Some Properties of Carbon Fiber Reinforced Magnetic Reactive Powder Concrete Containing Nano Silica

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ABSTRACT

This study involves the design of 24 mixtures of fiber reinforced magnetic reactive powder concrete containing nano silica. Tap water was used for 12 of these mixtures, while magnetic water was used for the others. The nano silica (NS) with ratios (1, 1.5, 2, 2.5 and 3) % by weight of cement, were used for all the mixtures. The results have shown that the mixture containing 2.5% NS gives the highest compressive strength at age 7 days. Many different other tests were carried out, the results have shown that the carbon fiber reinforced magnetic reactive powder concrete containing 2.5% NS (CFRMRPCCNS) had higher compressive strength, modulus of rupture, splitting tension, stress in compression and strain in compression than the corresponding values for the carbon fiber reinforced nonmagnetic reactive powder concrete containing the same ratio of NS (CFRNRPCCNS). The percentage increase in these values for CFRMRPCCNS were (22.37, 17.96, 19.44, 6.44 and 25.8) % at 28 days respectively, as compared with the corresponding CFRNRPCCNS mixtures.

Key word: nano silica, magnetic water, reactive powder concrete, carbon fiber, tap water

بعض خواص خرسانة المساحيق الفعالة الممغنطة المسلحة بألياف الكاربون الحاوية على النانو سيليكا

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الخلاصة

تضمنت هذه الدراسة تصميم 24 خلطة من خرسانة المساحيق الفعالة الممغنطة المسلحة وغير المسلحة بالالياف، حيث تم أستخدم ماء الإسالة في اعداد 12 خلطة منها أما الـ 12 خلطة الأخرى فقد أستخدم الماء الممغنط في خلطها ، تم استخدام النانو سيليكا بنسب (1، 1,5، 2، 2,5 و3)% من وزن السمنت لجميع الخلطات وبينت النتائج إن الخلطة الحاوية على 2,5% نانو سيليكا أعطت أعلى مقاومة انضغاط بعمر 7 أيام. أجريت فحوصات أخرى مختلفة على النماذج، وبينت النتائج أن فحوص مقاومة الانضغاط , الانثناء, شد الانفلاق, إجهاد الضغط وانفعال الضغط, لخرسانة المساحيق الفعالة الممغنطة المسلحة بالياف الكاربون والحاوية على 2,5 % نانو سليكا أعلى من الخرسانة

الغير ممغنطة حيث أبدت النتائج زيادة في قيم الفحوصات للخرسانة الممغنطة بنسب (22,37, 17,96, 19,44, 6,44 و 25,8) % عند العمر 28 يوم على التتابع مقارنة بنفس الخلطات الخرسانية الغير ممغنطة.
الكلمات الدالة: نانو سليكا، الماء الممغنط، خرسانة المساحيق الفعالة, الياف الكاربون, ماء الاسالة

1- INTRODUCTION

1-1 General

Recently, nano technology attracted considerable scientific interest due to the new potential uses of particles in nano (10^{-9} m) scale. The use of nano-scale size of particles can result in dramatically improved properties from conventional grain-size materials of the same chemical composition. Thus, industries may enable to reengineer many existing products and design new and novel ones that function at unprecedented levels. Few researches are available in literature about mixing nano particles in cement- based building materials, **Bauer, et al**., 1996, **Lau** and **Hui**, 2002, **Fuji Chimera Research Institute**, 2002 and **Li et al**., 2004.

Qing et al., 2006, stated that the pozzolanic activity of nano-SiO_2 was much greater than that of silica fume and with a small amount of nano-SiO_2, the $Ca(OH)_2$ crystal at the interface between hardened cement paste and aggregate at early ages may be effectively absorbed in high performance concrete.

Collepardi et al., 2002, investigated the combination of silica fume, fly ash and amorphous nano silica in super-plasticized high performance concretes. They found that concrete with ternary combination of silica fume, fly ash and amorphous nano silica reduced amount of silica fume about 15 to 20 kg/m^3 perform as well as silica fume alone content 60 kg/m^3 in result of strength and durability

An investigation was carried out by **Jo et al**., 2007 to study the characteristics of cement mortar with nano-SiO_2 particles. Five different water/cementitious ratios were used, including 0.23, 0.25, 0.32, 0.35, and 0.48 with four contents of NS (3, 6, 9, and 12) % by weight of cement. The compressive strengths of cement mortar specimens with the addition of silica fume were also evaluated at w/cm ratio of 0.35 to compare with mortar containing nano silica particles and three contents of silica fume 5, 10, and 15% by weight of cement. The experimental results showed that the compressive strengths of mortars with NS were all higher than those of mortars containing silica fume at 7 and 28 days.

Remzi. and **Meral**., 2008, had studied the effect of nano powders on cement paste, mortar and concrete and found that the use of nano powders in concrete technology affects the cement kinetics and accelerates hydration significantly due to larger surface area, stronger electrostatic forces of nano powders, and improvement in the microstructures of concrete having nano powders.

Roddy et al., 2008, applied particulate NS in oil well cementing slurries in two specific ranges of particles sizes, one between 5 to 50 nm, and the other between 5 to 30 nm. Also they used NS dry powders in encapsulated form and concentrations of 5 to 15%

by weight of cement. The respective test results for the slurries demonstrated that the inclusion of NS reduced the setting time and increased the strength (compressive, tensile, Young's modulus and Poisson's ratio)

Abbas, 2009, carried out an investigation to study the influence of nano-silica addition on properties of conventional and ultra-high performance concretes and found that the addition of both silica fume and nano-silica by total amount of 10%, may lead to an increase in the 28-day compressive strength of low cement content and high cement content concretes up to 40% and 50%, respectively, over the strength of comparable concretes. It was observed that the pozzolanic contribution of nano-silica becomes significant from the very early age, compared to silica fume, which begins its pozzolanic reactivity at the age of 7 days or later. This mechanism explained the outstanding mechanical performance of nano-silica concrete.

An experimental work was carried out by, **Skripkiunas**, and **Javavicius**, 2010, on the effect of nano $Na_2O \cdot nSiO_2$ dispersion on the strength and durability of Portland cement matrix and the principles of nanostructures formation in the cementitious materials consisting of several binding components. Three-component binding system consisting of colloidal sodium silicate solution, super-plasticizer suspension and Portland cement was used. The different contents of nano sodium silicate, namely (0, 0.2, 0.5 and 0.8) % by weight of cement were used. They observed that hardened cement with 0.5% nano sodium silicate admixture have high amount of amorphous (irregular shape) phases, which are coating the C-S-H and CH crystals. This factor has high influence on the porosity of hardened cement by the increasing of hardened cement close porosity. The capillary pores are closed with amorphous masses in the hardened cement paste.

