Non-Destructive Testing 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 has been used in mixing 12 of these mixtures, while the other 12 have been mixed using magnetic water. Nano Silica (NS) with ratios (1, 1.5, 2, 2.5 and 3) % were used. The results showed 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 showed that the fiber reinforced magnetic reactive powder concrete containing 2.5% NS (FRMRPCCNS) has the higher bulk density, dynamic modulus of elasticity, ultrasonic pulse velocity electrical resistivity and lesser absorption than fiber reinforced nonmagnetic reactive powder concrete containing 2.5%NS(FRNRPCCNS). The percentages of increase for FRMRPCCNS are (1.6, 19.03, 7.89 and 19.28) % and the percentage of reduction is 55.7 % at 28 days respectively, as compared with FRNRPCCNS mixtures.

Key word: nano silica, magnetic water, reactive powder, carbon fiber, non-destructive

الفحوص اللااتلافية لخرسانة المساحيق الفعالة الممغنطة المسلحة بالألياف الكاربون الحاوية على نانوسيليكا

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الخلاصة

تضمنت هذه الدراسة تصميم 24 خلطة من خرسانة المساحيق الفعالة المسلحة وغير المسلحة بالألياف، حيث تم أستخدم ماء الإسالة في خلط 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) % وبينت النتائج إن الخلطة الحاوية على 2.5 % نانو سيليكا أعطت أعلى مقاومة انضغاط بعمر 7 يوم. أجريت فحوصات أخرى مختلفة على النماذج، وبينت النتائج أن أعلى كثافة، معامل مرونة ديناميكي، ذبذبات فوق الصوتية ، مقاومة كهربائية وأقل مسامية لخرسانة المساحيق الفعالة المسلحة بالألياف الممغنطة الحاوية على 2.5 % نانو سليكا حيث أبدت النتائج نسبة زيادة (1.6، 19.03، 7.89، 19.28) % و نسبة انخفاض 55.7 %عند العمر 28 يوم على التتابع مقارنة بخلطات خرسانية المساحيق الفعالة المسلحة بالألياف الغير ممغنطة.

الكلمات الدالة: نانو سليكا، الماء الممغنط، المساحيق الفعالة، ألياف الكاربون، فحوص لااتلافية.

1- ITNRODUCTION

1-1 General

Nanotechnology has changed our vision, expectations and abilities to control the material world. The developments in nano-science can also have a great impact on the field of construction materials. Portland cement, one of the largest commodities consumed by mankind, is obviously the product with great, but not completely explored potential. Better understanding and engineering of complex structure of cement based materials at nano-level will definitely result in a new generation of concrete, stronger and more durable, with desired stress-strain behavior and, possibly, with the whole range of newly introduced “smart” properties, **Sobolev**, **et al**., **2006**.

Sadrmomtazi, **et al**., **2008** investigated the influence of nano-SiO_2 on different properties of cement mortar in comparison with silica fume (SF) as a well-known active pozzolan. Different amounts of nano-SiO_2 (0, 1%, 3%, 5%, 7%and 9%) were incorporated into the ordinary cement mortar. Mechanical properties, shrinkage, water absorption of the specimens were determined. Results showed that the optimal content of nano-SiO_2 in plain cement mortar was around 7%. Nano-SiO_2 particles were more effective in developing higher mechanical strength and lower water absorption than that of SF. Yet the mortar containing nano-SiO_2 experienced higher shrinkage than that of SF mortar

Khanzadi, **etn al**., **2010** carried out an investigation to study the influence of nano silica particles on the mechanical properties and durability of concrete through measurement of compressive and tensile strength, water absorption, and the depth of chloride penetration**.** The experimental results showed that the mechanical properties measured, and the durability of the concrete mixed with the nano particles were better than that of a plain concrete, also the SEM study of the microstructures showed that the nano particles filled the cement paste pores and, by reacting with calcium hydroxide crystals from calcium silicate hydration, decreased the size and amount of these crystals. Therefore the results indicated that nano scale silica behaves not only as a filler to improve microstructure, but also as an activator to promote pozzolanic reaction.

Furthermore, the initial research and scientific testing regarding the application of a magnetic field to concrete manufacturing were commenced in Russia in 1962 for military constructions such as airports and jetties. This research was continued step by step in other institutes, such as the Jelezobeton Research and Scientific Institute in Russia, and some positive results were found in this regard.

Magnetic devices include one or more permanent magnets, which induce changes and effects on ions and water molecule clusters passing through its magnetic field. A magnetic field has a considerable effect on clusters of water molecules and causes the decrease of such a mass from 13 molecules to 5 or 6 molecules, **Afshin**, **et al**., **2010**.

Such a decrease of molecules causes more participation of water molecules in the cement hydration reaction, **Gabrielli**, **et al**., **2001**. Also, 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. This fact results in a decrease in water demand for concrete mixing and, subsequently, in reducing the W/C ratio, which has positive effects on hardened concrete properties, such as strength, durability etc., **Eshaghi**, and **Gholizadeh**, **2004**.

