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Effect of Water to Cement Ratio (w/c) and Age on The Ultrasonic and Electrical Non-Destructive Testing (NDT) of Plain and Chemical Admixtured Concrete

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THE ULTRASONIC velocity, the electrical resistivity and the compressive strength of plain (N), accelerating admixture (A), high range water reducing admixture (H), and retarder admixture (R) concrete samples of 0.35, 0.42, 0.55 and 0.6 w/c ratios were measured, The effect of concrete age on the samples with 0.42 water to cement (w/c) ratio were studied.

The results show that, the ultrasonic velocity, the electrical resistivity and the compressive strength are inversely proportional to the w/c ratio for all samples and at the same w/c ratio the values of these parameters for the high range water reducing admixture (H) concrete, are relatively higher than that of the accelerating admixture (A) concrete then the Plain (N) concrete, then, retarder admixture (R) concrete.

For the samples with different ages, the results show that, the ultrasonic velocity, the electrical resistivity and the compressive strength increase rapidly at first 7 days, after that, the increment slows down significantly after 28 day, and at the same age, the values of theses parameters of the accelerating admixture concrete sample (A4) are higher than that of the other samples {high range water reducing concrete (H4), plain concrete (N4) - retarded concrete (R4)}

The destructive compressive strength was correlated to the nondestructive ultrasonic velocity and electrical resistivity measurements. Linear relationships between the compressive strength and either the ultrasonic velocity or the electrical resistivity were obtained.

The results were attributed to the hardening and the microstructure development in the different concrete samples

Keyword: **S**ultrasonic velocity, Electrical resistivity compressive strength , w/c ratio –plain concrete , Accelerating admixture, High range water reducing admixture , Retarder admixture nondestructive testing, chemical admixture.

Introduction

Portland cement concrete (PCC) is one of the primary materials used in the construction of the civil infrastructure. For typical civil structures such as bridges, buildings, and dams, concrete consisting of aggregates, sand, cement and water are combined and placed surrounding a mild reinforcing steel skeleton to provide a durable structure.

PCC by itself does not possess all the required properties. Hence, admixtures are widely used in the production of concrete to make it suitable for different conditions. Admixtures are natural (minerals) or manufactured chemicals which are added to the concrete before or during mixing.

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The most often used admixtures are accelerators, high range water-reducing and retarder admixtures. Admixtures are used to give special properties to fresh or hardened concrete. Admixtures may enhance the durability, workability or strength characteristics of a given concrete mixture. Admixtures are used to overcome difficult construction situations, such as hot or cold weather placements, pumping requirements, early strength requirements, or very low water-cement ratio specifications.

High range water reducing (H) admixtures are a special class of water-reducer. Often called super-plasticizers, they reduce the water requirements of a given concrete mixture between 12 and 25 % [1], Therefore, they are used to increase strength and reduce permeability of concrete by reducing the water content in the mixture, or greatly increase the slump to produce “flowing” concrete without adding more water.

These admixtures are essential for high strength and high performance concrete mixtures that contain higher contents of cementitious materials and mixtures containing silica fume.

Accelerators (A) admixtures reduce the initial set time of concrete and give higher early strength. Accelerators do not act as antifreeze; rather, they speed up the setting and rate of strength gain, thereby making the concrete stronger to resist damage from freezing in cold weather [1]. Accelerators are also used in fast track construction requiring early form removal, opening to traffic or load application on structures. Liquid accelerators meeting requirements for ASTM C 494 types C and E are added to the concrete at the batch plant.

Retarder (R) addmixtures are chemicals that delay the initial setting of concrete by an hour or more. Retarder admixtures are often used in hot weather to counteract the rapid setting caused by high temperatures [1]. Also, for large jobs, concrete with retarder is used to allow more time for placing and finishing.

During the past years non-destructive testing of concrete (NDT) has achieved increasing demand for the evaluation of laboratory samples and infrastructure system with regard to their strength, uniformity, durability and other properties. Electrical resistivity measurement has been found of an interest [2-8]. Many parametric studies using NDT methods, especially ultrasonic, have been performed over the years [9-22].

Also, some mechanical properties (elastic moduli) of different materials were studied by ultrasonic nondestructive technique [23-33].

Etsuzo et al. [21] studied the variation of ultrasonic velocity with different water contents. They found that the sound velocity varied gradually from 3000 m/s to 4500 m/s according to the water content. The frequency of maximum transmission also depended on the water content in this frequency range.

Kiran [2] studied the effect of moisture, type of aggregate, water /cement ratio, curing time, mineral admixture type and chloride content on the dielectric properties of PCC. He found that the aggregate type affects the measured dielectric constant of PCC. The dielectric constant depends on the amount of free water available in the PCC and the degree of hydration. When there is no free water available in the PCC, there is a large reduction in the polarization and conductivity and thus measured dielectric constant of PCC is mainly due to its composition (aggregate and the cement paste). Chlorides have a more significant influence on the loss part of the dielectric constant than the real part. There is a correlation between the permeability test (based on conductance measurements) of PCC and the measured complex dielectric constant; both values are related to the conductivity of PCC.

An efficient system for early age and regular assessment of concrete structure is urgently required to assure the structure safety and reliability. The most widely used methods to test early age properties of structural materials are the nondestructive testing (NDT) methods, which can provide some information about the material properties without damaging the structure. Also, they give a reliable view about the structure development. Ultrasonic NDT is one of the most successful and frequently applied methods for the quality control of metallic and composite materials. The measurement of the ultrasonic velocity has been used for a long time to characterize setting and hardening of cementitious systems [23-27, 8-15] .

Among the other characteristics of concrete, the strength of concrete is commonly considered as the most important property. Many NDT methods are now available for estimating the concrete strength. However, those conventional NDT methods are not fully capable of providing a reliable estimate of the concrete strength. Many authors, [9-22] have correlated the compressive strength to the velocity of ultrasonic propagation in different kinds of concretes.