Furthermore, the most important challenge for concrete technologists is to improve the properties of concrete. In Russia and China, a new technology, called magnetic water technology, was used in the concrete industry. In this technology, passing water through a magnetic field, some of its physical properties change and, as a result of such changes, the number of molecules in the water cluster decrease from 13 to 5 or 6, which causes a decrease in the water surface tension. Using magnetized water in concrete mixtures causes an improvement in the workability and compressive strength of concrete, **Afshin et al**, 2010.

Ahmed, **2009**, investigated the influence of magnetic water on compressive strength and workability of concrete. The results showed that the compressive strength of concrete samples prepared with magnetic water increases 10-20% more than that of the tap water samples. The results also showed that an increase in compressive strength of concrete is achieved when the magnetic strength of water is 1.2 T, and velocity of water current that passes through magnetic field is of 0.71 m/s. He also found that magnetic water improves the workability of fresh concrete.

Afshin et al., 2010, had studied the effects of magnetic water on some mechanical properties of high strength concrete, such as workability and compressive strength. For the production of magnetic water, a magnetic treatment device was used.

The results of tests showed that, in most cases, concrete made with magnetic water (magnetic concrete), has higher slump values than those of control concrete (up to 45%). Also in some cases, the compressive strength of the magnetic concrete samples was higher than that of the control concrete samples (up to 34%), but in other cases, with the same slump and compressive strength, cement content can be reduced by 28% in the case of magnetic concrete.

Arabshahi, 2010, investigated to examine the effect of magnetic water on concrete parameters. Strength parameters of concrete were obtained for more than 104 concrete samples, (including the ordinary water) and magnetic samples (made by magnetic water), with slump and compressive strength experiments. Based on slump experiments, magnetic samples were 7 centimeters more than nonmagnetic group and the average compressive strength of samples made by magnetic water was 23% more than that of samples made by ordinary water. The experimental results show the advantages of magnetic samples in concrete industry because of increase in plasticity, the efficiency and quality of concrete boosts in comparison with nonmagnetic samples.

1-2 Research Significance

The use of nano silica with 99.8% SiO_2 content in nano scale and average particle size 12 nm is a new approach. The nano silica reacts rapidly with the calcium hydroxide in the cement paste converting it into stable cementitious compounds. These refinement processes will strengthen the micro structure and reduce the micro cracking. On the other hand, the use of magnetic water and high range water reducing admixture (HRWRA) with nano silica is expected to improve the properties of concrete due to substantial water reduction of the nano silica – cement mixtures, which improves the dispersion of cement and other material particles with the breakdown of their agglomerations by the action of HRWRA and magnetic water.

1-3 Objectives

The Primary objectives of this research are:

- To present the possibilities of using nano silica for reactive powder concrete including micro materials. Due to unavailability of studies that tackled the effect of nano silica in RPC.
- To evaluate the effect of water dosage, nano silica (NS), micro carbon fiber addition, and technical requirements for reactive powder concrete. The key factors of materials proportion are investigated systematically through a series of experiments to investigate the influence of each the individual constituent material properties on overall behavior.

- To investigate the effect of magnetic water on the mechanical properties of reactive powder concrete containing NS with and without micro carbon fibers. Because of unavailability of research about using magnetic water in reactive powder concrete.
- To understand the axial stress-strain relationship of RPC reinforced with micro carbon fibers in compression. Due to rarity of research that investigated the axial stress-strain relationship of reactive powder concrete reinforced with micro carbon fibers.

2- MATERIALS

2-1 Cement

Ordinary Portland cement (Lebanon cement, Torabat Alsabia) type I was used throughout this research. It was stored in a suitable way to avoid any exposure to hazard conditions. The chemical properties of cement used throughout this research are shown in **Table 1**. Test results were indicated that the adopted cement was conformed to the **Iraqi specification** No.5/1984.

Particles size distribution was acquired by a SHIMADZU SALD-2101 LASER DIFFRACTION PARTICLE SIZE ANALYSIS instrument. The instrument used is attached to a computer that gives data about the amount of particles according to the diameter and plot as shown in **Fig**. **1**.

From **Fig**. **1**, it can be seen that 90% of particle is less than 8 µm.

2-2 Natural Sand

Al-Ekhaider natural sand was used throughout this research as the fine aggregate with particle size distribution smaller than 600 µm and greater than 150 µm.

2-3 Nano Silica (NS)

The nano silica used in this research named as **CAB-O-SIL** is made in Germany. It has a specific surface area 200 m^2/g. The chemical composition of this material is shown in **Table 2**. The NS used in this work conforms to the chemical and physical requirements of **ASTM** C1240-03. **Tables 3** and **4** show the chemical and physical requirements, respectively. According to the manufacture company average primary particle size is 12 nanometers. X-ray diffraction diagram shows that nano silica amorphous and has the ability to reacts as shown in **Fig**. **2**.

2-4 Mixing water

Two types of water were used in this research, the first one is tap water and the second is magnetized water. The magnetized water was produced by passing the tap water in a magnetic funnel

2-5 High Range Water Reducing Admixture

The super-plasticizer used was a modified polycarboxylates based polymer manufactured and supplied by **SIKA**® under the commercial name Sika® Viscocrete® Hi-Tech 36.

2-6 Carbon Fibers

The micro Carbon fibers used in this research was brought from **Alibaba Company**. It has small diameter 0.001mm and a length 8.5mm.

2-7 Materials Proportion

To determine the optimum mixtures of the RPC that give compressive strength higher than 100MPa, various mixtures were tried by using Al-Ekhaider natural sand, glass sand, tap or magnetized water as follow:

1- The first stage

Sand to cement ratio (S/C) in mortar and type of sand were expected to have significant effect on compressive strength. Hence, it^{s} effect was investigated using five mixtures;

a- Sand to cement ratios (S/C) was (2:1, 1.75:1, 1.5:1, 1.25:1 and 1:1).
b- Al-Ekhaider natural sand and glass sand.
c- Water cement ratio W/C of 0.44.

Results indicated that the mixture with S/C (1:1) using Al-Ekhaider natural sand gave compressive strength higher than other mixtures containing glass sand as shown in **Fig. 3**. This may be due to the roughness of surface texture of Al-Ekhaider sand that lead to a stronger bond between this sand and the cement paste than the bond between smooth surface texture of glass sand and the cement paste.

2- The second stage

The optimum ratio of the nano silica (NS) additive was obtained as follows:

1-By using tap water;
a- The used ratios of the additive NS are (1, 1.5, 2, 2.5 and 3) % by weight of cement.
b- S/C ratio of 1.
c- W/C ratio of 0.17.
d- Dosage of super-plasticizer of 7% by weight of cement.
e- Dosage of super-plasticizer of 7.3% by weight of cement for mixtures incorporated micro-carbon fibers.