1-2 Research Significance

The use of nano-SiO_2 in particles forms 99.8% of its in nano scale with average particle size 12 nm is relatively a new approach. It reacts rapidly with the calcium hydroxide in the cement paste, converting it into stable cementitious compounds thus, refining the microstructure of the concrete and reducing its permeation. On the other hand, the use of HRWRA with nano-SiO_2 is expected to improve the properties of concrete due to substantial water reduction of the nano SiO_2 cement mixtures, as well as to a better dispersion of cement and these material particles with permitting high cement content and a low water the breakdown of their agglomerations by the action of HRWRA. Also by using a super plasticizer, more workable mixtures can be achieved while / cement ratio. In addition, using magnetic water in mixing materials of mixture to obtaining increasing in compressive strength

1-3 Objectives

The Primary objectives of this investigation are:

- To present the possibilities of using nano Silica for Portland cement-based composites including micro materials and micro Carbon fiber.
- To evaluate the effect of water dosage, nano-SiO_2 (NS), micro Carbon fiber, and technical requirements for reactive powder concrete. The key factors of mix design are investigated systematically through a series of experiments to investigate the influence of individual constituent material properties on overall behavior.
- To investigate the effect of magnetic water on the dynamic properties of reactive powder concrete containing NS with and without 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. Chemical properties of cement used throughout this research are shown in **Table 1**. Test results 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 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 NS was 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.

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 **Fosroc 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- First stage

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

a- Sand to cement ratio (S/C) equals to (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 equal to 0.44.

The results indicated that the S/C equal to (1:1) and Al-Ekhaider natural sand give compressive strength higher than other mixtures containing glass sand as shown in **Fig. 2.** This is because the roughness surface texture of Al-Ekhaider sand lead to bond between it and cement past stronger then bond between smooth surface texture of glass sand and cement paste.

2-Second stage

The optimum ratio of additive nano Silica (NS)

1-By using tap water;
a- The used ratios of additive NS are (1, 1.5, 2, 2.5 and 3) % by weight of cement.
b- S/C ratio equal to 1.
c- W/C ratio equal to 0.17.
d- Dosage of super plasticizer equal to 7 % by weight of cement.
e- Dosage of super plasticizer equal to 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 to the fact that the quantity of NS particles present in the mixture is higher than the amount required to combine with the liberated lime during the process of hydration, this leads to exceed silica from leaching out and causing a deficiency in strength as it replaces part of the cementitious material but does not contribute to strength. It may also be due to the defects generated in dispersion of nano particles that cause weak zones.

2- By using magnetized water:

By adherence to the same previous procedure by using 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 immersed in tap water saturated with $Ca\ (OH)_2$ at laboratory temperature $(20\text{-}23)^o$ C up to test.

3- RESULTS AND DISCUSSION

A parametric study has been carried out to investigate the effect of HRWRA (SV-Hi-Tech-36), 2.5% of nano Silica, 2 % of micro Carbon fibers, tap and magnetic water on properties of reactive powder concrete by using non-distractive test.

3-1 Bulk Density

The bulk density has been performed according to **ASTM C642-97** (1997). The average of three 100 mm cubes was adopted at 7, 28, 90, 180 and 360 days for all types of RPC using tap or magnetic water.

The bulk densities for all types of RPC using tap or magnetic water are presented in **Table 7** and **Fig. 3**

From **Fig. 3**, it can be seen that when using HRWRA and 2.5%NS-HRWRA nonmagnetic reactive powder concrete it causes an increase in bulk density relative to the reference RPC at all ages. Such increase in bulk density is mainly due to the reduction in water /cementitious ratio caused by adding HRWRA (SV-Hi-Tech-36) which improves the uniformity of the microstructure and lowers capillary porosity which is leading to better packing and increasing the density. Ascribed also to the action of the NS reaction, it leads to the densification of the concrete matrix and the transition zone as well as the pore-size and grain-size refinement processes. The percentages of increase in bulk density of HRWRA and 2.5%NS-HRWRA nonmagnetic reactive powder concrete comparison with reference RPC were (6.95 and 6.86), (9.74 and 9.7) % at 28 and 360 days respectively.

Also it can be seen 2.5%NS-HRWRA nonmagnetic reactive powder concrete reinforced with 2% micro carbon fiber have revealed slightly higher increase than the same unreinforced mixtures. This slight increase in bulk density refers to an increase in HRWRA ratio for a given workability caused by adding the micro Carbon fiber.

Table 7 and **Fig. 3** demonstrate also the effect of magnetic water on bulk density of various types of RPC.

The effect of magnetic water on the bulk density of mixtures containing 2.5%NS-HRWRA with and without micro carbon fibers is lower than RPC and HRWRA-RPC. This behavior may be due to the active NS that leads to enhance the microstructure. The percentages of increase in bulk density for all magnetic mixtures compared with the same nonmagnetic mixtures were shown in **Fig. 4**.

3-2 Absorption

In this research, the results of absorption test were conducted on various types of RPC with and without micro carbon fibers using tap or magnetic water at 28 days are shown in **Tables 8**. The results revealed a great depreciation in percentage of absorption of all types of RPC mixtures with respect to reference RPC.

It can be seen from **Table 8** and **Fig**.**5** that HRWRA-RPC has a significant reduction in percentage of absorption relative to the reference RPC. The percentage of reduction in absorption of HRWRA-RPC was 85.9 %.

The percentages of absorption which have converse proportion with strength where when strength is increased, the absorption is decreased. The results also showed that 2.5**%**NS-HRWRA nonmagnetic reactive powder concrete have a little percentage of absorption in comparison with reference RPC and HRWRA-RPC. The percentage of reduction in absorption with respect to HRWRA-RPC was 56.03 % at 28 days.

The effect of adding 2% micro carbon fibers to 2.5**%**NS-HRWRA nonmagnetic reactive powder concrete shows a slight decrease in the percentage of absorption with respect to the corresponding unreinforced mixture. This is attributed to the type of micro carbon fibers where there is non-absorption water that is empty from voids. In addition to that, the w/c ratio fixed for all mixtures are to reach a given workability caused by adding the micro Carbon fibers used higher dosage of HRWRA (SV-Hi-Tech-36).