Del Rio et el. [9], have been found an exponential relationship between the compressive strength of concrete specimens and the longitudinal speed of propagation of ultrasound in them. Both variables were found to depend significantly on the water-cement ratio and on the proportion of gravel and pea gravel present in the samples. A time-dependent model was developed with which it was found to be straightforward to predict the value of the compressive strength at 28 days after fabrication of a specimen on the basis of the measurement of the ultrasonic velocity at only 2 and 5 days after fabrication.

Electrical resistivity is another important physical property of Portland cement concrete that affects a variety of applications. Electrical resistivity (or its inverse, conductivity) is important as a measure of the ability of concrete to resist the passage of electrical current. This has direct relevance to such applications as electrically powered rapid transit lines, where high resistivities are needed, and hospital operating room floors and cathodic protection systems, where low resistivities are required.

Fayad [8], David et al. [3], Huges et al. [7], Kiran et al. [3], Rob [4] and Hanson et al. [6] have studied and reported the factors affecting the electrical resistivity of different kinds of concretes.

Currently there is a lack of information about the effect of the admixtures on the ultrasonic velocity and the electrical resistivity of concrete, therefore, this work aims to study the effect w/c ratio and age of plain (N) and chemical admixture (A, H and R) concretes on the ultrasonic velocity, the electrical resistivity and the compressive strength and to correlate among these properties.

Experimental

Concrete Mixes and Sample Preparation

Ordinary Portland cement obtained from Helwan Company (Egypt) and crushed lime stones obtained from El-Mokatam (Egypt) were used in the preparation of the different concrete samples using 0.42 w/c ratio. The fine and coarse aggregates were sized using suitable sieve set, the aggregates sizes and some of the physical properties are listed in Table 1.

Plain concrete (N) and three different admixture concrete samples (High range water reducing (H), Accelerating (A) and Retarding (R) admixtures) were prepared by applying the absolute volume method, as specified by American Concrete Institute (ACI). The mix designs of these samples are listed in Table 2. The used admixtures were obtained from SIKA-Egypt Company.

The plain concrete samples (N) were prepared with four w/c ratios of 0.35, 0.42, 0.55 and 0.6 where the cement undergoes complete hydration at the 0.42 w/c ratio [2] and the w/c ratios of 0.35, 0.55 and 0.6 were selected in order to study the effect of w/c ratios above and below its optimum value (0.42).

The accelerating admixture concrete (A) and the retarding admixtures concrete (R) samples were prepared with 0.35, 0.42, 0.55 and 0.6 w/c ratio [28]. The high range water reducing admixture concrete samples (H) were prepared with 0.35, 0.42 and 0.55 w/c ratio. The 0.6 w/c ratio can't be used since there is no need to use this type of admixture with that high w/c ratio (2). After molding the samples, they were covered with polythene and left for 24 hr at room temperature before removing from the molds and then, immersed in water bath for curing at room temperature. The ultrasonic, the electrical resistivity measurement and compression test were carried out on 3 samples after 28 days of water curing.

Accelerating admixture concrete, High range water reducing admixture concrete and Retarding admixture concrete samples of 0.42 w/c ratio were prepared by adding the corresponding admixture to the corresponding amount of water then to the mix of the plain concrete. Mix designs of the samples are listed in Table 3. The 0.42 w/c ratio was used because the cement undergoes complete hydration at this ratio [2]

Before mixing, all raw materials were weighed carefully by digital balance of 1 gm resolution. The aggregate was washed and let to be air dried before mixing with cement and water. All samples used in this study were prepared using hand mixing because the quantities of concrete which have to be mixed are relatively small. The mixing was carried out according to the following:

1- The aggregate spreads in uniform layer on a hard, clean base.

2- Cement is then spread over the aggregate, and the dry materials are mixed by turning over from one end of the tray to the other and with a shovel until the mix appears uniform.

3- For A, H, and R admixture concrete samples each type of admixture is added to the corresponding amount of water then gradually added to the mix and turned over again, until it appears uniform in colors and consistency [14]

The molds used for placing of different mixes were cubic Perspex (100x100x100 mm^3). All samples were left in these molds for the first 24 hr before water curing.

The placing of concrete was made in three layers each layer as compacted with standard 16 mm diameter steel rod, rounded at the end with at least 30 stroks in each layer with avoiding the contact of the rod with the base of the mold. After placing of the concrete mix, the samples were covered with polythene and left for 24 hours at room temperature. After one day of casting the samples were removed from the mold and water cured at room temperature and the different measurements were carried out at 1, 7, 14, and 28 days. The number of samples for each measurement was 4 samples.

TABLE 1. Fine and coarse aggregate sizes and some of the physical properties.

Type	FA			CA		
	Size in mm	% pass	% remain	Size in mm	% Pass	% remain
	2	100	0	9.5	100	0
	1.18	99.8	0.17	6.7	51.95	48.05
Size	0.6	99.4	0.6	4.75	8.6	91.4
	0.3	43.8	56.2	2.36	1.2	98.8
	0.15	5.3	94.7			
	0.075	0	100			
Specific density g/cm^3		2.1			2.55	
Absorption %		0.169			0.069	

TABLE 2. Mix design for 1m^3, where, FA- is fine aggregate, CA- is the coarse aggregate, N- is the plain concrete, A- is the accelerated concrete samples, H- is the high range water reduced concrete samples, R- is the retarded concrete samples.

Sample code	Cement Kg	Water Kg	FA* Kg	CA* Kg	Adm. Liter
H3	400	140	600	1200	2.5
H4	"	168	"	"	"
H5	"	220	"	"	"
N3	400	140	600	1200	0
N4	"	168	"	"	"
N5	"	220	"	"	"
N6	"	240	"	"	"
R3	400	140	600	1200	1.6
R4	"	168	"	"	"
R5	"	220	"	"	"
R6	"	240	"	"	"
A3	400	140	600	1200	2.4
A4	"	168	"	"	"
A5	"	220	"	"	"
A6	"	240	"	"	"

The accuracy of sample dimensions measurements is of great importance in calculating each of the ultrasonic velocity, the electrical resistivity and the compressive strength, since all these quantities are related to the sample thickness or contact area.

A uniform thin film of coupling material (with intermediate acoustic impedance) is placed between the transducer and the sample.