The results indicated that the compressive strength increases with NS increase up to 2.5%, while it decreases when the NS increased to 3% as shown in **Table 5**. This can be justified by the fact that the additional quantity of NS particles (pozzolan) present in the mixture is higher than the amount required to combine with the liberated lime during the process of hydration, this leads to leaching out of non-reactive silica, leave space which causes a lack in strength.

2- By using magnetized water:

Using the same previous procedure but with magnetized water, the results indicated increasing in compression strength. It was obvious that the percentage increase varies from 17.8% to 23.3% as shown in **Table 6**. This is mainly due to the fact that the magnetic field has a considerable effect on clusters of water molecules which causes the decrease of such a mass from 13 molecules to 5 or 6 molecules. Such a decrease of molecules causes more participation of water molecules in the cement hydration reaction. When water is mixed with cement, cement particles are surrounded by water molecule clusters. In the case of magnetic water in which the clusters have a smaller size and lower density, the thickness of the water layer around the cement particle is thinner than in the case of normal water.

2-8 **Casting and Curing of Test Specimens**

The specimens were demoulded after 1 day immersion in tap water saturated with $Ca(OH)_2$ at laboratory temperature (20-23)^o C up to test.

3- RESULTS AND DISCUSSION

A parametric study was carried out to investigate the effect of HRWRA (SV-Hi-Tech-36), 2.5% of nano silica, 2 % of micro carbon fibers by weight of cement, tap and magnetic water, on properties of reactive powder concrete.

3-1 Compressive Strength

The compressive strength values of various types of RPC are given in **Table 7** and **Fig. 4**. It can be seen that the compressive strength considerably increases with the age progress up to 90 days, with slight increase at ages between 180 and 360 days. The compressive strength improvement of a nonmagnetic reactive powder concrete containing HRWRA (SV-Hi-Tech-36) is also shown, whereas that the percentages of increase were 68.2% and 34.73% at 28 and 360 days respectively with respect to reference RPC. This behavior is mainly due to the significant water reduction caused by incur-porating HRWRA which leads to the reduction in capillary porosity. In addition, the super-plasticizer surfactant tends to disperse the cementitious particles uniformly throughout the mix, therefore improving the uniformity of the microstructure.

The compressive strength of a nonmagnetic mixture containing 2.5%NS-HRWRA reactive powder concrete is higher than that of reference RPC, the percentages of increase were 88.4% and 52.1 % at 28 and 360 days respectively. This can be explained by the high pozzolanic reaction of NS, particles with calcium hydroxide released from cement hydration leading to pore size and grain size refinement processes which can strengthen the microstructure and reduce the micro cracking. The compressive strength of the 2.5%NS-HRWRA-CF nonmagnetic reactive powder concrete with respect to reference RPC was 92.2% and 55.38% at 28 and 360 days respectively. It is well known that the fibers embedded inside a cement mortar or concrete act as a link among the cracks caused by heavier loads and, as a consequence, this leads to an increase in the materials strength. This may also be related to the uniform dispersion of micro Carbon fibers throughout reactive powder concrete.

The influence of magnetic water on compressive strength is also illustrated in **Table 7** and **Fig. 4**. The results show that when using magnetic water in mixing materials of RPC, RPC-HRWRA, 2.5%NS-HRWRA, 2.5%NS-HRWRA-CF reactive powder concrete, it causes significant increase in the compressive strength. The percentages of increase in compressive strength were (16.04, 13.38), (21.51, 21.76), (24.0, 22.33) and (22.37, 21.99)% at 28 and 360 days respectively, compared to the same mixtures using tap water, This is mainly due to the reasons mentioned in article 2-7.

3-2 Modulus of Rupture

The modulus of rupture for each of the RPC mixtures was determined; results are shown in **Table 8** and **Fig. 5**.

These results indicated that all types of RPC exhibit continuous increase in modulus of rupture with age progress. However, the rate of modulus of rupture gain of concretes at early ages is higher than those at later ages.

HRWRA (SV-Hi-Tech-36) nonmagnetic reactive powder concrete shows a significant improvement in modulus of rupture at all ages relative to the reference RPC. The percentages of increase were 37.1% and 41.60% at 28 and 360 days respectively, this behavior is as mentioned above.

Nonmagnetic 2.5%NS-HRWRA reactive powder concrete demonstrates further increase in modulus of rupture. The percentages of increase relative to reference RPC were 66.74% and 69.2 % at 28 and 360 days, respectively. The results indicated also a considerable increase in modulus of rupture due to the adding of micro carbon fibers to the nonmagnetic 2.5%NS-HRWRA reactive powder concrete. The percentages of increase in modulus of rupture with respect to the same unreinforced mixtures were 62.97% and 60.82% at 28 and 360 days, respectively. This behavior may be due to the chopped fibers reinforcing the RPC at the micro-crack stages and enhances the response during crack-initiation whereas the large fibers provide the toughness at the stages of larger crack opening.

The influence of magnetic water on modulus of rupture of various types of RPC is illustrated also in **Table 8** and **Fig. 5**. The results show that the use of magnetic water in mixing will cause a significant increase in the flexural strength. From **Table 9**, it can be observed that the percentages increase in the modulus of rupture at all ages for all various types of magnetic RPC with and without micro carbon fibers with respect to the same nonmagnetic mixtures.

3-3 Splitting Tensile Strength

The effect of HRWRA (SV-Hi-Tech-36), NS, MCF and the age using tap or magnetic water on the splitting tensile strength for various types of RPC are presented in **Table 10** and **Fig. 6**.

The results indicate that all types of RPC show continuous increase in splitting tensile strength up to 360 days, but this increase is extremely slight at ages above 90 days. This may be attributed to the increased fineness which leads to increased activity at early ages. Additionally, because of (SV-Hi-Tech-36), a good dispersion of the cement grains throughout the mixing conduces to gain strength at early ages. The percentages of increase in splitting tensile strength of nonmagnetic HRWRA-RPC calculated with respect to reference RPC were 79.35% and 28.97 % at 28 and 360 days respectively. This behavior may be ascribed to the significant reduction in capillary porosity of the cement matrix because of the reduction in water/cementious ratio.

The percentages of increase in splitting tensile strength for 2.5%NS-HRWRA nonmagnetic reactive powder concrete with respect to reference RPC at 28 and 360 days were 158.15% and 87.16% respectively. 2.5%NS-HRWRA-nonmagnetic reactive powder concrete reinforced with 2% micro carbon fibers show continuous improvement in tensile strength at all ages. The percentages of increase in splitting tensile strength with respect to the same unreinforced mixtures were 50.00% and 48.14% at 28 and 360 days respectively. This increase in splitting tensile is attributed to the nature of binding fiber available in concrete. When the reinforced concrete is forced to split apart in the tensile strength test, the load is transferred into the fibers as pullout behavior when the concrete matrix begins to crack as it exceeds the pre-crack state.