The effect of magnetic water on the absorption of all types of reactive powder concrete reinforced with and without micro carbon fibers is presented in **Table 8**.

The results have indicated that using magnetic water in mixing of RPC tends to cause a high reduction in the percentage of absorption for various types of reactive powder concrete with and without micro carbon fibers especially when used 2.5**%**NS-HRWRA-2%CF as shown in **Table 8** and **Fig. 6**.

3-3 Dynamic Modulus of Elasticity

The effect of HRWRA (SV-Hi-Tech-36), NS and micro carbon fiber using tap or magnetic water on the dynamic modulus of elasticity of various types of RPC are illustrated in **Table 9** and **Fig. 7**.

The effect of HRWRA (SV-Hi-Tech-36) on the dynamic modulus of elasticity of nonmagnetic reactive powder concrete can be seen in **Fig. 7** whereas the percentages of increase in dynamic modulus of elasticity at 28 and 360 days calculated with respect to reference RPC (46.765 and 49.827) % respectively.

The results of 2.5%NS-HRWRA nonmagnetic reactive powder concrete had shown considerable increase in dynamic modulus of elasticity at all ages. The percentages of increase in dynamic modulus of 2.5%NS-HRWRA nonmagnetic reactive powder concrete with respect to reference RPC were (66.33 and 70.578) % at 28 and 360 days respectively. This is due to ultra fine pore structure created through the pore-size and grain-size refinement processes, in addition to the absence of micro cracking in the transition zone.

The results of micro carbon fibers on the dynamic modulus of elasticity of 2.5%NS-HRWRA nonmagnetic reactive powder concrete revealed to be slightly higher than the corresponding unreinforced mixtures at all ages. This behavior may be the percentage 2% micro carbon fibers by weight of cement which was adopted in this study are small to have slight increase on the densities values of RPC mixtures containing micro carbon fibers. The increase in the volume fraction of fibers leads to lower density of the mixture, which is attributed to the low density of micro carbon fibers; therefore, the percentage 2% micro carbon fibers were used to keep with the compressive strength, density and dynamic modulus of elasticity values of the specimens.

The effect of using magnetic water on dynamic modulus of elasticity for various types of RPC at all ages can be seen also in **Table 9** and **Fig. 7**

The results revealed that reference RPC, HRWRA, 2.5%NS-HRWRA magnetic reactive powder concrete reinforced with and without 2% micro carbon fibers presented significant higher dynamic modulus of elasticity than the corresponding nonmagnetic mixtures. The percentages of increase in dynamic modulus at all ages calculated relative to same nonmagnetic mixtures explained in **Table 10** and **Fig. 8**.

3-4 Ultrasonic Pulse Velocity

The influence of HRWRA (SV-Hi-Tech-36), NS, and micro carbon fiber using tap or magnetic water on the ultrasonic pulse velocity of various types of RPC is illustrated in **Table 11** and **Figs**. **9**.

The results showed that PRC exhibits continuous increase in ultrasonic pulse velocity up to 360 days but extremely slight at ages above 28 days.

Nonmagnetic HRWRA-RPC revealed a noticeable increase in ultrasonic pulse velocity at all ages compared with reference RPC. The percentages of increase were 16.4 and 17.5 % at 28 and 360 days respectively. This result is mainly due to a significant reduction in water to cementitious ratio of the mixture also continuity of hydration that leads to scanty voids.

Nonmagnetic 2.5%NS-HRWRA reactive powder concrete showed significant increase in ultrasonic pulse velocity at all ages with respect to reference RPC. The percentages of increase were (21.39 and 22.72) % at 28 and 360 days respectively. These mainly refer to the fact that chemical reaction of nano particles with calcium hydroxide can reduce the capillary voids and micro cracks. The nano particles may also act as filler leading to increase the density.

The results also revealed that nonmagnetic 2.5%NS-HRWRA reinforced with 2% MCF slightly increase in ultrasonic pulse velocity at all ages with respect to the same unreinforced mixtures.

From **Fig**. **9**, it can be seen that the effect of using magnetic water on all types of the RPC mixtures causes an increase in ultrasonic pulse velocity at all ages with respect to the same nonmagnetic mixtures. The percentages of increases in the ultrasonic pulse velocity compared to nonmagnetic mixtures are illustrated in **Table 12** and **Fig. 10**

3-4 Electrical Resistivity

In this investigation, the results of D. C. electrical resistivity test conducted on various types of RPC reinforced with and without micro carbon fibers using tap or magnetic water at 7, 28, 90, 180 and 360 days are showed in **Table 13** and **Fig. 11**.

For all types of RPC, the electrical resistivity increases with age progress. Despite of this increasing in electrical resistivity, there is a reduction in increasing at later age. This behavior can be attributed to the increasing hydration of cement and filling of pores with hydration products. The fact that the electrical conductivity of concrete depends mainly on the quantity of the evaporable water inside the capillary pores of the cement paste. Since the volume of evaporable water decreases as the hydration reaction precedes, the electrical resistivity increases with age progress of specimens.

From **Table 13** and **Fig. 11**, it can be seen that nonmagnetic HRWRA-RPC had a considerable increase in electrical resistivity at all ages compared with reference RPC. The percentages of increase were 128.86 and 120.34 % at 28 and 360 days respectively. This behavior may be attributed to the amount of SV-Hi-Tech-36 that was added to obtain the desired workability. It can bring about finer packing of different phases. Moreover a lower w/c ratio 0.17 can also assist in better contact between the electrode and matrix.

