ACTA SCIENTIAE

ISSN: 2178-7727

Influence of Natural Pozzolan Addition on Concrete via Compressive Strength and Propagation of Ultrasonic Wave Velocity Methods

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ABSTRACT

The evaluation of concrete structures using non-destructive techniques has garnered significant interest among civil engineers. This study aims to examine the influence of natural pozzolan addition (5, 10, 15, 20, 25, and 30% by weight) on concrete by utilizing compressive strength (CS) and the propagation of ultrasonic wave velocity (UPV) methods. The results indicated that all samples increased CS between 28 and 180 days. At 28 days, samples C0 and C25 had lower CS than the other samples; otherwise, at 180 days, samples C5, C10, C15, C20, and C25 had higher CS. Concrete samples' UPV rises over time. Sample C20 has the greatest value and C5 the lowest. UPV peaks at 180 days for all samples. This study indicates that natural pozzolan has a positive effect on the mechanical properties of concrete mixtures, particularly over long periods of time. The inclusion of an appropriate quantity of natural pozzolan offers notable benefits in terms of both strength and cost-effectiveness.

Keywords : Concrete. Non-destructive. Natural pozzolan. Compressive strength (CS). Ultrasonic wave velocity (UPV). Mechanical properties.

INTRODUCTION

Concrete is a composite material composed of portland cement, aggregate, and water. It is widely recognized as the predominant material in terms of structural applications. Destructive tests conducted for quality control purposes on concrete specimens are characterized by their relatively high costs, time-consuming nature, and potential for causing damage to the structural integrity of the member from which the specimen was extracted. In contrast, concrete non-destructive tests are characterized by lower costs and greater ease of execution. Consequently, numerous non-destructive approaches have been employed to assess the performance of concrete (Bungey and Grantham, 2006).

Several studies suggest that the use of natural pozzolan in concrete can have an impact on its strength. Amankwah et al. (2014) found that concrete mixes containing calcined clay pozzolans exhibited a reduction in compressive and tensile strength at early ages but showed improved strength beyond 28 days. Menadi and Kenai (2018) investigated self-compacting concrete containing natural pozzolan and found that a substitution content of 10% had a favorable effect on rheological characteristics, but there was a slight decrease in strength and durability compared to the control. Rahma and Jomaa (2018) studied the cementitious effect of pozzolan and concluded that it improves the compressive strength of concrete by accelerating the hydration reaction.

ISSN: 2178-7727

Uzal et al. (2007) demonstrate that high-volume natural pozzolan concrete mixtures can be suitable for structural applications with satisfactory compressive strengths. Bessenouci (2011) discusses the thermal advantage of using pozzolan in building materials, particularly in terms of insulation properties. Mouli and Khelafi (2008) explore the performance characteristics of lightweight aggregate concrete containing natural pozzolan and find that using pozzolan at 20% of the weight of cement produces the highest strength increase in the mixtures tested.

Osei and Jackson (2012) and OseiD (2012) found that replacing up to 30% of cement with pozzolan resulted in increased compressive strength without compromising the overall strength of the concrete. However, workability decreased as the percentage of replacements increased. Shannag (2000) also supports the use of natural pozzolan in combination with silica fume to improve the compressive and splitting tensile strengths, workability, and elastic modulus of high-strength concrete. On the other hand, Hammond (1980) focused on the durability of bauxite-waste pozzolan cement concrete and found that adding the pozzolan to the cement was more successful than replacing it in terms of resistance to various environmental conditions.
Emmanuel et al. (2012) found that concrete samples cast and cured with freshwater gained appreciable compressive strength over a 150-day period, while samples cast and cured with ocean and lagoon water showed slower strength increases and lower overall strength compared to freshwater concrete. Younis et al. (2019) compared freshwater and seawater mixed concretes and found that seawater concrete had slightly higher early-age strength performance but was 7–10% inferior to freshwater concrete after 28 days or later. Sariman et al. (2022) investigated the use of white cement in seawater curing and found that substituting white cement increased the compressive strength of concrete cured in both freshwater and seawater. Concretes et al. (2017) examined the effect of mixing and curing concrete with artificial seawater and found that different blended cement concretes performed well in terms of compressive strength, with slight variations in density and water absorption. Overall, the papers suggest that freshwater is generally more favorable for achieving higher compressive strengths in concrete compared to seawater.