The effect of using magnetic water in all types of the RPC mixtures is presented in **Table 10** and **Fig. 6**. The results revealed that for various types of the magnetic RPC mixtures an increase was observed in splitting tensile strength at all ages with respect to the same nonmagnetic mixtures. The percentages of increases in the splitting tensile strength relative to the same nonmagnetic mixtures are illustrated in **Table 11**.

3-4 The Axial Stress-Strain Relationship of RPC in Compression

This research shows the actual effect of age and the main variables (HRWRA (SV-Hi-Tech-36), nano silica admixture, 2% micro carbon fibers and magnetic water) on the axial stress-strain relationship of RPC in compression. The effect of each variable is shown in a separate figure that contains a set of curves constructed to cover all ages of test.

The compression stress-strain curves for various types of magnetic or nonmagnetic reactive powder concrete are shown in **Figs. 7**, **8** and **Table 12**

Fig. **7** (a and b) shows that the ascending portion of the stress-strain curves of the reference RPC and HRWRA-RPC specimens is steep and almost a straight line at later ages, whereas the descending portion has almost vanished. Therefore, plain composite reactive powder concrete fails violently and suddenly.

For 2.5%NS-HRWRA nonmagnetic reactive powder concrete, the shape of the ascending portion of the stress-strain curve is steeper than that of HRWRA-RPC at all ages as shown in **Fig**. **7 (c)**. This may be attributed to the ability of NS to produce high strength concrete. Consequently more brittleness is produced by the addition of this admixture to HRWRA-RPC.

Fig. **7** (d) shows the effect of the micro carbon fibers on the compression stress-strain curve of 2.5%NS-HRWRA nonmagnetic reactive powder concrete with age progress. The figure shows only slightly variations during the ascending portion while the descending portion is modified significantly.

At 28 days, the maximum strain reached at the peak stress was 0.00357 for 2.5%NS-HRWRA-CF-RPC-TW and decreased with age progress to reach 0.00349 at 360 days as shown in **Fig. 7** and **Table 12**. This behavior may be attributed to the ability of micro carbon fibers to arrest and slow down the progress of propagation of micro cracks, thus producing noticeable increase in the strain at the peak stress, ductility and improve the integrity of the composite

The effect of magnetic water on the compressive stress-strain curves of various types of reactive powder concrete is shown in **Fig.8** from (a to d). It can be seen that by using magnetic water two advantages were achieved. First, it increases compressive strength for various types of reactive powder concrete at all ages. Second, it reduces the slope of the descending portion and results in an increase in ductility as seen in **Fig. 8 (d**). The percentages increase for stress and strain of various types of magnetic composite reactive powder concrete in comparison with the same nonmagnetic mixtures at 28 and 360 days are shown in **Table 13**.

4- CONCLUSIONS

According to the results obtained from the experimental work of this investigation, the following conclusions can be deduced:

HRWRA-RPC, 2.5%NS-HRWRA and 2.5%NS-HRWRA-CF nonmagnetic RPC have shown considerable increase in compressive strength, modulus of rupture and splitting tensile strength. The percentages increase relative to reference RPC were (68.2, 34.9 and 79.35), (88.4, 66.74 and 158.15) and (88.4, 62.97 and 52.67) % at 28 days respectively.

Two advantages of magnetic water were observed. First, it increases compressive strength, modulus of rupture and splitting tensile strength for various types of RPC at all age with respect to the same nonmagnetic mixtures.. The percentages of increase range between (16.04 to 24.0), (17.96 to 18.90) and (15.30 to 19.44) % at 28 days respectively

Second, it reduces the slope of the descending portion for reinforced mixtures and results in an increase in ductility. The percentages increase in the axial stress-strain relationship in compression related to the same nonmagnetic mixtures range between 6.44 to 9.58% at 28 days.

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Table 1. Chemical composition and main compounds of cement*

Oxides composition	Content %	Limits of Iraqi specification No.5/1984
CaO	62.2	---
SiO_2	20.1	---
Al_2O_3	5.89	---
Fe_2O_3	3.08	---
MgO	2.31	<5.00
SO_3	2.01	<2.80
L.O.I.	2.53	<4.00
Insoluble residue	1.03	<1.5
Lime Saturation Factor, L.S.F.	0.87	0.66-1.02
Main compounds (Bogue's equations)		
C_3S	50.68	-
C_2S	19.474	-
C_3A	10.3	-
C_4AF	9.55	-

* Chemical analysis has been conducted by the National Center for Construction Laboratories and Researches.

Table 2. Chemical analysis of nano Silica *

Oxide composition	Oxide content %
SiO_2	99.8
Al_2O_3	0.05
Fe_2O_3	0.003
Na_2O	0.05
K_2O	0.03
MgO	0.01
TiO_2	0.03
HCl	0.025

*Chemical analysis has been conducted by National Center for Geological Survey and Mining.

Table 3. Chemical requirements of nano Silica ASTM C 1240-03

Oxide composition	NS	Limit of specification requirement ASTM C 1240
SiO_2, min. percent	99.8	85.0
Moisture content, max. percent	1.5	3.0
Loss on ignition, max	1	6.0

Table 4. Physical requirements of nano Silica ASTM C 1240- 03

Physical properties	NS	Limit of specification requirement ASTM C 1240
Percent retained on 45-µm (No.325) sieve, max.	-	10
Accelerated pozzolanic Strength Activity Index with Portland cement at 7 days, min. percent of control	210.58	105
Specific surface, min., m^2/g	200	15

Table 5. Details of the RPC mixtures proportion (kg/m^3) used throughout this investigation using tap water

Mixtures	Cement	Sand	Additive Material	Water	HRWRA	Fiber	Comp. Strength (MPa), 7days
RPC Tap Water (TW)	875	875	_	385	_	_	42.6
HRWRA-RPC-TW	1100	1100	_	188.7	61	_	85.32
1% NS–HRWRA–RPC–TW	960	960	9.6	164.81	67.86	_	92.3
1% NS–HRWRA–CF–RPC–TW	950	950	9.5	163.1	70	19	94
1.5% NS–HRWRA–RPC-TW	920	920	13.8	158.74	65.36	-	93.78
1.5 NS–HRWRA–CF–RPC–TW	910	910	13.65	157	67.4	18.2	95.2
2% NS–HRWRA–RPC-TW	880	880	17.6	152.59	62.83	_	94.88
2% NS–HRWRA–CF–RPC-TW	870	870	17.4	150.85	64.78	17.4	96.41