Nonmagnetic 2.5**%**NS-HRWRA reactive powder concrete showed considerable improvement in electrical resistivity. The percentages of increase in electrical resistivity of 2.5**%**NS-HRWRA were (41.06 and 35.18) % at 28 and 360 days respectively as compared with HRWRA-RPC. This is due to the high activity of NS which strengthens the transition zone and reduces the micro cracks through the processes of pore size and grain size refinement

The results of nonmagnetic 2.5**%**NS-HRWRA reinforced reactive powder concrete showed reduction in electrical resistivity compared with the same unreinforced mixtures. The percentages of reduction were (57.67 and 56.35) % at 28 and 360 days respectively. Carbon fibers are known in reducing the electrical resistivity of reactive powder concrete.

The effect of magnetic water on the electrical resistivity of all types of composite reactive powder concrete reinforced with and without micro carbon fibers is presented in **Table 13** and **Fig**. **11**. The results demonstrated that all types of reactive powder concrete exhibit a noticeable increase in electrical resistance up to 360 days in comparison with the same nonmagnetic mixtures. The percentages of increase in resistivity of all types of reactive powder concrete are illustrated in **Table 14** calculated with respect to the same nonmagnetic mixtures.

4- CONCLUSIONS

Using HRWRA, 2.5%NS-HRWRA, 10%MHRM-HRWRA, and 10%MGGBFS-HRWRA magnetic and nonmagnetic RPC reinforced with and without micro carbon fibers causes an increase in bulk density relative to the reference RPC at all ages.

Magnetic RPC mixtures tends to reveal high reduction in the percentage of absorption for various types of RPC with and without micro Carbon fibers especially when using 10%MGGBFS.

The effect of using magnetic water on dynamic modulus of elasticity and ultrasonic pulse velocity for various types of reactive powder concrete was significant higher than dynamic modulus of elasticity and ultrasonic pulse velocity of the corresponding nonmagnetic mixtures. The percentages of increase range between 12.02 to 19.03% and 4.91 to 9.685 % at 28 days respectively.

Nonmagnetic 2.5**%**NS-HRWRA RPC reinforced with 2% micro carbon fibers revealed a reduction in electrical resistivity compared with the same unreinforced mixtures. The percentages of reduction were (57.67, 56.35) % at 28 and 360 days respectively.

Results of the effect of magnetic water on the electrical resistivity of all types of reactive powder concrete reinforced with and without micro carbon fibers were revealed a noticeable increase in electrical resistivity up to 360 days. The percentages of increases in the electrical resistivity related to nonmagnetic mixtures range between 9.64 to 19.28 % 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

*According to the manufacture company

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. Streng (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	Fiber	Compressive 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. Bulk density of various types of magnetic and nonmagnetic mixtures.

Mixtures	Dry bulk density kg/m^3*10^3				
	Age (days)				
	7	28	90	180	360
RPC Tap Water (TW)	2.207	2.217	2.2193	2.225	2.227
HRWRA-RPC-TW	2.359	2.371	2.375	2.3771	2.3799
2.5% NS-HRWRA-RPC-TW	2.415	2.433	2.439	2.442	2.443
2.5% NS–HRWRA–2% CF–RPC-TW	2.419	2.437	2.442	2.446	2.449
RPC Magnetic Water (MW)	2.278	2.290	2.297	2.305	2.310
HRWRA -RPC- MW	2.417	2.431	2.439	2.443	2.448
2.5% NS-HRWRA-RPC- MW	2.451	2.471	2.476	2.48	2.482
2.5% NS–HRWRA–2% CF–RPC-MW	2.459	2.476	2.482	2.486	2.488

Table 8. The percentage of absorption, density and compressive strength at 28 days for various types of magnetic and nonmagnetic mixtures

Mixtures	Absorption %	Density (kg/m$^{3)}$	Compressive Strength (MPa)
RPC Tap Water (TW)	2.6435	2217.3	57.48
HRWRA-RPC-TW	0.373	2373.8	96.7
2.5% NS–HRWRA–RPC-TW	0.164	2417.6	108.3
2.5% NS–HRWRA–2% CF–RPC-TW	0.161	2420	110.48
RPC Magnetic Water (MW)	1.295	2322.4	66.7
HRWRA -RPC- MW	0.179	2411	117.5
2.5% NS - HRWRA - RPC-MW	0.0738	2544.9	134.3
2.5% NS–HRWRA–2% CF–RPC-MW	0.0713	2548.09	135.2

Table 9. Dynamic modulus of elasticity of various types of magnetic and nonmagnetic

Mixtures	Dynamic modulus of elasticity (GPa) Age (days)				
	7	28	90	180	360
RPC Tap Water (TW)	27.082	28.795	28.993	29.178	29.2096
HRWRA-RPC-TW	40.369	42.261	43.08	43.721	43.7639
2.5% NS–HRWRA–RPC-TW	45.846	47.894	48.748	49.454	49.8251
2.5% NS–HRWRA–2% CF–RPC-TW	46.174	48.23	49.104	49.814	50.1515
RPC Magnetic Water (MW)	30.503	32.255	32.996	33.138	33.275
HRWRA -RPC- MW	46.77	49.21	50.38	51.15	51.35
2.5% NS - HRWRA - RPC- MW	54.101	56.974	58.132	58.677	58.7938
2.5% NS–HRWRA–2% CF–RPC-MW	54.397	57.41	58.619	59.131	59.4924

Table 10. The percentage of increase in dynamic modulus of elasticity for various types of magnetic mixtures with respect to the same nonmagnetic mixtures

Mixtures	The percentage increase in dynamic modulus of elasticity Age(days)				
	7	28	90	180	360
RPC Magnetic Water (MW)	12.63	12.02	13.81	13.57	13.92
HRWRA-RPC-MW	15.86	16.44	16.94	16.99	17.33
2.5% NS-HRWRA-RPC-MW	18.01	18.96	19.25	18.65	18.00
2.5% NS-HRWRA-2%CF-RPC-MW	17.81	19.03	19.38	18.70	18.63