Measurement of the ultrasonic velocity

Among various techniques of ultrasonic measurements, the through transmission technique was applied to measure the velocity of propagation of ultrasonic waves in concrete samples. It is the most energy efficient arrangement because the pulse receiver is directly opposite to the pulse transmitter. Since the distance between the two transducers is minimized, the amount of pulse energy lost through the material friction is also minimized.

The ultrasonic velocity was measured by using USIP-20 flaw detector (Krautkramer) attached to two 500 KHz frequency and 24 mm diameter longitudinal wave probes for the longitudinal velocity measurements according to the ASTM: C597-16 (ASTM) and described in details in [29, 30] The through transmission technique was applied in the measurements. In this technique; an automatically adjusted short duration pulse (1 ~ 2 μ sec) of high frequency is applied to the transducer; consequently, the transducer is driven at its center frequency. A uniform thin film of coupling material (with intermediate acoustic impedance) is placed between the transducer and the sample.

The transducer transmits (transmitter) ultrasonic wave with certain duration time that is received by the other transducer placed at the opposite face on the center line. The receiver feeds the pulse to the receiving input of USIP 20 ultrasonic flaw detector. The flaw detector screen shows the sent pulse (initial) and the received pulse through the material and can calculate the time between them, and by entering the sample thickness, the ultrasonic velocity can be automatically calculated, and displayed on the digital screen of the instrument. The ultrasonic pulse velocities (longitudinal and shear) were measured in two perpendicular directions in the sample then each velocity was averaged. A schematic diagram for ultrasonic velocity measurement is shown in Fig. 2.

The mold used in measurement of the ultrasonic velocity and the electrical resistivity is shown in Fig. (1a, 1b). Two copper plates acting as two electrodes were fixed to the cube surface by means of two screws which act as alligator plugs for the electrical resistivity measurement. The other two opposite sides were designed to hold two concentric opposite probes for the ultrasonic measurements

The Electrical Resistivity Measurement

The electrical resistance (R) was measured using HP4194A Impedance analyzer. The measurements were carried out at (100 KHz, 10V) (3, 7). The contact between the electrodes and the sample was made by low resistivity gel which has a negligible effect on the resistance being measured. When the electrical resistance was measured, the sample surface was dried. The dried surface ensured that the volume resistance not the surface resistance was being measured [7]. The electrical resistivity (ρ) was calculated from

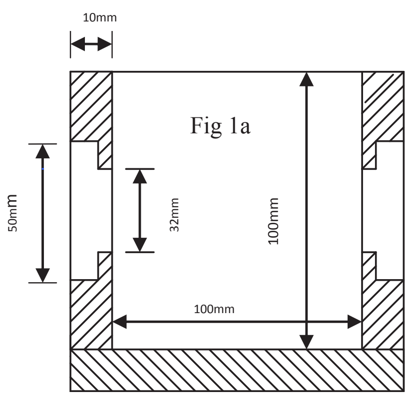

Fig. 1a, Cross section view in the mold used for ultrasonic velocity and electrical resistivity measurements. Fig. 1b, Photograph of he mold used for ultrasonic velocity and electrical resistivity measurements.

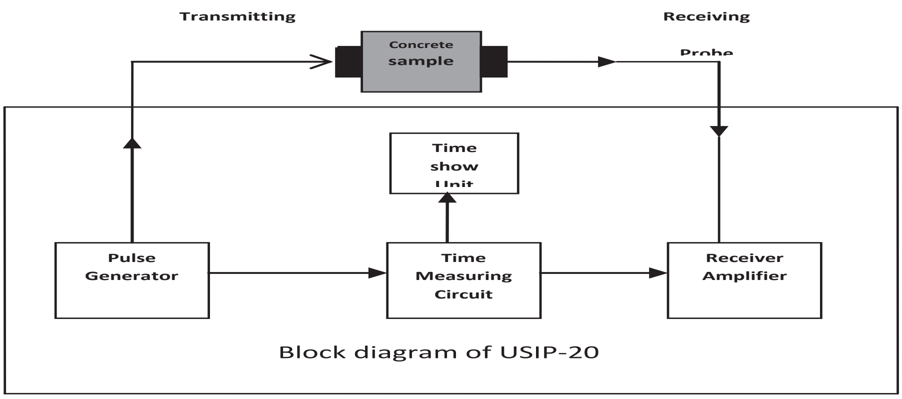

Fig. 2, Schematic diagram of the equipment used in the ultrasonic measurement (Adopted from ASTM: C 597-16).

the following equation:

$$\rho = R.\frac{A}{L} \quad (1)$$

Where; L- is the specimen length, A is the cross - section area of the specimen, R- is the electric resistance and ρ- is the electrical resistivity.

Compressive strength measurements

Concrete compressive strength was measured on three specimens of each mix by hydraulic compression testing machine "RMU 200" with accuracy ± 0.5%.

Results

Effect of the w/c Ratio and early age on the Ultrasonic Velocity

Figure (3), shows the relation between the ultrasonic velocity and the w/c ratio of the plain (N) and the chemical admixture (A, H and R) concrete samples where, the ultrasonic velocity inversely proportional to the w/c ratio for all samples (N, A, H and R) and at the same w/c ratio its value for "H" samples is higher than that of "A" then "N", then "R" samples. As the w/c ratio increase from 0.35 to 0.6, the ultrasonic velocity decreases from 4588 to 4338 m/s, from 4550 to 4272 and from 4535 to 458 and from 4511 to 4241 m/s and m/s for H, A, N and R samples respectively as listed in Table 3.

Figure 4 shows the relation between the ultrasonic velocity and the concrete age of A4, H4, N4, and R4, where, the ultrasonic velocity increases rapidly at first 7 days, but after that the increase in the ultrasonic velocity slows down significantly. The ultrasonic velocity at 1 day is approximately (70 – 81 %) from that of 28 days, while at 7 days it reaches approximately (96 – 97 %) from that of 28 days. At early ages, the increase in the ultrasonic velocity for "A4" sample is higher than that of "H4" than "N4", and "R4" samples, while at later ages the values of ultrasonic pulse velocities have nearly the same trend, and approaching a constant value as listed in Table 3.