2.5% NS–HRWRA–RPC-TW	840	840	21	146.34	60.27	_	95.92
2.5% NS–HRWRA–CF–RPC-TW	830	830	20.75	144.6	62.1	16.6	97.84
3% NS–HRWRA–RPC-TW	810	810	24.3	141.83	58.4	_	95.2
3% NS – HRWRA–CF– RPC -TW	800	800	24	140	60	16	96.9

Table 6. Details of the RPC mixtures proportion (kg/m^3) used throughout this investigation using magnetized water

Mixtures	**Cement**	**Sand**	**Additive Material**	**Water**	**HRWRA**	**Fibers**	**Comp. Strength (MPa), 7days**
RPC Magnetic Water (MW)	875	875	-	385	-	-	48.9
HRWRA -RPC- MW	1100	1100	-	188.7	61	-	99.45
1% NS -HRWRA - RPC - MW	960	960	9.6	164.81	67.86	-	108.1
1% NS-HRWRA - CF- RPC- MW	950	950	9.5	163.1	70	19	110.64
1.5% NS - HRWRA - RPC- MW	920	920	13.8	158.74	65.36	-	109.5
1.5 NS - HRWRA - CF - RPC- MW	910	910	13.65	157	67.4	18.2	112
2% NS - HRWRA - RPC- MW	880	880	17.6	152.59	62.83	-	110.9
2% NS - HRWRA - CF- RPC - MW	870	870	17.4	150.85	64.78	17.4	113.76
2.5% NS - HRWRA - RPC- MW	840	840	21	146.34	60.27	-	113.05
2.5% NS - HRWRA - CF - RPC- MW	830	830	20.75	144.6	62.1	16.6	115.9
3% NS-HRWRA-RPC- MW	810	810	24.3	141.83	58.4	-	112.86
3% NS - HRWRA - CF - RPC - MW	800	800	24	140	60	16	114.43

Table 7. Compressive strength for various types of mixtures

Mixtures	Compressive strength MPa				
	7 days	28 days	90 days	180 days	360 days
RPC Tap Water (TW)	42.6	57.48	72.24	73.3	74
HRWRA-RPC-TW	85.32	96.7	99.4	99.66	99.7
2.5%NS-HRWRA-RPC-TW	95.92	108.3	111.86	111.95	112.56
2.5%NS-HRWRA-2%CF-RPC-TW	97.84	110.48	114.6	114.84	114.98
RPC Magnetic Water (MW)	48.9	66.7	82.9	83.2	83.9
HRWRA-RPC-MW	99.45	117.5	120.77	120.9	121.4
2.5%NS-HRWRA-RPC-MW	113.05	134.3	136.7	136.9	137.7
2.5%NS–HRWRA-2%CF-RPC-MW	115.9	135.2	140.3	141.5	142.2

Table 8. Modulus of rupture for various types of mixtures

Mixtures	Modulus of rupture (MPa)				
	7 days	28 days	90 days	180 days	360 days
RPC Tap Water (TW)	6.45	9.2	10.2	10.23	10.24
HRWRA-RPC-TW	9.69	12.61	13.84	14.2	14.5
2.5%NS-HRWRA-RPC-TW	12.6	15.34	16.7	17.1	17.33
2.5%NS-HRWRA-2%CF-RPC-TW	20.45	25	26.69	27.1	27.87
RPC Magnetic Water (MW)	7.65	10.88	12.05	12.08	12.11
HRWRA-RPC-MW	11.49	14.95	16.4	16.81	17.15
2.5%NS-HRWRA-RPC-MW	14.99	18.24	19.85	20.26	20.51
2.5%NS–HRWRA-2%CF-RPC-MW	24.1	29.49	31.38	31.78	32.63

Table 9.The percentages increase in the modulus of rupture for various types of magnetic mixtures with respect to the same nonmagnetic mixtures

mixtures	The percentages of increase in the modulus of rupture				
	Age(days)				
	7	28	90	180	360
RPC Magnetic Water (MW)	18.60	18.26	18.14	18.08	18.26
HRWRA -RPC- MW	18.58	18.56	18.50	18.38	18.28
2.5% NS - HRWRA - RPC- MW	18.97	18.90	18.86	18.48	18.35
2.5% NS–HRWRA–2% CF–RPC-MW	17.85	17.96	17.57	17.27	17.08

Table 10. Splitting tensile strength for various types of magnetic and nonmagnetic mixtures.

mixtures	Splitting tensile strength (MPa)				
	Age(days)				
	7	28	90	180	360
RPC Tap Water (TW)	2.13	3.68	5.16	5.42	5.45
HRWRA-RPC-TW	5.78	6.6	6.96	7.02	7.029
2.5% NS-HRWRA-RPC-TW	8.6	9.5	10.11	10.2	10.2
2.5% NS-HRWRA-2%CF-RPC-TW	12.9	14.25	14.98	15.11	15.11
RPC Magnetic Water (MW)	2.476	4.28	6.01	6.32	6.36
HRWRA-RPC-MW	6.65	7.61	8.03	8.11	8.13
2.5% NS-HRWRA-RPC-MW	10.23	11.31	11.85	11.96	11.97
2.5% NS-HRWRA-2%CF-RPC-MW	15.4	17.02	17.53	17.67	17.69

Table 11. The percentages increase in the splitting tensile strength for various types of magnetic mixtures with respect to the same nonmagnetic mixtures.

Mixtures	The percentages of increase in splitting tensile strength % Age(days)				
	7	28	90	180	360
RPC Magnetic Water (MW)	16.24	16.30	16.47	16.61	16.69
HRWRA -RPC- MW	15.05	15.30	15.37	15.53	15.66
2.5% NS - HRWRA - RPC- MW	18.95	19.05	17.21	17.25	17.35
2.5% NS–HRWRA–2% CF–RPC-MW	19.38	19.44	17.02	16.94	17.06

Table 12. Peak Compression Stress and Strain values for various types of mixtures

Mixtures		Age (days)				
		7	28	90	180	360
RPC Tap Water (TW)	C	35	48.4	61.5	62.4	62.9
	S	0.0029	0.00271	0.00263	0.00258	0.00254
HRWRA-RPC-TW	C	73.72	85.5	88.5	88.74	90.36
	S	0.00271	0.00265	0.00258	0.00256	0.00255
2.5% NS–HRWRA–RPC-TW	C	83.42	96	99.76	99.85	100.5
	S	0.0026	0.00255	0.0025	0.00245	0.00241
2.5% NS–HRWRA–2% CF–RPC-TW	C	85.14	98.08	102.3	102.54	102.88
	S	0.0036	0.00357	0.00348	0.00345	0.00349
RPC Magnetic Water (MW)	C	40.5	58.5	74.8	75.15	75.9
	S	0.0031	0.0029	0.00286	0.0028	0.00272
HRWRA -RPC- MW	C	86.15	104.4	107.72	107.9	108.3
	S	0.0031	0.002845	0.00283	0.00278	0.00274
2.5% NS - HRWRA - RPC- MW	C	98.6	117.3	122.8	123.9	124
	S	0.0028	0.00275	0.0027	0.00268	0.0026
2.5% NS–HRWRA–2% CF–RPC-MW	C	101.1	120.8	126	137.4	128.1
	S	0.0039	0.0038	0.00379	0.00375	0.00373