Table 11. Ultrasonic Pulse Velocity of various types of magnetic and nonmagnetic mixtures

Mixtures	Ultrasonic Pulse Velocity km/sec Age(days)				
	7	28	90	180	360
RPC Tap Water (TW)	3.702	3.792	3.808	3.816	3.82
HRWRA-RPC-TW	4.324	4.414	4.454	4.488	4.489
2.5% NS–HRWRA–RPC-TW	4.519	4.603	4.641	4.672	4.688
2.5% NS–HRWRA–2% CF–RPC-TW	4.548	4.637	4.675	4.706	4.7181
RPC Magnetic Water (MW)	3.876	3.978	4.018	4.026	4.034
HRWRA -RPC- MW	4.65	4.745	4.767	4.78	4.789
2.5% NS - HRWRA - RPC- MW	4.883	5.003	5.052	5.071	5.086
2.5% NS–HRWRA–2% CF–RPC-MW	4.867	4.98	5.025	5.046	5.052

Table 12. The percentages of increase in ultrasonic pulse velocity of various types of magnetic mixtures with respect to the same nonmagnetic mixtures

Mixes	The percentage increase in Ultrasonic Pulse Velocity Age(days)				
	7	28	90	180	360
RPC Magnetic Water (MW)	4.7	4.91	5.51	5.5	5.6
HRWRA -RPC- MW	7.54	7.499	7.03	6.51	6.68
2.5% NS - HRWRA - RPC- MW	7.53	7.89	7.93	7.68	7.532
2.5% NS–HRWRA–2% CF–RPC-MW	7.39	7.89	7.95	7.95	7.81

Table 13. Electrical resistivity of various types of magnetic and nonmagnetic mixtures

Mixtures	**Electrical resistivity (kΩ . cm)**				
	Age(days)				
	7	**28**	**90**	**180**	**360**
RPC Tap Water (TW)	55.3	64.8	68.1	69.5	70.3
HRWRA-RPC-TW	131.5	148.3	151.9	153.7	154.9
2.5% NS–HRWRA–RPC-TW	185.5	204.6	207.6	208.9	209.4
2.5% NS–HRWRA–2% CF–RPC-TW	76.4	86.6	88.79	90.26	91.4
RPC Magnetic Water (MW)	59.8	71.4	74.9	76.3	76.7
HRWRA -RPC- MW	145.2	162.6	165.7	167.6	168.5
2.5% NS - HRWRA - RPC- MW	213.7	236.8	239.5	240.9	242.1
2.5% NS–HRWRA–2% CF–RPC-MW	89.6	103.3	105.9	107.5	108.6

Table14. The percentages of increase in the electrical resistivity of various types of magnetic mixtures with respect to the same nonmagnetic mixtures

mixtures	**The percentage increase in electrical resistivity**				
	Age(days)				
	7	**28**	**90**	**180**	**360**
RPC Magnetic Water (MW)	8.14	10.19	9.99	9.78	9.1
HRWRA -RPC- MW	10.42	9.64	9.08	9.04	8.78
2.5% NS - HRWRA - RPC- MW	15.20	15.74	15.37	15.32	15.39
2.5% NS–HRWRA–2% CF–RPC-MW	17.28	19.28	19.27	19.10	18.82

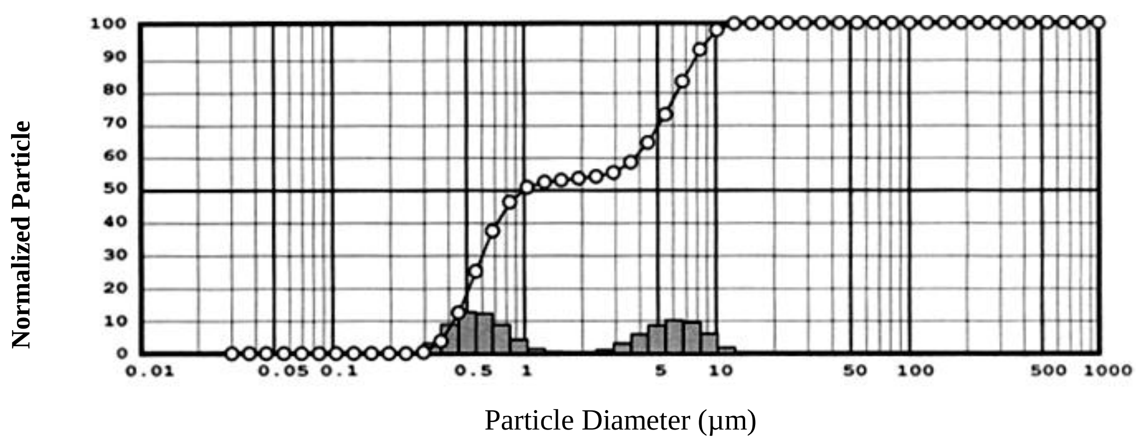

Figure 1. Particle size distributions of cement.