Effect of the w/c Ratio and age on Electrical Resistivity

The relation between the electrical resistivity and the w/c ratio of the plain (N) and the chemical admixture (A, H and R) concretes is shown in Fig. 5.

In general, the electric resistivity is inversely proportional to the w/c ratio for all samples. For the same w/c the electrical resistivity value for H samples is higher than that for A then H then R samples.

The electrical resistivity values of for "H" samples decreases from 88.2 to 49.12 Ohm.m, its value for A samples decreases from 81.12 to 42.95 Ohm.m, its value for N samples decreases from 72.05 to 43.02 Ohm.m and its value for R samples decreases from 65.8 to 37.5 Ohm.m with the increase of w/c from 0.35 to 0.60 as listed in Table 3.

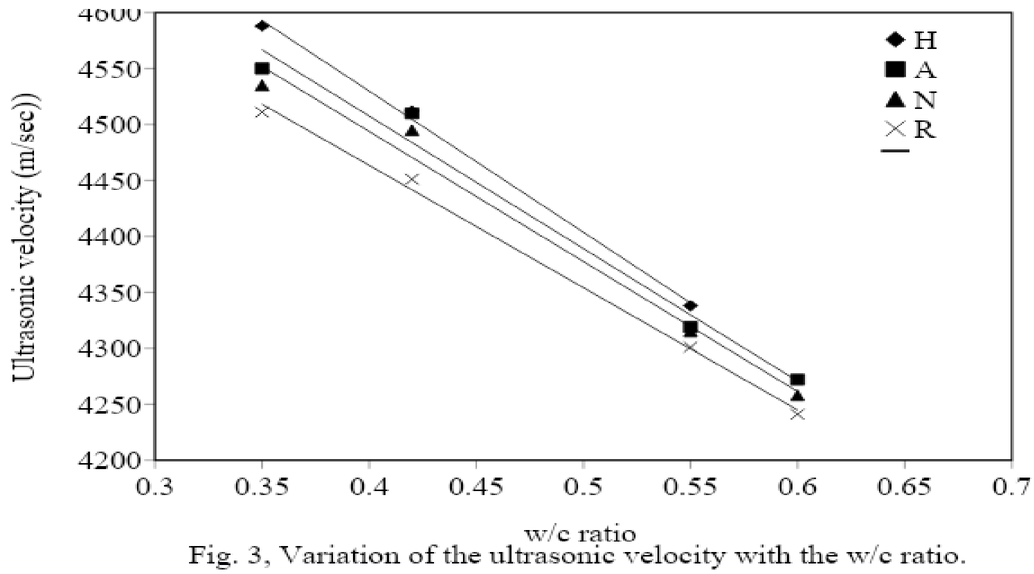

Fig. 3, Variation of the ultrasonic velocity with the w/c ratio.

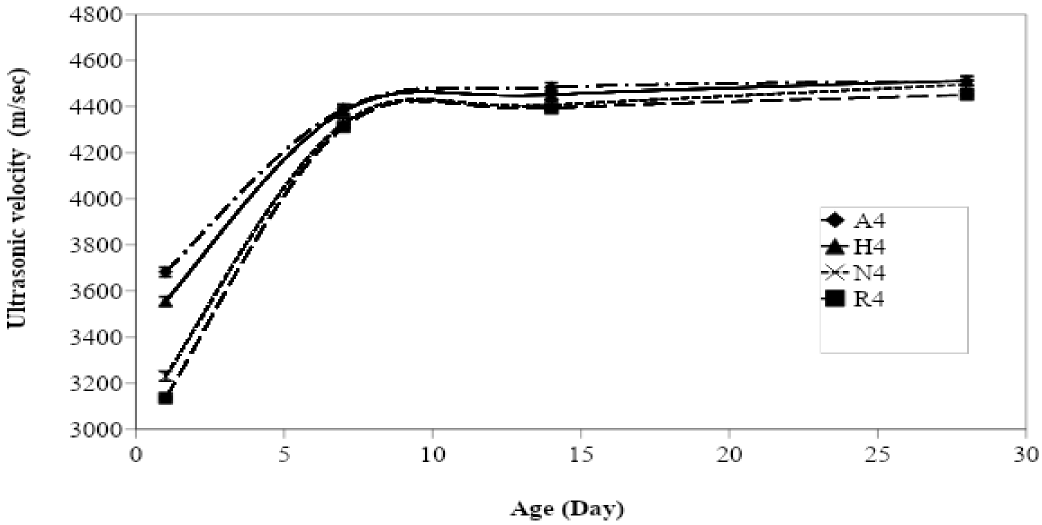

Fig.4. Variation of the ultrasonic velocity with the concrete age of plain (N4) and admixtured (A4, H4 and R4) concrete of 0.42 w/c ratio.

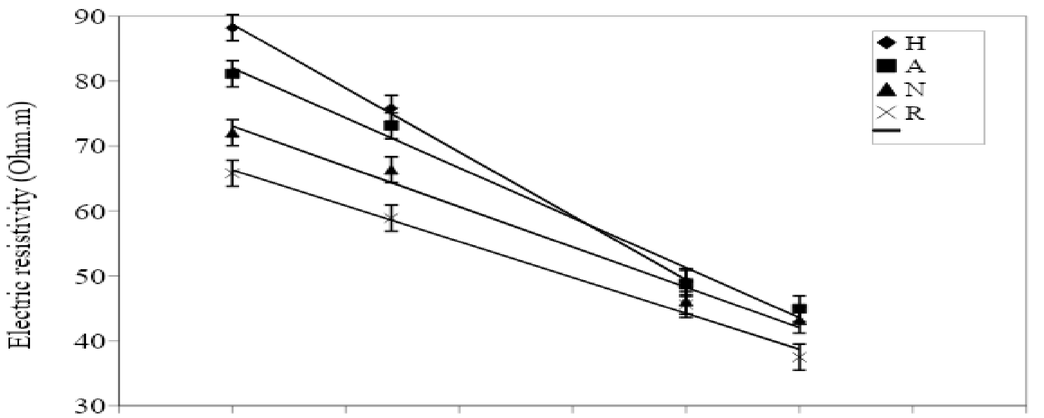

Fig. 5. Variation of the electric resistivity with the w/c ratio.

