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ASSESSING SOME MECHANICAL PROPERTIES OF CO2 CURED, SUSTAINABLE NO-FINE CONCRETE

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ABSTRACT

Over the past two decades, more and more attention has been given to the use of emission gases and sustainable concretes. An experimental study was carried out to evaluate the performance of sustainable light weight no-fine concrete (SLNFC) through early exposure to carbon dioxide (CO2) gas. Three categories of SLNFCs were assessed: 1:4, 1:5 and 1:6 (cement: gravel) by weight. Two parameters were used in order to evaluate the strength of SLNFC: CO2 gas concentration and water/cement ratio. Experiments were performed to estimate the fresh (compaction factor test) as well as hardened properties (compressive strength, splitting tensile strength and flexural strength) of SLNFC at 28-day. In addition, density evaluations were also conducted before and after CO2 curing process.

The results show an improvement in the mechanical properties of all the investigated SLNFC samples by using the accelerated CO2 curing method. In addition, excessive carbonation rate associated with pure gas carbonation (100% CO2) exhibits highest mechanical performance as compared to control (0% CO2) samples with w/c of 30 %.

Keywords: CO2 curing, carbonation, mechanical properties, no fine concrete, sustainability, ITZ.

INTRODUCTION

No-fines concrete, also known as porous, pervious, permeable and cellular concrete, has no fine aggregates and has just enough cementitious paste to coat the coarse aggregate particles **[1]**. In addition, no-fines concrete could be also more interesting than an ordinary concrete, considering its environmental impact in terms of reducing the carbon dioxide emission and natural resources use **[2, 3]**.

Extensive amounts of carbon dioxide gas is discharged into the air not only as a by-product from glowing up fossil fuels in vehicles, power plants, and manufacturing actions but, also from natural cycles in the environment **[4]**. Carbonation of calcium hydroxide has been the subject of several studies since the 1970's **[5-7]**. The utilization of CO2 or CO2-rich flue gas as an accelerated curing process in concrete has been submitted as a CO2 sequestration method that contribute a value-added product and carbon dioxide cured process **[8]**. In addition, the consequences of carbonation on cement are the stability of the chemical hydration products and mechanical properties; densification of the cementitious matrix and reduction of its permeability (capillary) and porosity, which constitutes a positive process with respect to the sealing quality of the cement **[9].**

An experimental study was conducted by **Soroushian et al. [10]** to assess the effects of CO2 curing on the physical and mechanical characteristics of cellulose fiber-cement mortars. They found that CO2 curing in some conditions yielded better results when compared with moist curing by 150 % of the control boards.

Neville and Brooks [11] suggested that the preferred water/cement ratio for no- fines concrete is between (0.38 -0.52). Cement paste separation from gravel surfaces may be a result of higher water/cement ratio. While, a weaker cohesion between the cement paste and the gravel may happen due to lower water/cement ratio and thus a proper compaction of fresh concrete cannot be reached.

According to **Alam et al. [12]** the density of no-fines concrete is about 70 percent of conventional concrete when made with similar constituents. In addition, the density of no-fines concrete using normal aggregates varies from 1600 to 1922 kg/m3.

Zaetang et al. [13] found that the flexural strength in no-fines concretes generally ranged between about (1.0-3.8) MPa, depending on many factors particularly level of compaction, porosity, and the cement to aggregate ratio.

OBJECTIVES

This study aims to develop the manufacture of light weight concrete units in a way that the products can be made with higher mechanical properties using sustainable processing methods. The major objectives are:

1. Studying the effect of accelerated hardening with carbon dioxide on the properties of light weight concrete made without fine aggregate.
2. Studying the effect of manufacturing parameters, such as gas concentrations, mix proportions and water/cement ratios, on the development of carbonation reaction, density and strength of sustainable light weight no- fine concrete.
3. Reducing the emissions of carbon

dioxide gas (CO2) in the atmosphere.

Materials and Mix Proportions

In this study, ordinary Portland cement, commercially known (MAS), was used to produce all samples. The physical properties and chemical composition of cement used throughout this work indicated that the cement is conformed to Iraqi specification No. 5/1984. The coarse aggregate was AL-Nibaei gravel with a single size of 10 mm as shown in Table 1. The properties of gravel is conformed to Iraqi specification No.45/1984. The super plasticizer used in this work was based on a unique carboxylic with long lateral chains, which greatly improves cement dispersion. It is commercially known as GLENIUM 51. Table 2 shows the typical properties of it. This admixture is complying with type (F) according to ASTM C494-03. Table 3 presents the mix proportions and notations used in this study. In addition, a polypropylene fibers of 12 mm in length and 0.018 mm in diameter were used in order to increase the internal bond of concrete (Vf =0.2 % by concrete volume).