Compressive strength (MPa) = C, Strain = S

Table 13. The percentages increase in stress-strain for various types of magnetic mixtures with respect to the same nonmagnetic mixtures

Mixtures		The increasing percentage at age (days) %	
		28	360
RPC Magnetic Water (MW)	C	20.87	20.67
	S	7.01	7.08
HRWRA -RPC- MW	C	22.11	19.85
	S	7.36	7.45
2.5% NS - HRWRA - RPC- MW	C	22.19	23.38
	S	7.84	7.88
2.5% NS–HRWRA–2%CF–RPC-TW	C	23.16	24.5
	S	6.44	6.88

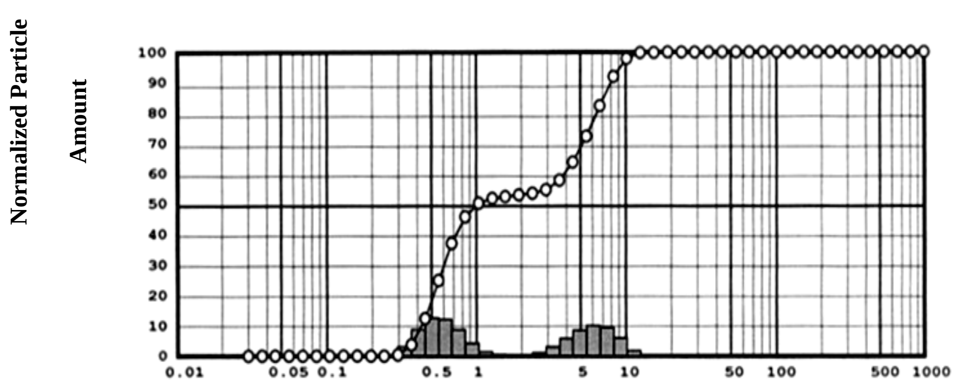


Figure 1. Particle size distribution of cement.

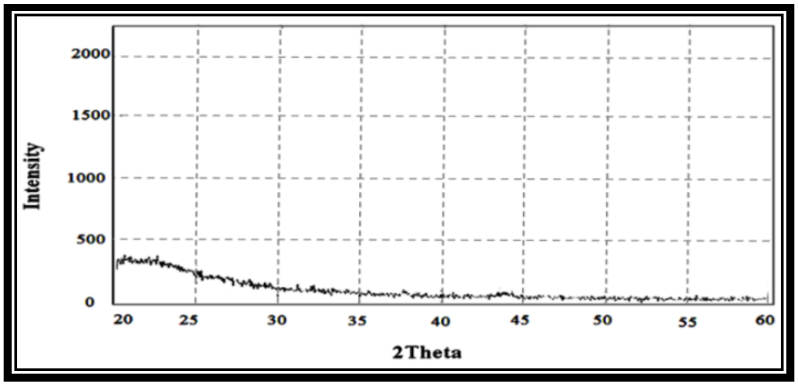


Figure 2. X-Ray diffraction patterns of NS.

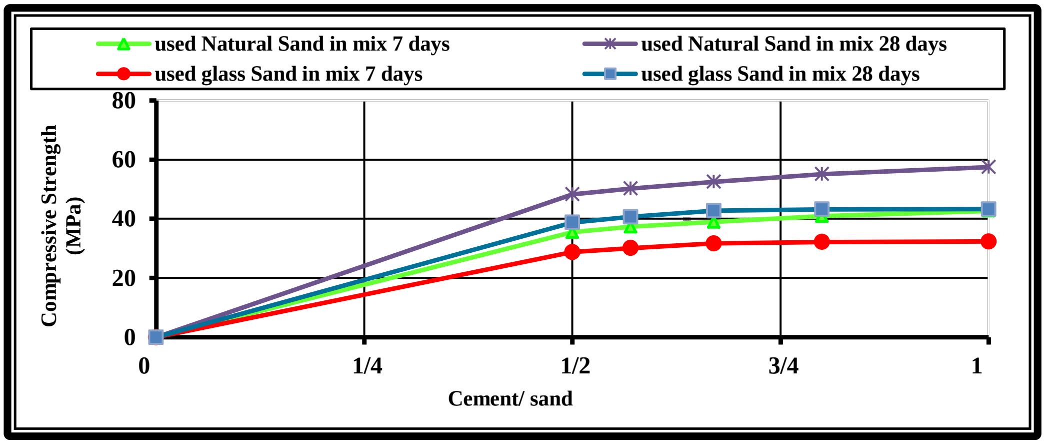


Figure 3. Relationship between compressive strength and percent of Cement/ Natural or Glass sand.

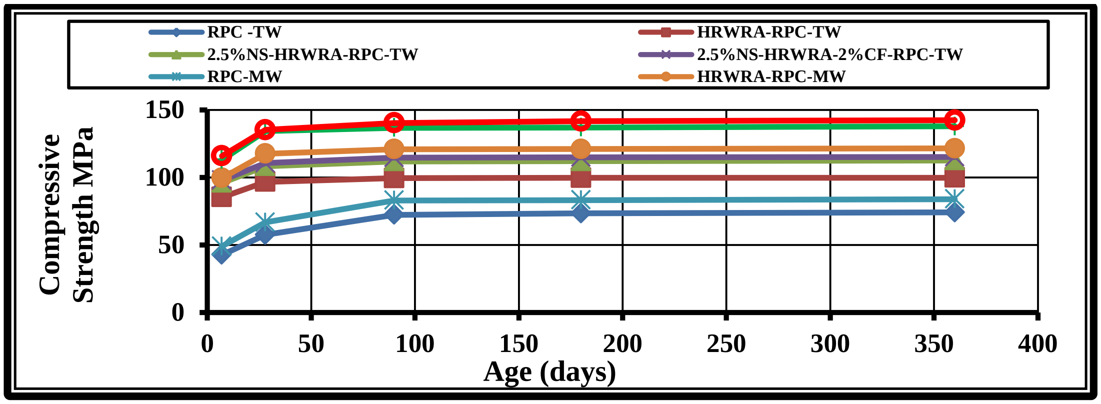


Figure 4. Effect of magnetic and nonmagnetic mixtures containing HRWRA, 2.5%NS-HRWRA and 2.5%NS-HRWRA on the compressive strength with age.