TABLE 3. The ultrasonic velocity V, the electrical resistivity and the compressive strength, for the high range water reducing admixture (H) concrete, the accelerating admixture (A) concrete, the Plain (N) concrete, retarder admixture (R) concrete.

	W/C ratio	V m/s	r Ohm.m	S kg/cm2		age day	V m/s	r Ohm.m	S kg/cm2
H3	0.35	4588	88.2	486.2	A4	1	3682	41.605	270
H4	0.42	4512	75.8	433.5	"	7	4390	55.71	399.9
H5	0.55	4338	49.12	388	"	14	4482.9	63	417.2
A3	0.35	4550	81.12	457	"	28	4510	73.1	430
A4	0.42	4510	73.1	430	H4	1	3555.2	35	259.3
A5	0.55	4319	48.85	361	"	7	4380	53.395	388
A6	0.6	4272	44.95	348	"	14	4451.8	61	408.48
N3	0.35	4535	72.05	444	"	28	4512	75.8	433.5
N4	0.42	4495	66.34	419	N4	1	3230	26.99	188.6
N5	0.55	4315	46.1	351	"	7	4327.5	49.145	378.74
N6	0.6	4258	43.2	333	"	14	4405	56.825	407.4
R3	0.35	4511	65.8	432.5	"	28	4495	66.34	419
R4	0.42	4451	58.9	408	R4	1	3135	24.26	174.01
R5	0.55	4301	45.6	348.2	"	7	4312	42.655	356
R6	0.6	4241	37.5	278	"	14	4392	51.235	398
					"	28	4451	58.9	408

Figure 6 shows the variation between the electrical resistivity with concrete age. The electrical resistivity increases rapidly at first 7days, but after that it slows down significantly. The value of electrical resistivity at 1 day is approximately (40 – 56 %) from that of 28 days, while at 7 days it reaches approximately (70 – 76 %) from that of 28 days. The electrical resistivity at early ages for the "A4" sample is higher than that of the "H4", then "N4" then "R4" samples, while at later ages their values have nearly the same feature.

Effect of the w/c ratio early on the compressive strength

The relation between the compressive strength and the w/c ratio of the plain (N) and the chemical admixture (A, H and R) concretes is shown in Fig. 7. In this figure, the compressive strength is inversely proportional to the w/c ratio for all samples. The values of the compressive strength for all samples have the same trend as the ultrasonic velocity and electrical resistivity, in other word, for the same w/c ratio the compressive value for H samples is higher than that for A then N then R samples. The compressive strength for H samples, is decreasing from 486.2 to 388 Kg/cm^2, for A samples is decreasing from 457 to 348 Kg/cm^2, for N samples is decreasing from 444 to 333 Kg/cm^2 and for R samples is decreasing from 432.5 to 278 Kg/cm^2 as listed in Table 2.

The relation between the compressive strength and the concrete age is presented in Fig. 8. the compressive strength increases rapidly at first 7 days, but after that, the gained strength slows down approaching a constant value. The compressive strength at 1 day is approximately (42 – 62 %) from that at 28 days compressive strength, while at 7 days it reaches approximately (87 – 93 %) from its value at 28 days. The development of early strength for "A4" is higher than that for "H4" samples then that of "N4" then "R4" samples.

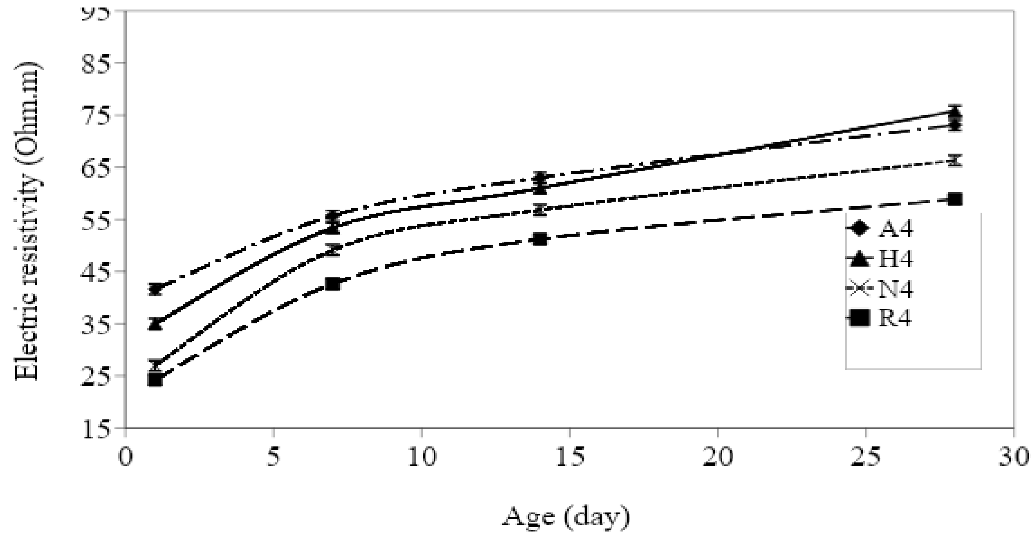

Fig.6.Variation of the electric resitivity with the concrete age of plain (N4) and admixtured (A4, H4 and R4) concrete of 0.42 w/c ratio.