Table (1): Grading and properties of coarse aggregate.

Sieve size	**Cumulative passing**	**Limits of Iraqi specification No. 45/1984 10mm nominal single size**
14	100	100
10	92.2	85-100
5	15.3	0-25
2.36	2.12	0-5
Specific gravity = 2.69		
Sulfate content = 0.08% (Iraqi specification requirement < 0.1%)		
Absorption = 1.2 %		

* Chemical analysis was done by National Center for Construction Laboratories and Research.

Table (2): Typical Properties of SP.

Form	Viscous Liquid
Color	Dark brown
Density	1.1 g/cm^3 @ 20 ^{o}C
pH	6.6
Viscosity	128 +/-30 cps @ 20 ^{o}C
Transport	Not classified as dangerous
Labelling	No hazard label required

Table (3): Mix proportions, notations and fresh properties of all mixes.

Mix notatio	**Cement: gravel by**	**w/c %**	**CO_2 concentration (%)**	**SP (%) by w.t. of cement**	**Compaction factor**
RT1	**1:4**	25	Control 25 50 100	0.5	94.4
RT2		30			95.7
RT3		35			96.1
LT1	**1:5**	25	Control 25 50 100	0.5	95.2
LT2		30			96.1
LT3		35			96.8
CT1	**1:6**	25	Control 25 50 100	0.5	96.6
CT2		30			97.5
CT3		35			97.8

All the specimens were kept inside their molds underneath wet burlap covered with a plastic sheet for 24 hrs. They were then demolded, dried at 60 oC for 30 minutes and cured for the 60 minutes in the CO2 curing chamber (Plate 1). Three water to cement ratios: 25%, 30%, and 35%, were used with three CO2 concentrations: 25%, 50% and 100% for each mix.

Plate 1: Carbonation curing apparatus in the University of Technology/Baghdad.

Program of Work

All specimens were cast following the standard practice for making and curing concrete test specimens in the laboratory according to ASTM C 192-03 specification.

One day after completion of processing, the samples were carefully removed from the molds, dried at 60 oC for 30 minutes and then subjected to CO2 curing. The drying process will ensure the availability of empty paths for CO2 to take place. The CO2 curing chamber process was performed at different CO2 concentrations (25%- 50%-100%) for 60 minutes duration time. A comparison has to be made for the CO2 cured specimens with control (0 % CO2) specimens.

The carbonation curing apparatus was used to subject samples to a low pressure of carbon dioxide gas and oxygen gas. The samples in the curing chamber was treated with CO2 gas at 6.9 MPa (1000 psi) at laboratory temperatures. In the specimen preparation of this section and the following ones, 20-

minutes vacuum were applied before CO2 injection, and the CO2 flow rate was 10 L/min that mean about 30 min. is needed to reach 100 % concentration.

TEST PROCEDURES

Compacting Factor Test

The compacting factor test is used to determine the extent with which the fresh concrete compacts itself when allowed to fall without the application of any external compaction, according to BS 1881: Part 103:1993. This is probably the most appropriate method for testing the consistency of no-fines concrete as it is considered a self-compacting material and can be dropped from height without affecting its properties.

Compressive Strength

The compressive strength for the (150*150*150) mm cubes was performed at 28-day from initial casting according to British Standard BS 1881 part 116:1983. The measurement of concrete compressive strength was carried out, by a digital compression machine of 3000 kN capacity (MATEST digital tester), and taking the average result of three samples for each mix. All specimens were kept in air tight plastic bags in the laboratory until the day of testing to prevent CO2 from being escaped.

Splitting Tensile Strength

This test method consists of applying a diametric compressive force along the length of the cylindrical concrete specimen according to ASTM C 496-04 using (100*200) mm cylindrical samples and the load was applied continuously up to failure. For this test, concrete cylinders were all kept in air tight plastic bags in the laboratory until the day of testing. An hour before testing, concrete cylinders were removed from the curing bags, and set-up on the loading machine used in the compression test. The average result of three cylinders was calculated 28-day age for each mix.

Modulus of Rupture

Flexural tests were performed at 28-day according to ASTM C 78-02 and following the method of loading (third-point-loading), using (400 * 100 * 100) mm prism samples and the load was applied continuously up to failure. The measurement of concrete flexural strength was carried out, by a digital testing machine of 3000 kN capacity (MATEST digital tester). The average result of three prisms was calculated at 28-day age for each mix. All samples were casted and cured in similar manner as for compressive test.