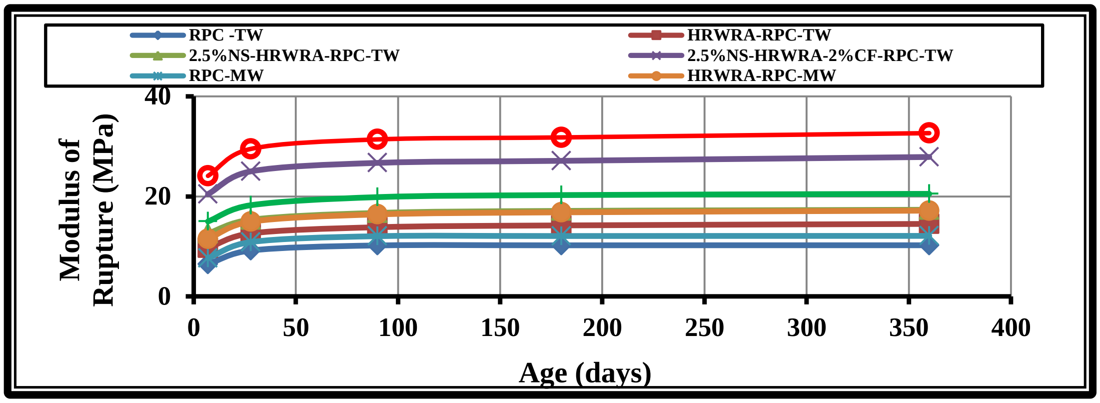


Figure 5. Effect of magnetic and nonmagnetic mixtures containing HRWRA, 2.5%NS-HRWRA and 2.5%NS-HRWRA on the Modulus of Rupture with age.

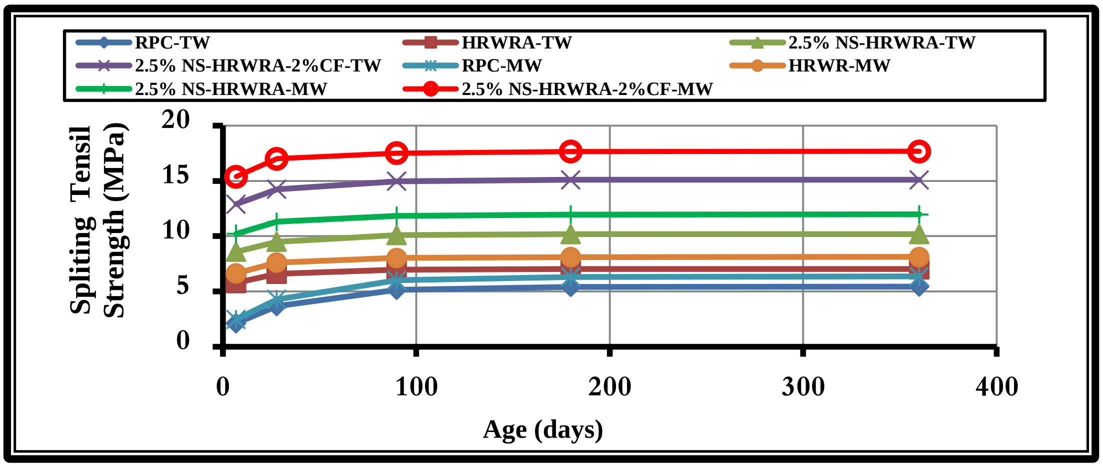
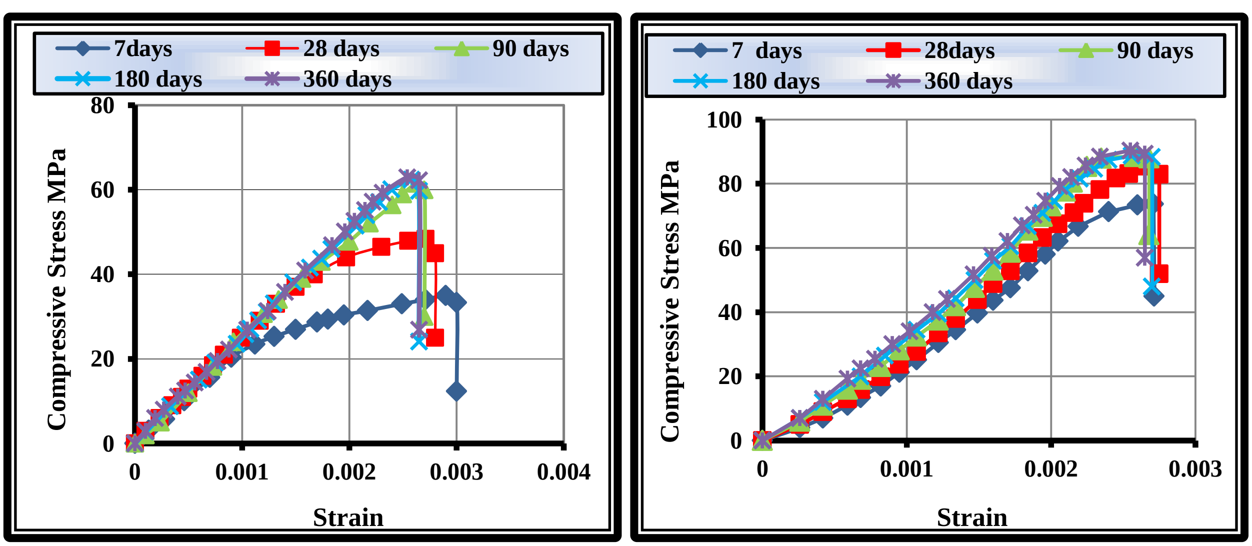
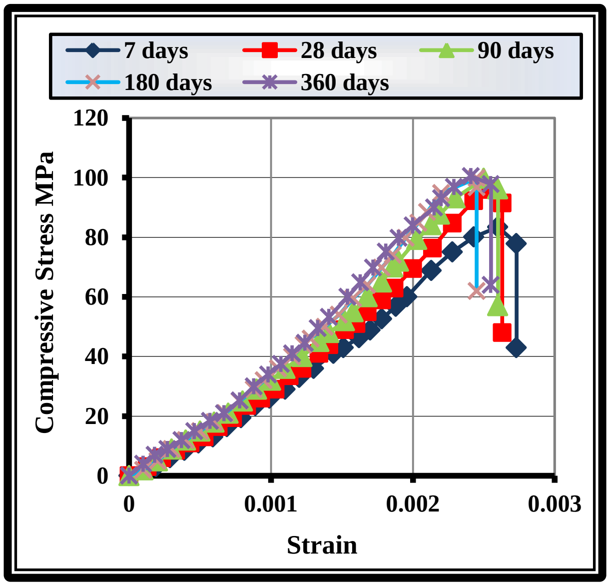