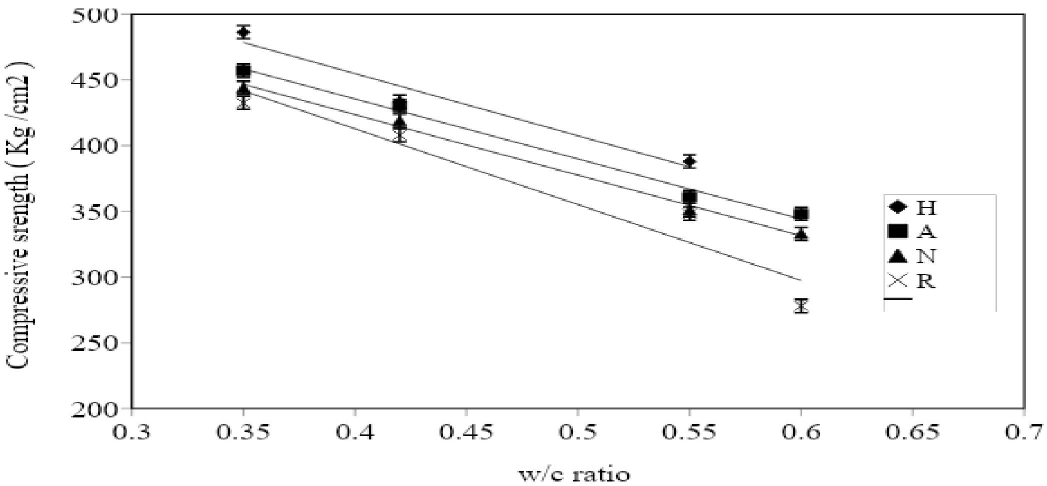

Fig. 7. Variation of the compressive strength with the w/c ratio.

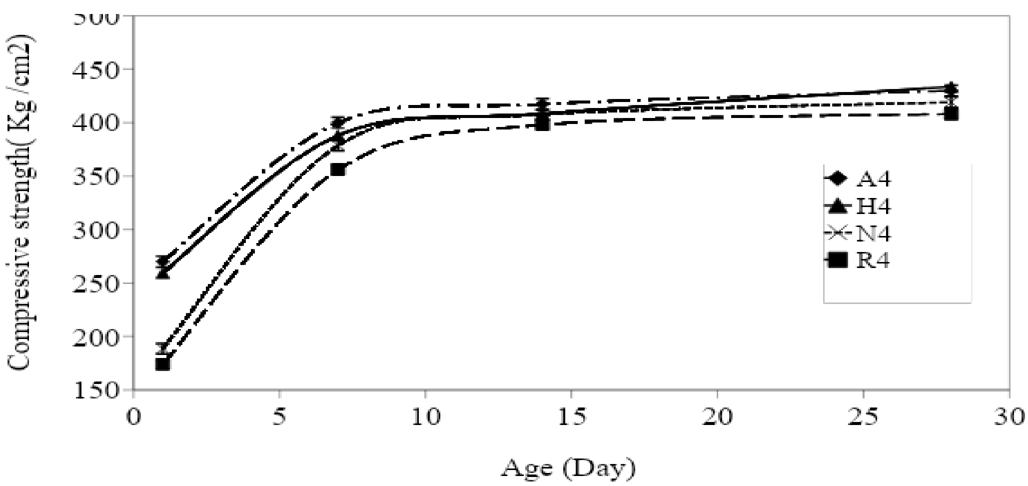

Fig.8. Variation of the compressive strength with of the concrete age of plain (N4) and admixtured (A4, H4 and R4) concrete of 0.42 w/c ratio.

Discussion

The decrease in the ultrasonic velocity can be attributed to the increase of porosity with the increase of w/c ratio where the ultrasonic velocity inversely proportional to porosity [2]. At low w/c (0.35) ratio the high range water reducing admixture produces more flowable mix resulting in good compaction with comparison to the other three mixes at the same w/c ratio. The good compaction reduces the porosity consequently, increases the ultrasonic velocity. Generally, the ultrasonic velocity increases with the decrease of imperfection (porosity inclusion, cavities…… etc.) (31).

The decrease of the electrical resistivity with the increase of the w/c ratio results from the increase of capillary pores which contain dissolved salts in the evaporable water and so acts as an electrolyte. As mentioned above at low w/c ratio (0.35), the high range water reducing admixture can produce more flowable mix resulting in a good compaction with comparison to the other three mixes at the same w/c ratio. The good compaction reduces the pores consequently, increases the electrical resistivity.

The compressive strength of concrete is inversely dependent on the capillary pores, which decreases as the w/c ratio decreases assuming good compaction was done, i.e., as the w/c ratio decreases, the compressive strength increases. In practice at low w/c ratio (0.35) the good compaction is difficult to be achieved for "A", "N", and "R" samples. The use of high range water reducing admixture can produce more flowable mix, i.e., a good compaction can be achieved for "H" mixes that decreases the porosity and increases the compressive strength for "H" samples at the lower w/c ratio.

The hydration of concrete is greatly affected by the concrete age, *i.e.,* as the time increases, the hydration product (gel) increases and the capillary pores decrease, consequently, the ultrasonic velocity increases rapidly at first days.

The use of accelerating admixture accelerates the hydration of cement paste, and that allows faster development of hardened concrete for "A4" sample than that of "N4", "H4", and "R4" samples. The faster development of hardened concrete explains the early increase of ultrasonic velocity for "A4" sample.

Since the electric conduction can be regarded as, essentially, electrolytic in nature where it takes place through the cement paste, the observed initial increase in resistivity may be attributed to the reduced amount of evaporable water within the cement paste; this reduction continues as the hydration proceeds. As mentioned above, the accelerating admixture accelerates the hydration of cement greater than that of the "N4", "H4", "R4" samples, this will leaves less ions and decreases the pores concentration for the "A4" sample compared to the "N", "H" and "R" samples which leads to much higher resistivity at early ages. However, at later ages, the other three samples "N4", "H4" and "R4" also hydrate and their resistivity increases. The difference in the electrical resistivity at later ages is most probably related to the difference in chemical compositions and resulting pores for the four samples.

The hydration of concrete is greatly affected by concrete age, so the gained strength is also controlled by that factor, i.e., as the concrete age increases, the hydration product (gel) increases and the capillary pores decrease, leading to a rapid increase in the compressive strength at first days. The accelerating admixture speeds up the chemical reaction of the cement and water, consequently, accelerates the rate of setting and early gained strength of concrete as observed for "A4" sample, while at later ages, the compressive strength may be decreased as compared with the "N4" and "R4" samples [22].

The high range water reducing admixture, generally, used to produce high strength concrete by decreasing the w/c ratio; so, an increase in gained compressive strength for "H" sample was noted.

