCA replacement, the use of higher dosage of NZ leads to more 7-day compressive strength loss.

Table 3. Mechanical properties of recycled coarse concretes

Notation	Compressive strength (MPa)		Strength Gain (%)	f_{ct} (MPa)	Ec (GPa)	UPV (Km/s)
	7 days	28 days				
CC-Z10	32.2	37.4	16	3.4	41.1	4.7
RC25-Z10	31.9	39.6	24	3.4	36.9	4.47
RC50-Z10	34.1	38.7	13	3	32.4	4.43
RC100-Z10	32.2	36.3	13	2.7	28.3	4.24
CC-Z20	28.8	34.8	21	3.2	39.7	4.47
RC25-Z20	31.5	37.2	18	2.7	35.2	4.45
RC50-Z20	29.5	31.3	6	2.6	32.9	4.3
RC100-Z20	27.5	32.4	18	2.5	23.8	4.07
CC-Z30	31.4	37.4	19	2.5	36.1	4.44
RC25-Z30	26	31.3	20	2.7	33.9	4.34
RC50-Z30	23.7	29.2	23	2.4	29.4	4.2
RC100-Z30	20.6	23.7	15	2.3	23.9	3.88

b. 28-day compressive strength

The average results of 28-day compressive strength of concretes are shown in Table 3, Fig. 3. The compressive strength of conventional concretes containing 10%, 20% and 30% of NZ found 37.4, 34.8 and 37.4 MPa, respectively. As it can be seen from Fig. 3 the 28- day compressive strength of RC25-Z10 and RC50-Z10 were 6% and 3% higher than that of CC-Z10, meanwhile 3% reduction in compressive strength of RC100-Z10 was observed. Fig. 3 clearly shows that the 28-day compressive strength of RC containing 10% of NZ were higher than RC containing 20% and 30% of NZ.

Like as the 7-day compressive strength, increases in RA replacement lead to higher differences between compressive strength of concretes containing a different level of NZ where 21%, 25% and 35% differences in compressive strength of RC were found for RC25, RC50 and RC100, respectively.

As it can be seen from Fig. 3, the compressive strength of RC containing 10% of NZ were too close, in contrast the compressive strength of RC containing 30% of NZ strongly affected by RCA replacement level. Although, the previous research showed that the ultimate compressive strength of RC is strongly affected by pozzolanic materials [10] it could be deduced that the trend of 28-day compressive strength of recycled concrete affected by pozzolan content.

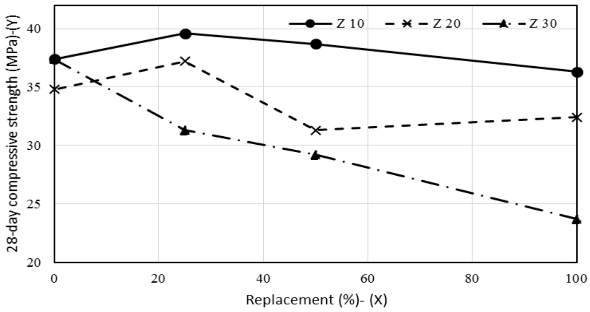

Fig 3. 28-day compressive strength of specimens

B. Modulus of Elasticity

It is known that the modulus of elasticity of RC is influenced by aggregate replacement level, aggregate size, mixing method, environment condition, chemical admixtures and the addition of SCM [27]. The simultaneous effect of replacement level of aggregates and NZ have shown in Fig. 4. The modulus of elasticity of CC-Z10 was found 41.1 GPa; and 3% and 12% losses were found for CC-Z20 and CC-Z30. It can be concluded that the use of NZ higher than 20% in conventional concretes leads to decrease in modulus of elasticity. Fig. 4 shows that compared to CC, the 25% replacement of RCA has a minimal effect on a modulus of elasticity losses where 10%, 11% and 6% decrement were found for RC25-Z10, RC25-Z20 and RC25-Z30. The use of up to 25% of RCA shows a tangible effect on modulus of elasticity where an average 19% and 35% loss were found for recycled concretes containing 50% and 100% of RCA. Based on Table 3 and Fig. 4 it can be seen that the addition of various dosages of NZ cannot reduce the negative effect of higher replacement of RA.

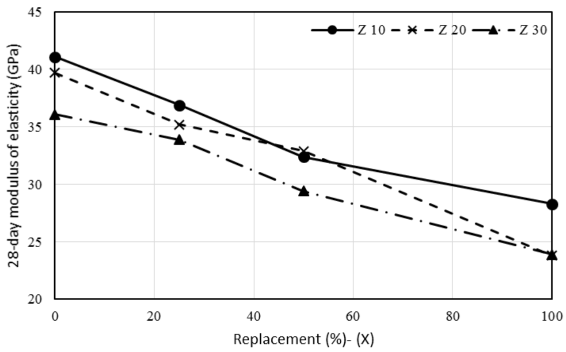

Fig 4. 28-day modulus of elasticity of specimens

C. Splitting Tensile Strength

The SPT values for the mixes are given in Table 3 and Fig. 5. At 28 days, when compared to CC containing NZ, the RC containing NZ indicated an average 10% decrement in SPT. Compared to CC-Z10, the SPT of RC25-Z10 was unchanged and 12% and 21% reduction were found for RC50-Z10 and RC-100-Z10, respectively. Meanwhile, the SPT values for all the mixes containing 10% of NZ were higher than that of the mixes containing 20% and 30% of NZ. Fig. 5 shows that the negative effect of using the 30% of NZ where the maximum SPT of the mixes containing 30% of NZ (RC25-Z30) was similar to minimum SPT of the mixes containing 10% of NZ (RC100-Z10). The inverse relationship between RCA content and SPT were found for the mixes containing a different level of NZ.