Dry Density

The measurement of concrete dry density was carried out according to American Standard ASTM C 567-10 using cylindrical samples size (100 * 200) mm; and taking the average result of three samples at 28-day age for each mix.

RESULTS AND DISCUSSION

It is difficult to produce a homogeneous no-fine concrete without the addition of super plasticizers. Table 3 shows the compaction factor results of all mixes associated with different water to cement ratios and mix proportions. These results indicated that increasing the water content by 5 % and 10 % increases the compacting factor by (1.4-1.8) %, (0.95-1.7) % and (0.93-1.3) % for RT, LT and CT mixes respectively.

The compressive strengths of all the samples were measured after 28 days and the results are presented in Figures 1 to 3. From these figures it can be seen that the compressive strength increases after CO2 curing exposure. After CO2 curing, mixes with w/c equal to 30 % show higher compressive strength by (4.8-6.8) %, (7.9-12.8) % and (8.5-11.1) % as compared to those of 25 % and 35 % for all the three concentrations respectively. During carbonation, the CO2 gas permeates through thesolid dissolves in water and hydrates to form H2CO3. When calcium hydroxide is exposed to dissolve CO2 under high pH medium (like concrete), a chemical reaction will take place to form a stable calcium carbonate that fill the empty spaces and make the ITZ thicker and stronger. Conversely, a negative effect happen as the w/c ratio increased to 35 % which indicates that the CO2 curing has a lower compressive strength than those of 25 % and 30 %. This result suggests that the carbonation process decreased by the low solubility of CO2 gas in higher amounts of water. On the other hand, increasing the aggregate content reduces the compressive strength of the end product. For control samples, mixes of 1:4 cement to aggregate ratio show higher 28- day compressive strength by 4.5 % and 15 % than those of 1:5 and 1:6 respectively. This trend is comparable to that found by Soroushian et al. [10].

Data presented in Figures 4 to 6 show that the 28-day splitting tensile strengths for CO2 cured samples are greater in all cases of the mixtures as compared to control mixes. However, the differences between samples contain 25 % and 30 % of water to cement ratio are lower than that of 35 % in all cases. As the CO2 content increased from 0 to 100% the splitting tensile strength of all mixtures increased accordingly. The maximum tensile strength recorded was 1.35 MPa which corresponds to the RT2 of 100 % CO2 and 30 % w/c ratio, while the minimum recorded was 0.87 MPa which corresponds to CT3 of 0 % CO2 and 35 % w/c ratio.

From the results in Figures 7 to 9 it can be seen that RT samples show higher flexural strength than those of LT and CT samples for all mixes. Furthermore, increasing the water to cement ratio from (25 to 35) % decreases the flexural strength by (1.6-3.4) %, (1.2-2.5) % and (0.9-1.1) % for 1:4, 1:5 and 1:6 of control mixes respectively. This observation was noticed by Chindaprasirt et al [1] and Alam et al [12]. These figures also show the flexural strength development for different CO2 curing conditions. It is clear that all specimens are positively affected by CO2 curing due to the formation of extra carbonation products that fill the voids in concrete samples which enhanced the surface bonding between the aggregate and cement paste. It is evident that the mechanical strengths of all the investigated samples are directly related to their density. The 28-day density curves, shown in Figures 10 to 12, indicated that differences between the control mixture and the mixtures exposed to CO2 curing are likely negligible for samples of w/c of 25 % and 35 % and notable for samples of w/c of 30 %. In addition, it can be observed that the overall densities of CO2 cured samples were higher than those for control.

To summarize, all these results implied that the carbonation curing process was beneficial for improving the strength and density of no-fine concrete. In addition, 28-day strength can be significantly improved through pure and/or flue gas carbonation; subsequent carbonation contributes to the long-term strength development.