Relation between the Ultrasonic Velocity and the Compressive Strength at different w/c Ratios and ages

The compressive strength (S) values of "H", "A", "N" and "R" samples at different w/c ratio are directly proportional to the ultrasonic velocity (V), Figure (9), and this can be represented by the following linear relationship empirical linear equation:

$$S = aV - b \qquad (2)$$

Where, a and b are constants depending on the mix proportions and type of admixture and their values are listed in Table 3.

The relation between the ultrasonic velocity (*V*) and the compressive strength (*S*) for "A4", "H4", "N4", and "R4" samples at different ages is shown in Figure (10).

In this figure as the ultrasonic velocity increases, the compressive strength increases and this can be presented by the following linear relationship:

S = AV - B (3)

Where, a and b are constants depending on mix proportions and type of admixture and their values are listed in Table 3.

Relation between Electrical Resistivity and Compressive Strength at Different w/c Ratio and ages

The relation between electrical resistivity and the compressive strength of "H", "A", "N" and "R" samples at different w/c ratio are shown in Figure (11), In this figure, as the electrical resistivity (ρ) increases the compressive strength (S) increases and this can be represented by the following linear relationship:

S = c ρ + d (4)

Where, c and d are constants depending on mix proportions and type of admixture and their values are listed in Table 4.

The relation between the electrical resistivity (ρ) and the compressive strength (*S)* of "A4", "H4", "N4", and "R4" samples different ages is shown in Figure (12). In this figure as the electrical resistivity increases the compressive strength increases and this can be represented by the following linear relationship:

S = C ρ+ D (5)

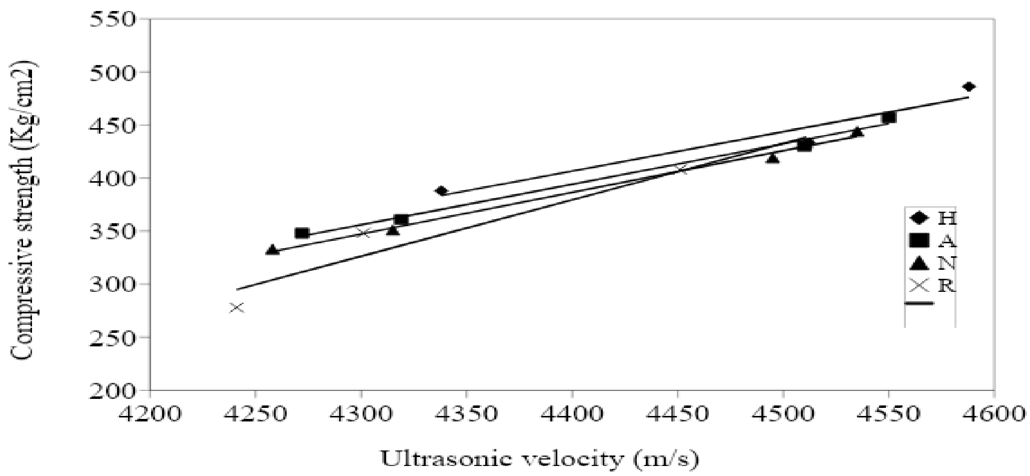

Fig. 9. The relation between the ultrasonic velocity and the compressive strength.

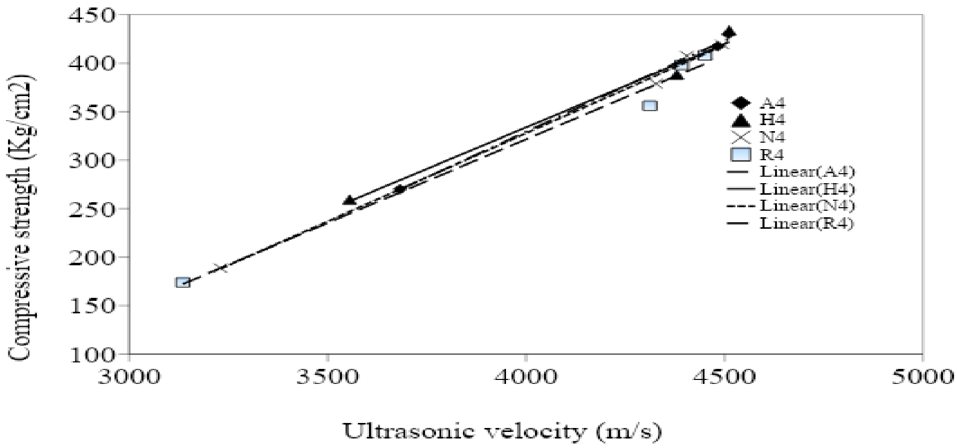

Fig. 10. The relation between the ultrasonic velocity and the compressive strength (from 1 to 28 days).

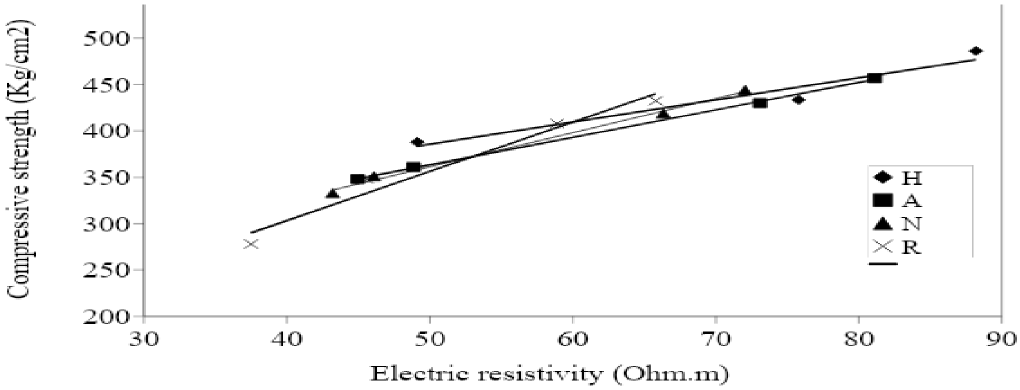

Fig. 11. The relation between the electric resistivity and the compressive strength.