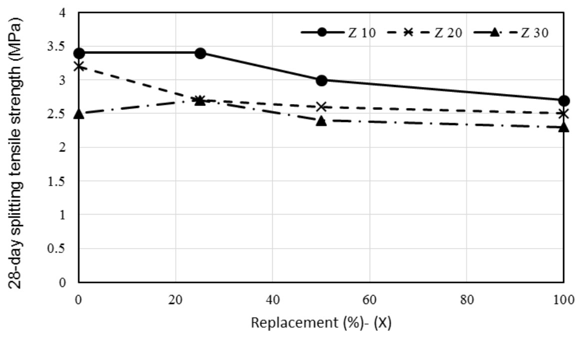

Fig 5. 28-day splitting tensile strength of specimens

D. Ultrasonic Pulse Velocity

The cubic specimens of size 150 x 150 x 150 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 [28] in the direct transmission state. All of the specimens were tested in the saturated condition, at the age of 28 days.

Table 3 and Fig. 6 present the conventional and recycled concrete UPV results. The descending slope of graphs clearly demonstrates the inverse relationship between UPV value and aggregate replacement level. The CC-Z10 showed higher-quality results with speed of 4.7 km/s. The highest UPV value of RC containing 10% of NZ was assigned to the RC25-Z10 with a speed of 4.47 followed by 4.43 and 4.24 km/s for RC50-Z10 and RC100-Z10, respectively. As it can be concluded, the CC-Z10 classified in the range of "excellent" values according to the UPV values proposed by Whitehurst [29] while all RC containing 10% of NZ lies in "good" level. On the other hand, compared to CC-Z10, the UPV test results of CC-Z20 and CC-Z30 showed 5% and 5.5% loss, respectively. These results show that the use of NZ more than 10% lead to reduce the quality of concretes where both CC-Z20 and CC-Z30 classified in the range of "good" level.

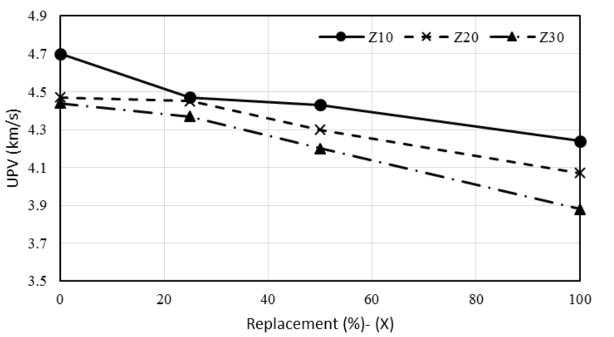

Figure. 6. 28-day UPV of specimens

The average UPV test results of concretes containing 20% of NZ showed a 3 % loss than that of concrete containing 10% of NZ. The UPV test value of CC-Z20 was observed as 4.47 and 4.45, 4.3, and 4.07 km/s for RC25-Z20, RC50-Z20 and RC100-Z20, respectively. Compared to concrete containing 10% of NZ, concretes containing 30% of NZ show an average 5.5% loss in UPV test results. Based on the UPV test classification of concretes proposed by Whitehurst [29] and Malhotra [30], all conventional and recycled concretes containing 20% and 30% of NZ are categorize in ‘‘good’’ condition. Although the increase of RA replacement lead to decrease in concrete quality and increase the pore spaces, but all of the RC containing NZ lies in "good" level. It implies that the use of NZ like fly ash and silica fume [31] had a proper impact on filling RA voids and limited the development of large voids or cracks that would affect the structural integrity. Decrement of UPV test results in both CC and RC with the increase in dosage of NZ more than 10%, means that the optimum level of NZ would be 10%.

VI. Conclusions

The following conclusions were made based on the results of the experiment performed to assess the mechanical properties of RCA made with multiple dosages of NZ:

1) All types of RC containing 10% of NZ unless RC100-Z10 showed more 28-day compressive strength than CC-Z10. Although the use of more dosages of NZ than 10% lead to decrease in 28-day compressive strength, but the use of 20% of NZ in RC containing 25% of RA showed similar 28-day compressive strength to CC-Z10
2) The maximum reduction of modulus of elasticity of CC and RC25 containing various dosages of NZ were too close and found 12% and 11%, respectively. Meanwhile, the RC containing 50% and 100% RA met 19% and 35% reduction. It can be concluded that the addition of various dosages of NZ cannot reduce the negative effect of higher replacement of RA.
3) Compared with CC containing NZ, the average SPT reduction in RC containing various dosages of NZ was found 10%. The appropriate effect of using NZ in RC was found for RC25 where compared to CC containing similar dosages of NZ, the SPT of RC25-Z10 and RC25-Z30 were found unchanged and 8% increment, respectively.
4) The negative effect of high dosage usage of NZ of UPV test for CC can be seen where CC containing 10% of NZ lies in "excellent" level, meanwhile the use of more dosage of NZ lead to "good" level for CC. Although the increase of RA replacement lead to decrease in concrete quality and increase the pore spaces, but all of UPV results of the RC containing NZ lie in "good" level.

Acknowledgment

The authors wish to thank the Amir Salar Beton Company (Iranian concrete and SCM producer in Ahvaz-Iran) and Emen Khak Jonob (Iranian Consulting Engineering Company) for their supports including the use of machines and materials for making the specimens of research.

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