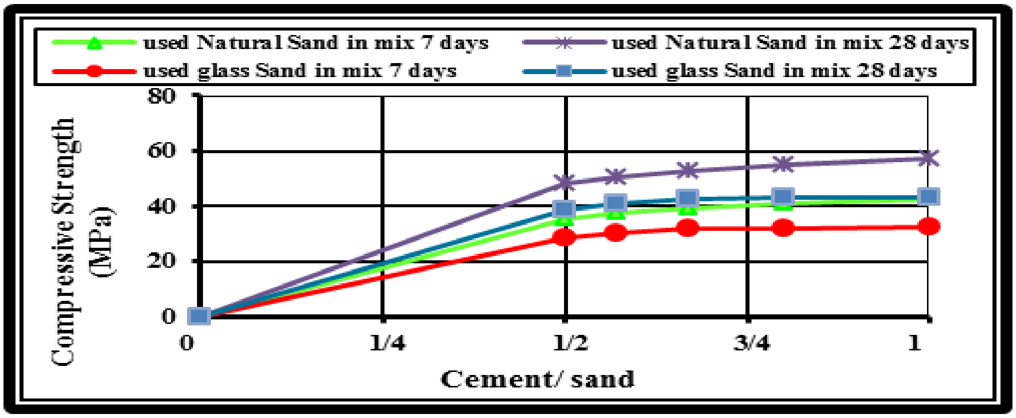

Figure 2. Relationship between compressive strength and percent of Cement/ Natural or Glass sand.

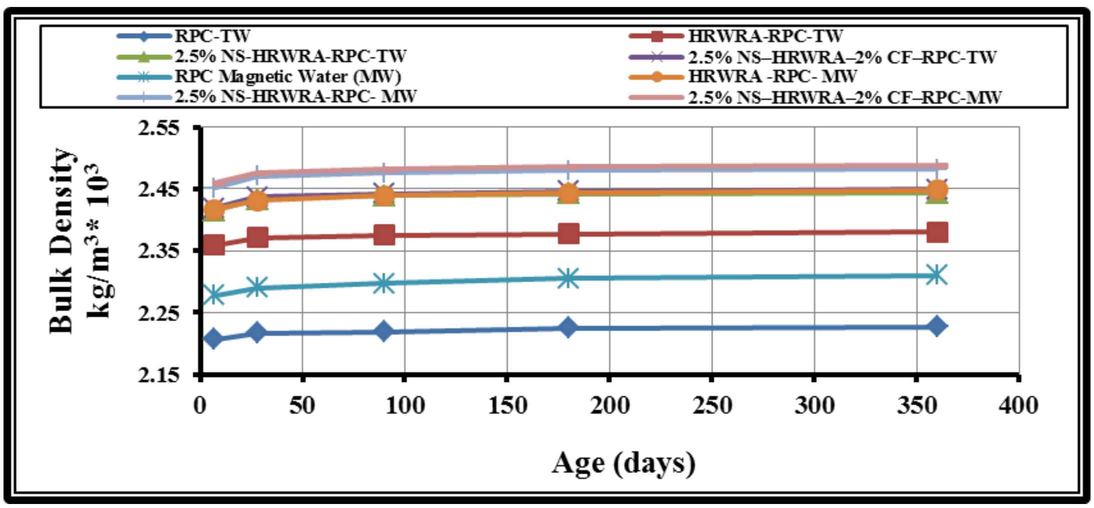

Figure 3. Effect of magnetic and nonmagnetic mixtures containing HRWRA, 2.5%NS-HRWRA and 2.5%NS- HRWRA-2%CF on the bulk density with age.

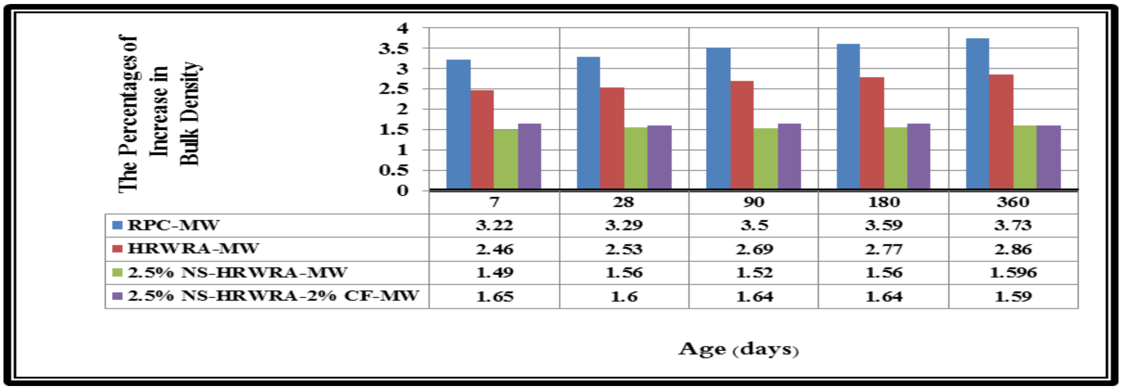

Figure 4. The percentages of increase in bulk density of various types of magnetic mixtures with respect to the same nonmagnetic mixtures with age.

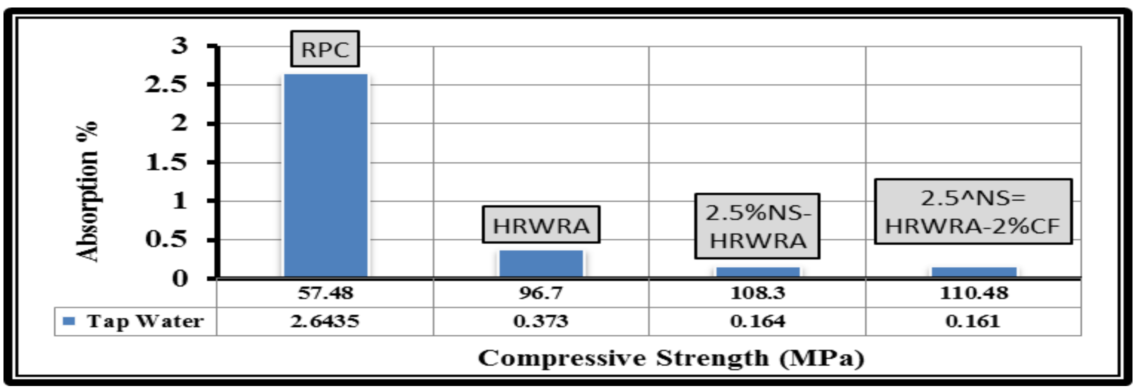

Figure 5. Percentages of absorption versus compressive strength at 28 days for various types of nonmagnetic RPC with and without micro carbon fibers