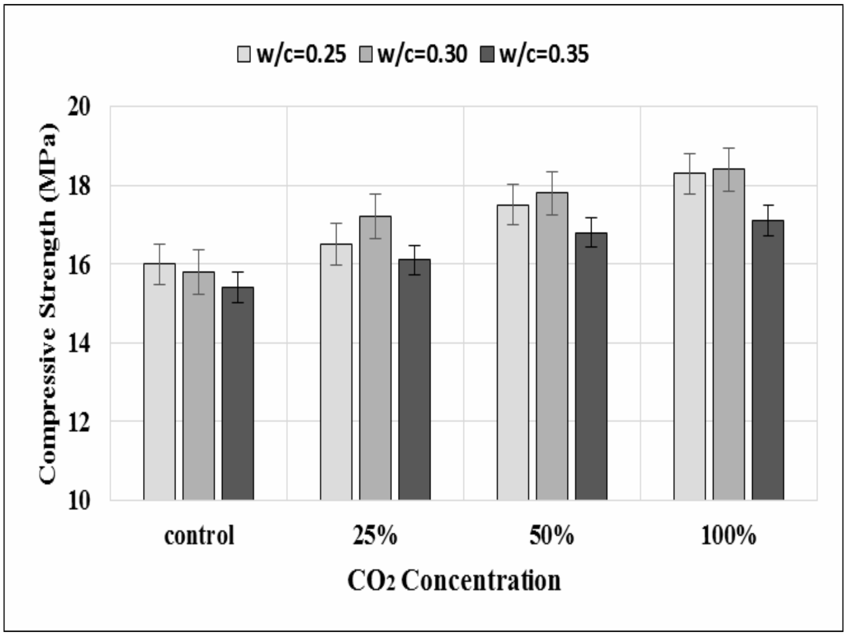

Figure (1): Compressive strength results of all mixtures for proportion (1:4) at 28-day of different W/C ratios and CO_2 concentrations, mean and standard deviation.

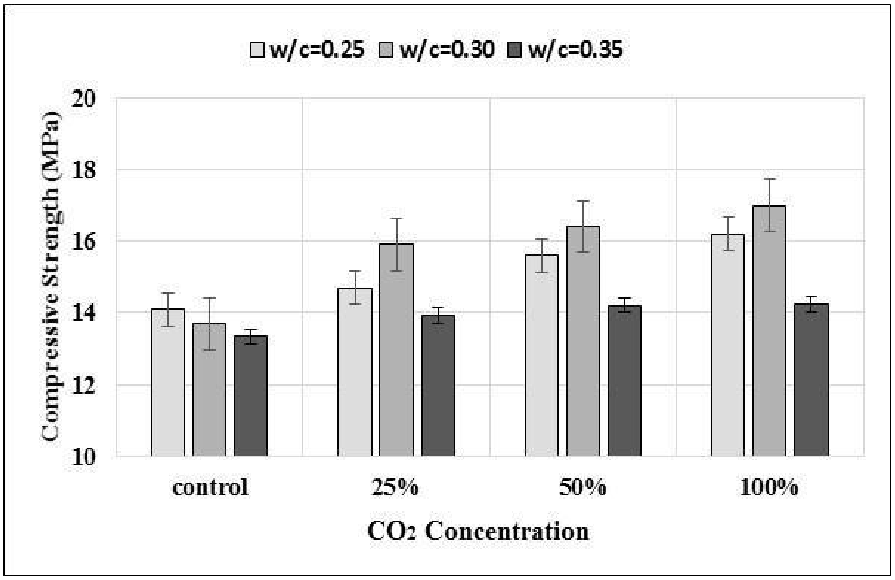

Figure (2): Compressive strength results of all mixtures for proportion (1:5) at 28-day of different W/C ratios and CO_2 concentrations, mean and standard deviation.

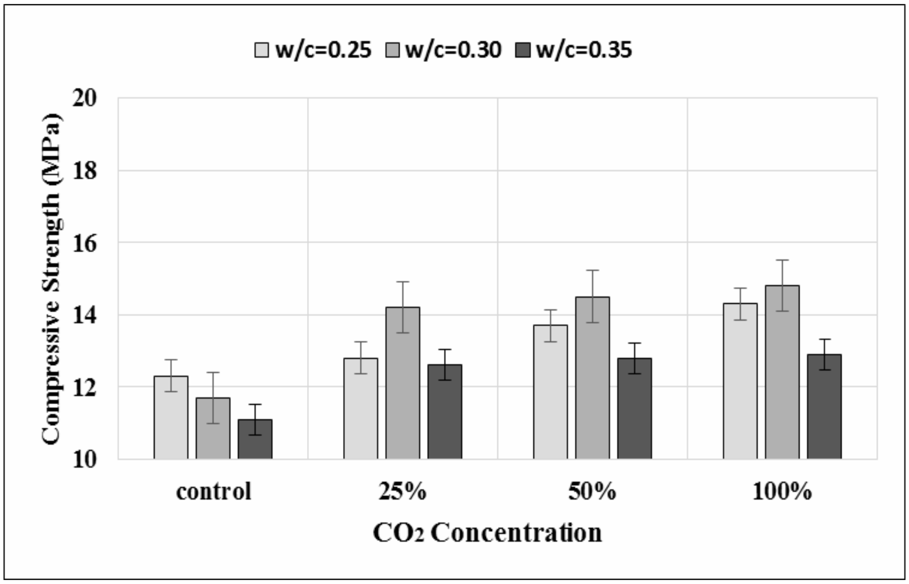

Figure (3): Compressive strength results of all mixtures for proportion (1:6) at 28-day of different W/C ratios and CO_2 concentrations, mean and standard deviation.