On the other hand, for the ultrasound wave velocity (UPV) background of previous studies, Kachanov et al. (2019) propose a technique based on ultrasonic bulk wave velocity measurement using correlation methods. Ozsoy et al. (2017) analyze ultrasonic pulse velocity in concrete using hypothesis testing, considering different water-to-cement ratios. Chenning (2013) investigates the effect of low temperature on ultrasonic wave velocity in concrete, finding that velocity increases with decreasing temperature. Reynolds et al. (1978) calculate the elastic constants and densities of concrete specimens and demonstrate satisfactory agreement between calculated and measured velocities. Overall, these papers offer various methods and factors to consider when measuring ultrasound wave velocity in concrete.

The objective of this study is to investigate the impact of incorporating different percentages of natural pozzolan (5, 10, 15, 20, 25, and 30% by weight) on concrete. This will be achieved by evaluating the compressive strength and the propagation of ultrasonic wave velocity in the concrete samples.

ISSN: 2178-7727

USED MATERIAL

Concrete samples made with Portland cement CPA-CEM I 42.5N and various amounts of natural pozzolan, sand, and gravel are used in this study.

Cement: the cement utilized is CPA-CEM I 42.5N, which guarantees a minimum strength of 8.00 MPa at 2 days and 40.00 MPa at 28 days. The cement has a specific surface area of 3308 cm²/g and an absolute density of 3.16 g/cm3. Table 1 provide the chemical composition of cement and natural pozzolan, and their mineralogical composition.

Table 1. The chemical composition of cement and Natural pozzolan.

Elements	Cement (%)	Natural pozzolan (%)	
Sio_2	21.33	43.00	
Al_2O_3	4.60	17.18	
Fe_2O_3	5.50	9.69	
CaO	63.92	12.51	
MgO	1.33	4.20	
SO_3	2.71	0.01	
Na_2O	0.15	3.70	
K_2O	0.42	1.42	
LIO	0.04	0.01	
Mineralogy composition of cement			
C_3S	47.00	C_3A	2.90
C_2S	25.70	C_4AF	16.80

The Pozzolan: the ground pozzolan used is of volcanic origin from northeast of Algeria, the specific surface area of the pozzolan is 3000 cm2/g and the absolute density is 2.45 g/cm3.

The Sand: they used sand is prepared to be classified according to French standards NF P 15-403, and its particle size distribution curve is shown in Fig. 1.

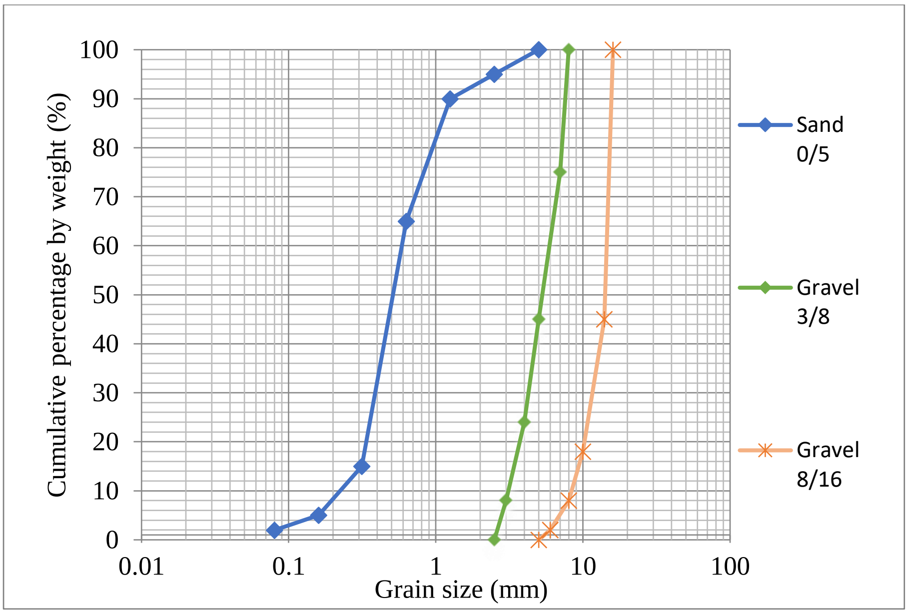

Fig. 1. Particle size distribution curve of the used sand and gravel.