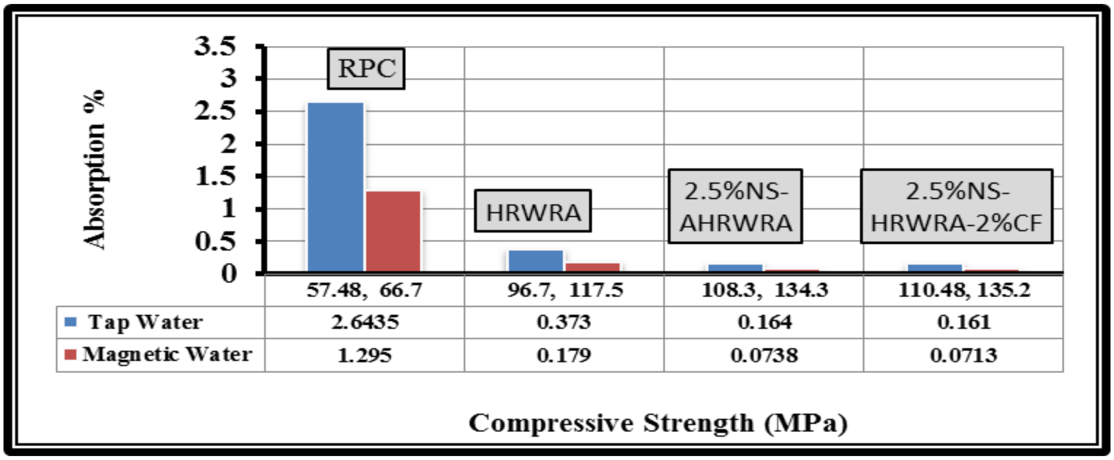

Figure 6. Percentages of absorption versus compressive strength at 28 days for various types of magnetic and nonmagnetic RPC with and without micro carbon fibers

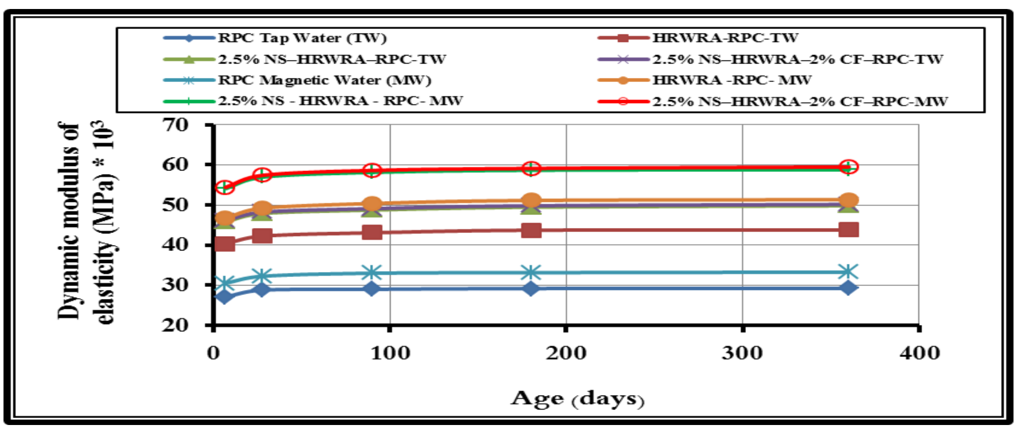

Figure 7. Effect of magnetic and nonmagnetic mixtures containing HRWRA, 2.5%NS-HRWRA or 2.5%NS-HRWRA-2%CF on the dynamic modulus of elasticity with age.

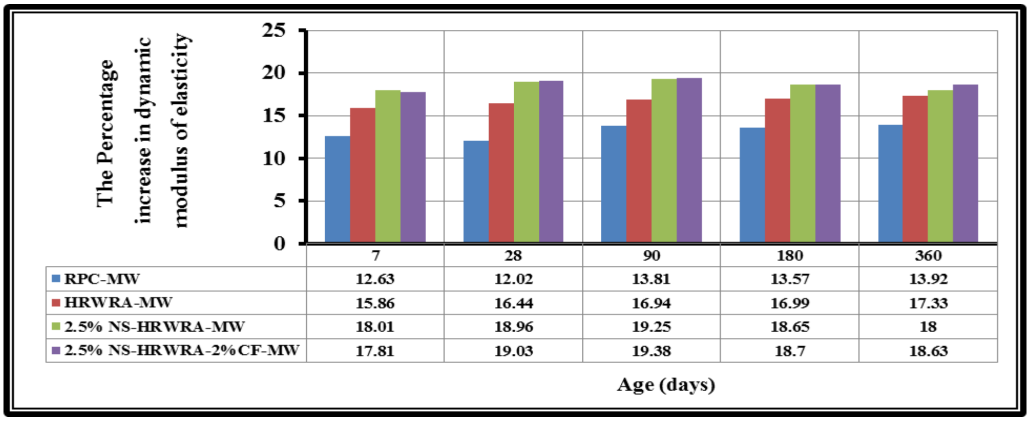

Figure 8. The percentages of increase in the dynamic modulus of elasticity of various types of magnetic mixtures with respect to the same nonmagnetic mixtures with age.