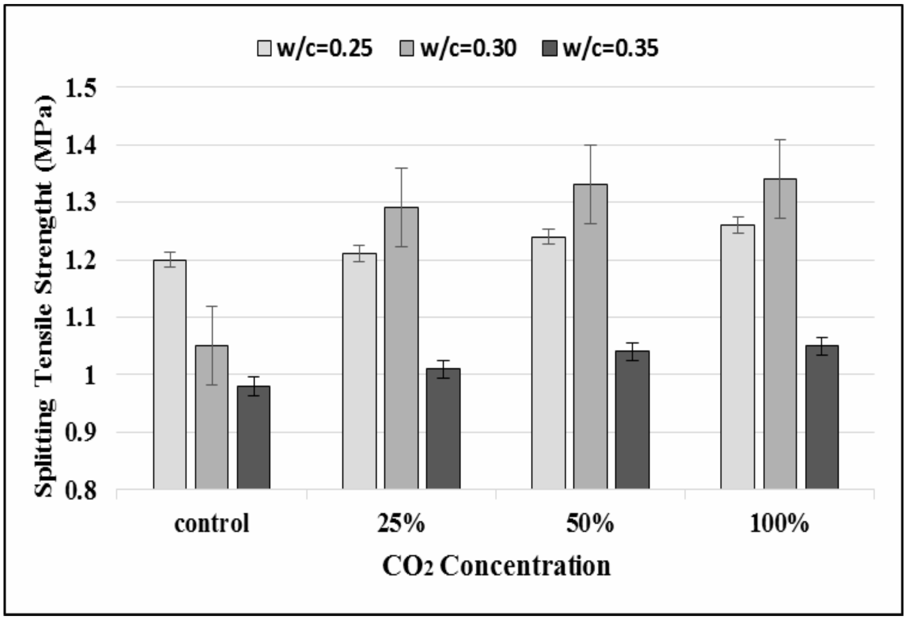

Figure (4): Splitting tensile strength results of all mixtures for proportion (1:4) at 28-day of different W/C ratios and CO2 concentrations, mean and standard deviation.

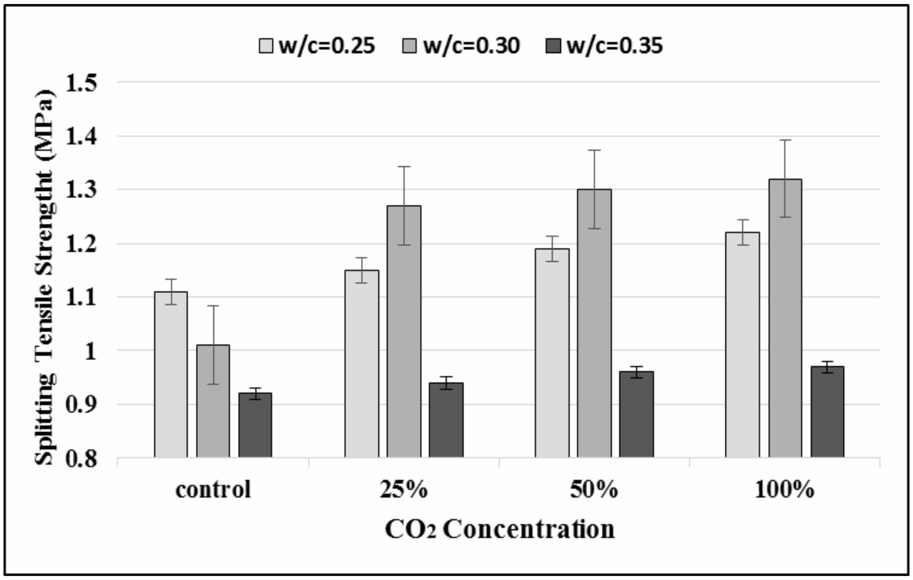

Figure (5): Splitting tensile strength results of all mixtures for proportion (1:5) at 28-day of different W/C ratios and CO2 concentrations, mean and standard deviation.