ISSN: 2178-7727

The Gravel: the gravels used are crushed silico-limestone nature from the Kristel quarry in Algeria, the physical characteristics of the sand and gravel are given in Table 2.

Table 2. Physical properties of used sand and gravel.

Characteristics	Sand	Gravel 3/8	Gravel 8/15
Absolute density (g/cm^3)	2.45	2.65	2.66
Apparent density (g/cm^3)	1.60	1.37	1.36
Sand equivalent (%)	83.00	-	-
Los Angeles Coefficient (%)	-	23.00	23.50

Mixing Water: the mixing water used for preparing the concrete is tap water taken from the civil engineering laboratory.

FORMULATION OF CONCRETE

The composition of the reference concrete chosen in this study using the Dreux-Gorisse method has a cement dosage of 350 kg/m3 and six combinations of binders obtained by partial replacement of cement by different amounts of natural pozzolan (5%,10%,15%, 20%,25% and 30% by weight). The concrete is intended for making specimens of dimensions (10x10x10) cm3. The compositions selected for the tests are presented in Table 3.

Table 3. Composition of 1 m^3 of concrete.

Composition	C0	C5	C10	C15	C20	C25	C30
Cement	350	333	315	298	280	263	245
Natural pozzolan	0	18	35	45	56	66	74
Sand 0/5	920	918	918	922	925	932	938
Gravel 3/8	225	225	225	225	225	225	225
Gravel 8/16	675	675	675	675	675	675	675
Water	180	180	180	180	180	180	180
W/C	0.50	0.50	0.50	0.50	0.50	0.50	0.50

The seven concrete series used in this study are: C0: zero-pozzolanic concrete (reference), C5, C10, C15, C20, C25, and C30 concrete have 5, 10, 15, 20, 25, and 30% of natural pozzolan, respectively.

METHODS

Destructive uniaxial compressive strength method

To measure the uniaxial compressive strength (UCS) of concrete, a destructive testing method can be used. This involves breaking cylindrical or cubic concrete specimens between the steel plates of a hydraulic pressure uniaxial compression test machine (Fig. 2). The strength is typically determined by testing cylindrical or cubic samples under a constant loading speed of 0.2 to 1 MPa/s, following the guidelines outlined in the standard test NF EN 12390-3 (2019).

ISSN: 2178-7727

Fig. 2. Uniaxial compressive strength device.

NON-DESTRUCTIVE ULTRASONIC METHOD

The ultrasonic method is a commonly used technique to determine the mechanical and dynamic characteristics of concrete structures both in the laboratory and in the field. This method is based on the theory of elastic wave propagation, where the time taken for high-frequency elastic waves to pass through the concrete sample is measured to determine the compressive (P) and shear (S) wave velocities (VP and VS). The wave velocities can then be calculated from the known length of the sample.

In-situ velocities are determined by measuring the time taken for the elastic wave to pass through the concrete and the distance between the receiver and transmitter. P waves are able to propagate in any environment, including solids, liquids, and gases, whereas S waves only propagate in solid environments. Due to the lack of resistance to form changes in liquids and gases, S waves cannot pass through such environments.

To ensure accurate measurements with ultrasonic devices (Fig. 3), it is important to perform a zero setting before beginning the measurement process. The zero setting involves inverting the received electrical pulse to the ultrasonic pulse using a transducer, which takes a few microseconds to complete. This delay needs to be removed, and therefore, the zero setting must be carried out separately for both P and S waves.