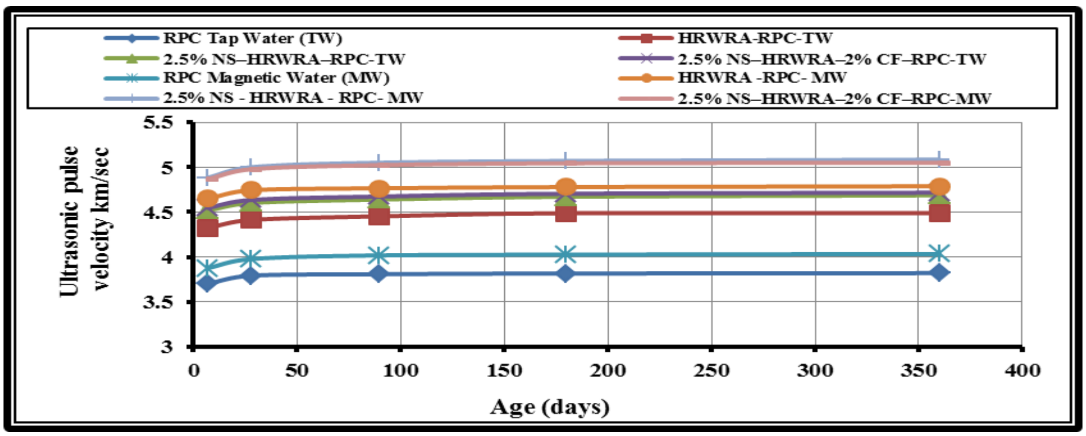

Figure 9. Effect of magnetic nonmagnetic mixtures containing HRWRA, 2.5% NS-HRWRA and 2.5% NS-HRWRA-2%CF on the ultrasonic pulse velocity with age.

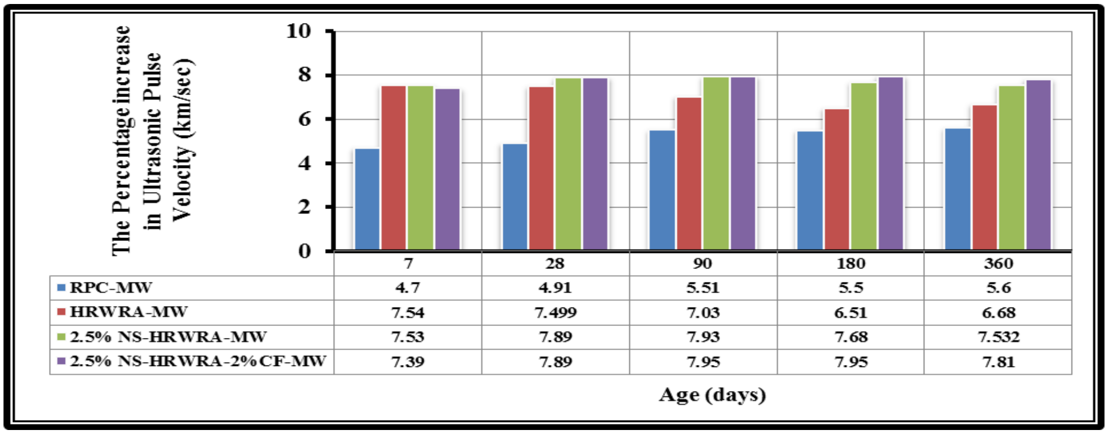

Figure 10. The percentages of increase in ultrasonic pulse velocity of various types of magnetic mixtures with respect to the same nonmagnetic mixtures with age.

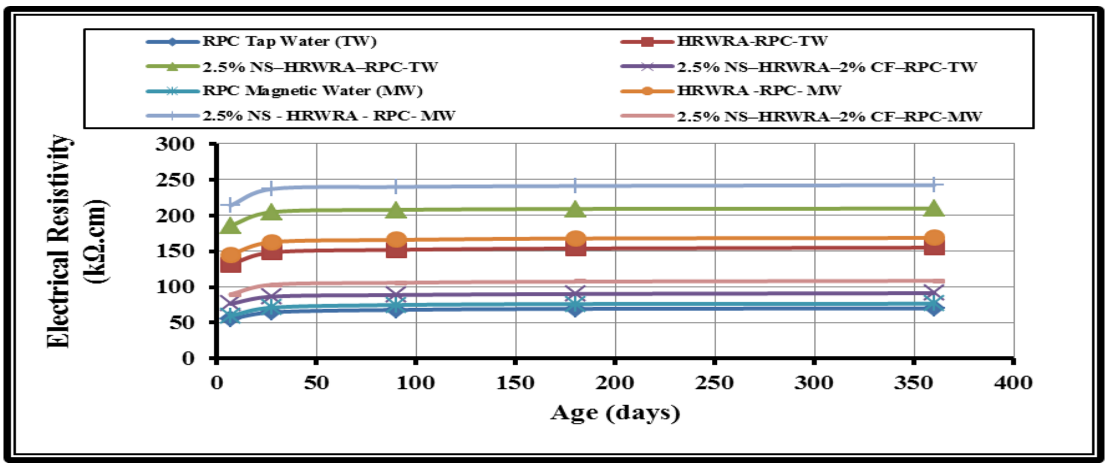

Figure 11. Effect of magnetic and nonmagnetic mixtures containing HRWRA, 2.5% NS-HRWRA and 2.5% NS-HRWRA-2%CF on the electrical resistivity with age.