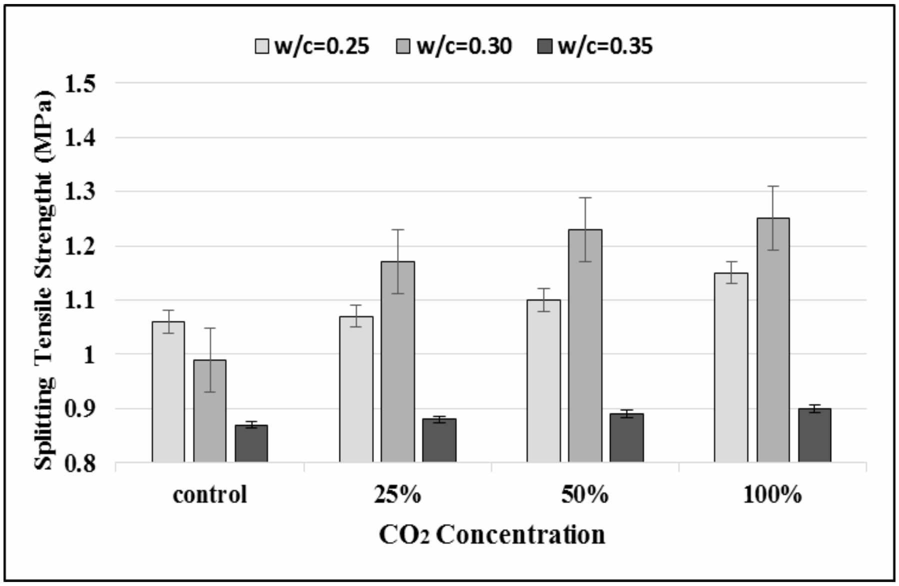

Figure (6): Splitting tensile strength results of all mixtures for proportion (1:6) at 28-day of different W/C ratios and CO_2 concentrations, mean and standard deviation.

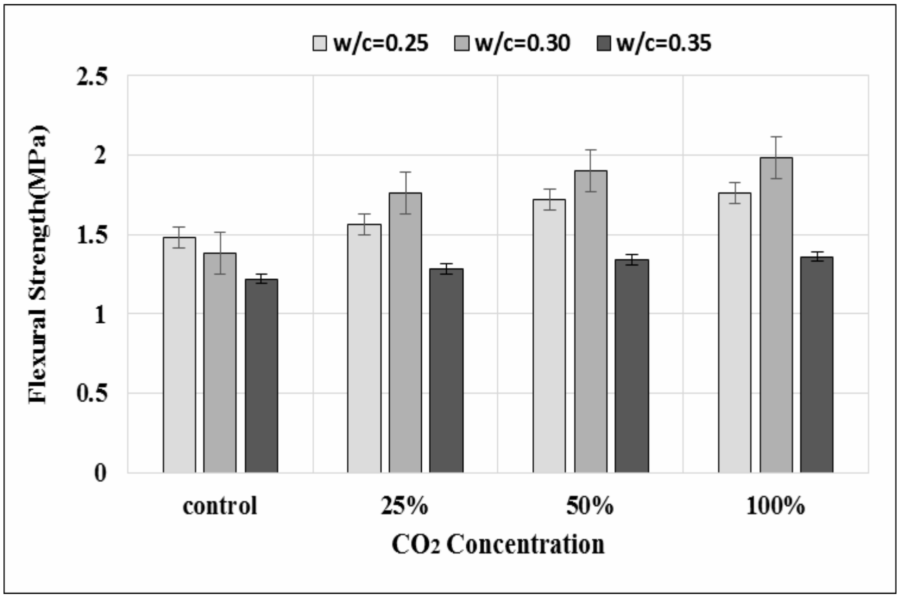

Figure (7): Flexural strength results of all mixtures for proportion (1:4) at 28-day of different W/C ratios and CO_2 concentrations, mean and standard deviation.