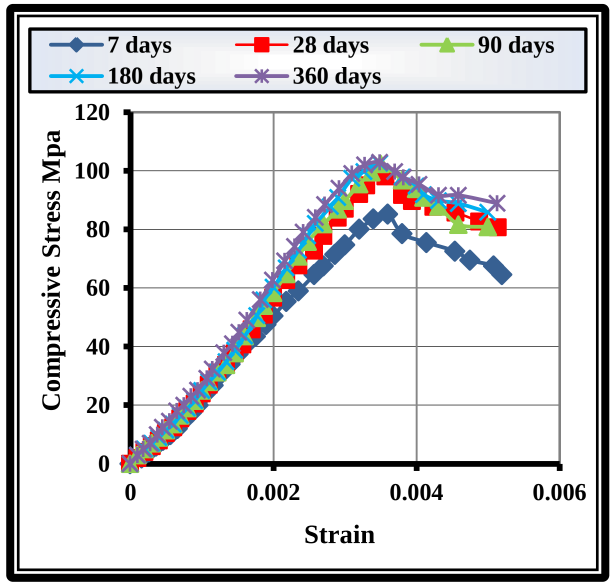
Figure 6. Effect of magnetic and nonmagnetic mixtures containing HRWRA, 2.5%NS-HRWRA and 2.5%NS- HRWRA-MCF on the splitting strength with age.



(a) RPC **(b)** HRWRA-RPC

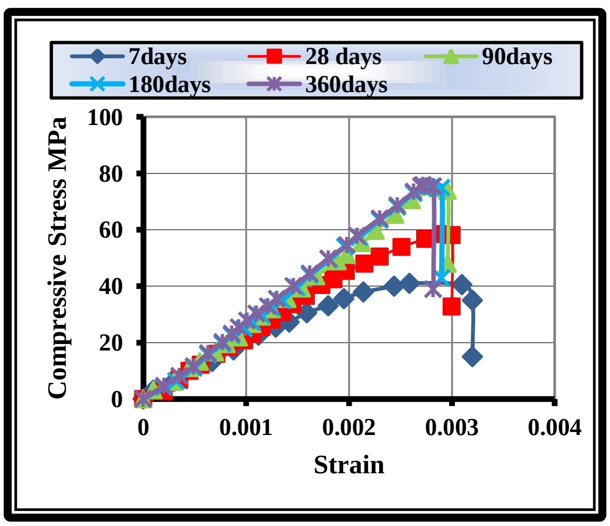


(c) 2.5% NS-HRWRA-RPC-TW

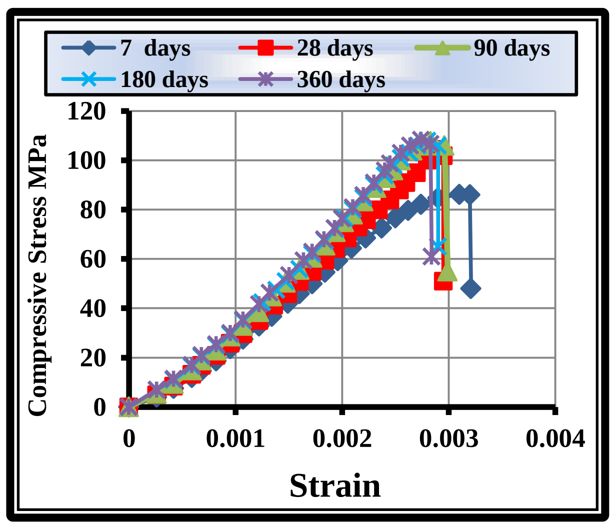


(d) 2.5% NS-HRWRA-2%CF-RPC-TW

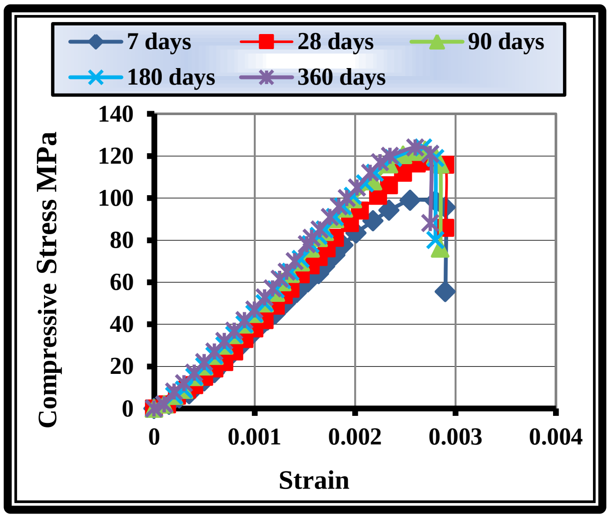
Figure 7. Effect of nonmagnetic mixtures (a) RPC, (b) HRWRA, (c) 2.5% NS-HRWRA and (d) 2.5% NS-HRWRA-2%CF on the axial stress – strain behavior with age progress.

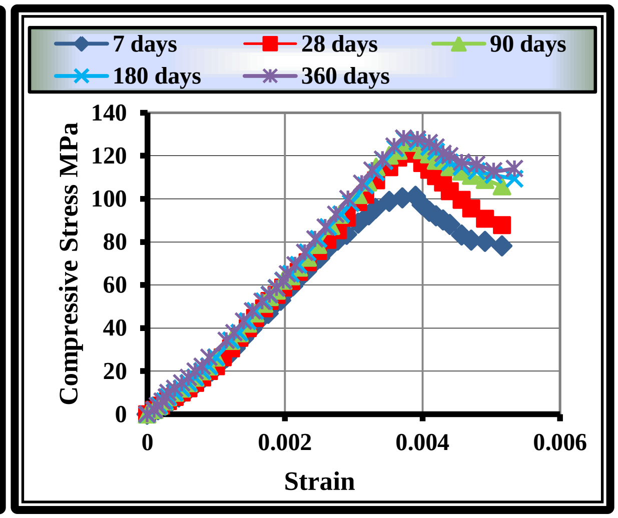


(a) RPC



(b) HRWRA-RPC





(c) 2.5% NS-HRWRA-RPC-MW

(d) 2.5%NS-HRWRA-2%CF-RPC-MW

Figure 8. Effect of magnetic mixtures (a) RPC, (b) HRWRA, (c) 2.5% NS-HRWRA and (d) 2.5% NS-HRWRA-2%CF on the axial stress – strain behavior with age progress.