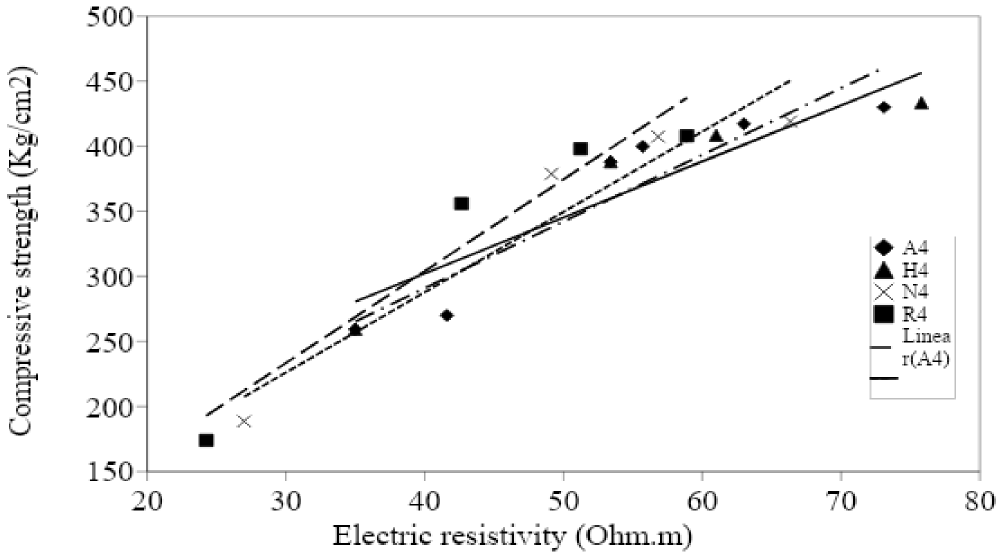

Fig. 12. The relation between the electric resistivity and the compressive strength (from 1 to 28 days).

Where, c and d are constants depending on mix proportions and type of admixture and their values are listed in Table 4.

Conclusions

Experimental tests on samples of plain (N), the accelerating admixture (A), the high range water reducing admixture (H) and the retarder admixture (R) concrete show that their ultrasonic velocity, the electrical resistivity and the compressive strength are inversely proportional to the w/c ratio.

The compressive strength is directly proportional to the ultrasonic velocity or the electrical resistivity. These results can be used to give an assessment of the value of the compressive strength of the concrete structures of comparable conditions of the investigated concrete samples and can't be generalized to different types of concrete.

In general, for the same w/c ratio, the ultrasonic velocity, the electrical resistivity and the compressive strength, for the high range water reducing admixture (H) concrete, is relatively higher than that of the accelerating admixture (A) concrete then the Plain (N) concrete, then, retarder admixture (R) concrete.

The ultrasonic velocity, the electrical resistivity and the compressive strength of

TABLE 4. Values of constants a, b, c , d, A, B, C and D

Group Constant	H	A	N	R		A4	H4	N4	R4
a	0.37	0.38	0.39	0.53	A	0.19	0.17	0.18	0.17
b	1221	1285	1342	1958	B	422	351	398	368
c	2.38	2.96	3.68	5.3	C	5.1	4.3	6.2	7
d	266	215	177	91	D	86	129	41	22

plain concrete and different chemical admixture concrete samples increase rapidly at first 7 days of water curing, after that, the increment slows down significantly and nearly reaches a constant value after 28 days of water curing. The values of the ultrasonic velocity, the electrical resistivity and the compressive strength of the accelerating admixture concrete sample (A4) is higher than that of the other samples {high range water reducing concrete (H4), plain concrete (N4) - retarded concrete (R4)} at first days. An empirical simple linear relationship could be obtained to assess the destructive compressive strength of the investigated concrete samples by nondestructive ultrasonic pulse velocity and/or electrical resistivity measurements.

This study assure that ultrasonic and electric nondestructive testing is very suitable technique to assure the quality and integrity of different kinds of on service or under construction concrete.

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تأثير نسبة الماء الى الاسمنت والعمر على الاختبارات فوق الصوتية والكهربية غير المتلفة للخرسانة العادية وذات الاضافات الكيميائية

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تم قياس سرعة الموجات فوق الصوتية والمقاومة الكهربية النوعية وشدة التحمل للضغط لعينات من الخرسانة العادية وعينات ذات أضافات كيميائية مسرعة لزمن الشك أو أخرى مؤخرة لزمن الشك أو أخرى مخفضه لمحتوى الماء وكانت كل تلك العينات تحتوى على نسب مختلفه من الماء الى الاسمنت وهى ٠,٣٢ و ٠,٤٢ و٠,٥٥ و٠,٦٠ وتم دراسة تأثير عمر العينات على سرعة الموجات الفوق صوتيه و المقاومه الكهربيه النوعيه و شدة التحمل للضغط.

وأوضحت النتائج ان كلا من سرعة الموجات الفوق صوتيه والمقاومه الكهربيه النوعيه وشدة التحمل للضغط يتناسب عكسيا" مع نسبة الماء الى الاسمنت المستخدمه لكل العينات وانه عند نفس نسبة الماء الى الاسمنت فأن قيم هذه المعاملات تكون اكبر نسبيا للعينات ذات الاضافة المسرعه للشك ثم العاديه ثم الموفره للماء. وبالنسبه للعينات ذات العمر المختلف اوضحت النتائج ان قيم كلا من الموجات الفوق الصوتيه والمقاومه الكهربيه وشدة التحمل للضغط تزداد بسرعه خلال الاسبوع الاول وان هذا الزياده تبطىء بوضوح بعد ٢٨ يوم وعند نفس العمر فان هذه المعاملات تكون اكبر مايمكن للعينات ذات الأضافه المسرعه للشك يليها الموفره للماء ثم العاديه ثم المؤخره للشك و تم استنباط علاقات تربط اختبار شدة التحمل للضغط المتلف بالقياسات الفوق صوتيه او الكهربيه الغير متلفه.

تم تفسير تلك النتائج وإعزائها الى تطور الصلادة والتركيب الداخلى للعينات.