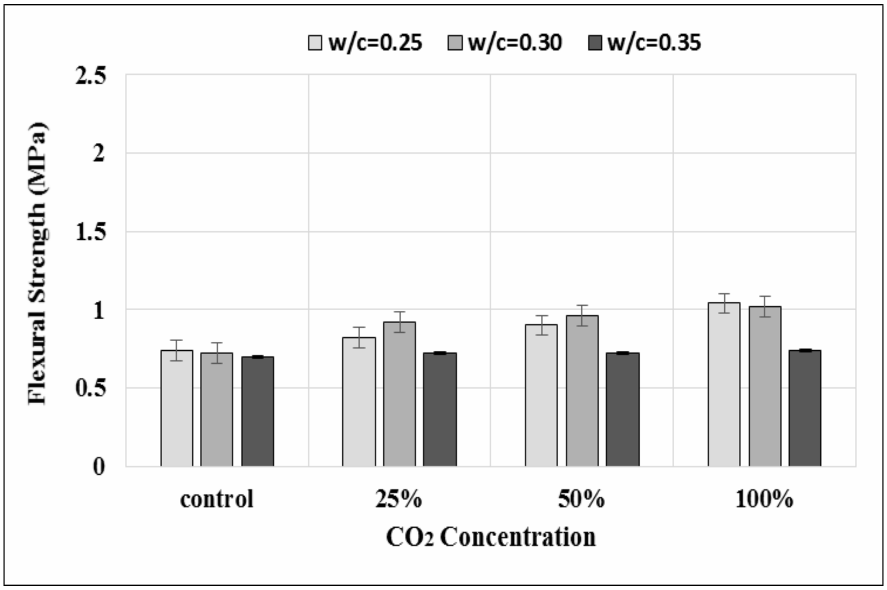

Figure (8): Flexural strength results of all mixtures for proportion (1:5) at 28-day of different W/C ratios and CO_2 concentrations, mean and standard deviation.

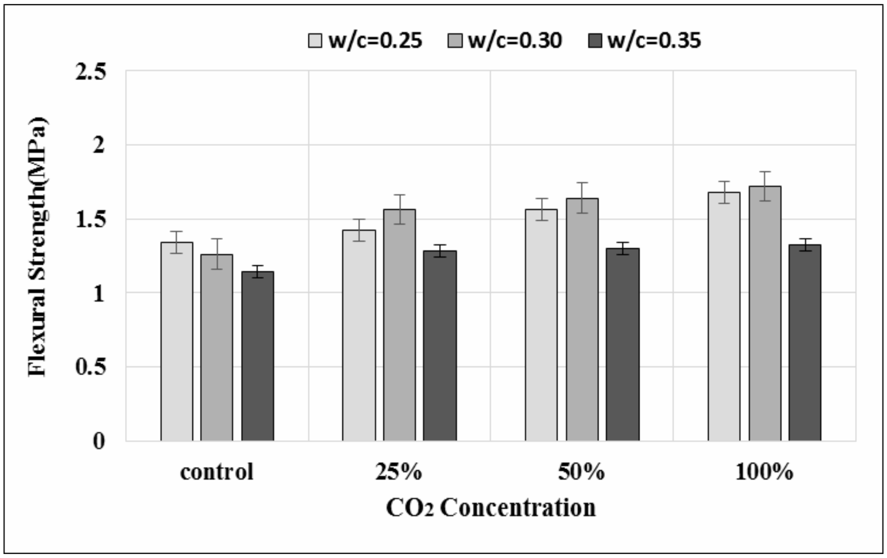

Figure (9): Flexural strength results of all mixtures for proportion (1:6) at 28-day of different W/C ratios and CO_2 concentrations, mean and standard deviation.

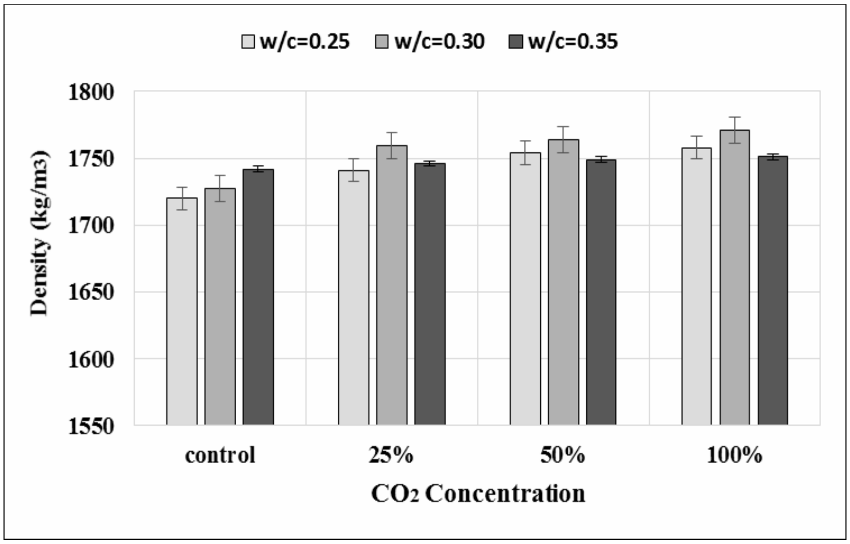

Figure (10): Density results of all mixtures for proportion (1:4) at 28-day of different W/C ratios and CO2 concentrations, mean and standard deviation.

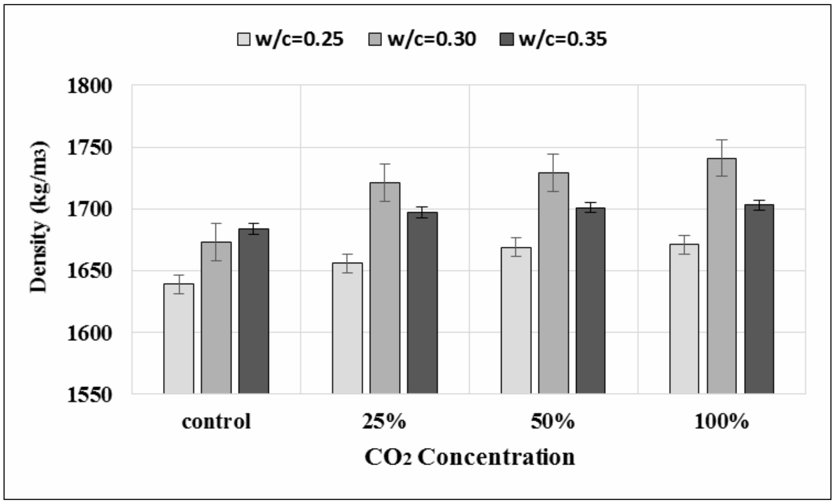

Figure (11): Density results of all mixtures for proportion (1:5) at 28-day of different W/C ratios and CO2 concentrations, mean and standard deviation.

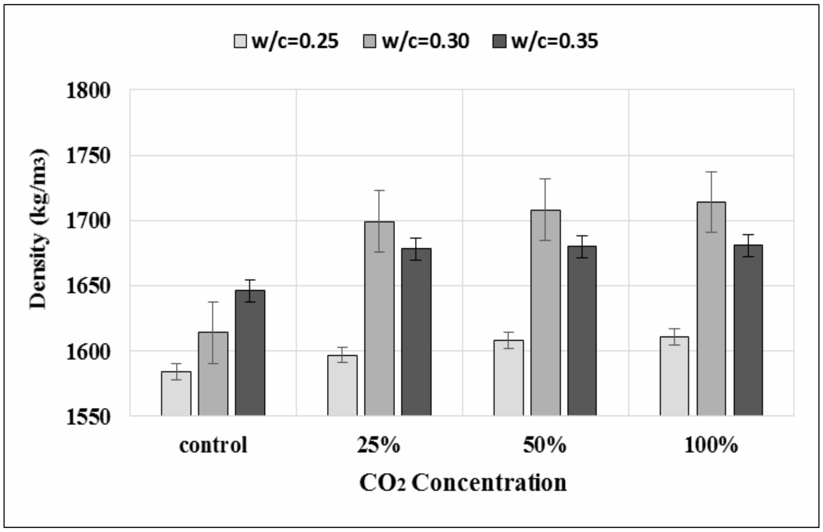

Figure (12): Density results of all mixtures for proportion (1:6) at 28-day of different W/C ratios and CO2 concentrations, mean and standard deviation.

CONCLUSIONS

A comprehensive study, investigating the effects of CO2 curing on no-fine concrete, was made. From this investigation, the following conclusions can be drawn:

1. increasing the water content by 5 % and 10 % increases the compacting factor by (1.4-1.8) %, (0.95-1.7) % and (0.93-1.3) % for 1:4, 1:5 and 1:6 mixes respectively.
2. mixes with w/c equal to 30 % show higher compressive strength by (4.8&6.8) %, (7.9&12.8) % and (8.5&11.1) % as compared to those of 25 % and 35 % for 1:4, 1:5 and 1:6 mixes respectively.
3. increasing the aggregate content reduces the compressive strength of the end product.
4. the differences in splitting tensile strength between samples contain 25 % and 30 % of water to cement ratio are lower than that of 35 % in all cases.
5. increasing the water to cement ratio from (25 to 35) % decreases the flexural strength by (1.6-3.4) %, (1.2-2.5) % and (0.9-1.1) % for 1:4, 1:5 and 1:6 of control mixes respectively.
6. It is evident that the mechanical strengths of all the investigated samples are directly related to their density. In addition, the overall densities of CO2 cured samples were higher than those for control.
7. density differences between the control mixture and the mixtures exposed to CO2 curing are likely negligible for samples of w/c of 25

% and 35 % and notable for samples of w/c of 30 %.

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