Once the zero setting is completed, the necessary settings for the P or S wave can be selected, and the measurement process can begin. It is important to ensure a good transmission between the transceiver probes and the sample to avoid any delays. Ultrasonic energy can be delayed by an air gap, so minimizing any gaps and ensuring good contact between the probes and the sample is crucial for accurate measurements.
To ensure complete transmission, materials such as grease and gel can be used. However, it is important to note that these materials cannot be used for S wave measurement as S waves cannot propagate through fluids. Another important factor that affects the accuracy of ultrasonic measurements is the smoothness and uniformity of the sample surface (Uyanık and Çatlıoğlu, 2015).

The ultrasonic device typically consists of one transmitter and one receiver probe. A wave is sent from one side of the sample, and the arrival time of the wave is recorded by the receiver probe on the other side. The velocity (V) is then determined from the ratio of the distance (L) between the transmitter and receiver probes to the time (T) (Uyanık and Çatlıoğlu, 2017).

ISSN: 2178-7727

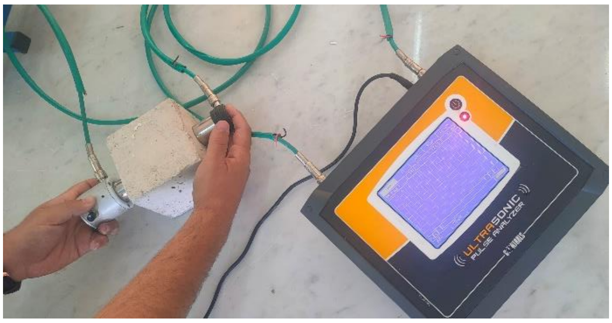

Fig. 3. Measurements by ultrasonic device.

RESULTS AND DISCUSSION

Compressive strength (CS)

The concrete specimens were subjected to a storage period in water, then the compression strength of the concrete was tested according to the European standard NF EN 12390-3 (2019), using three cubes for each mixture volume (10x10x10) cm3, and the average values of the resistance of the samples are defined as the CS. The results of the variation in CS of the concrete over time were plotted in Fig. 4, which shows the evolution of CS as a function of the age of the concrete in water.

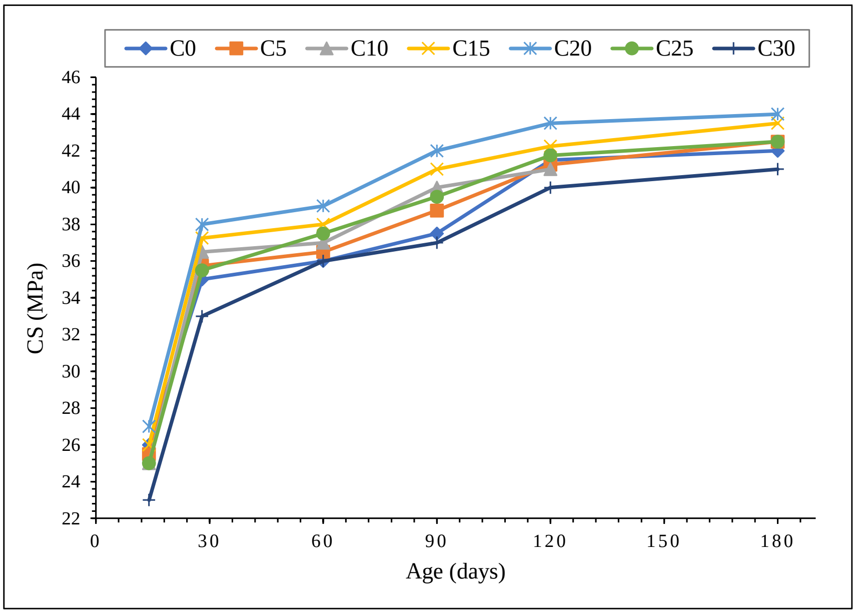

Fig. 4. Evolution of CS as a function of the age of concrete mixtures.

From Fig.4 the CS generally increases between 28 and 180 days for all samples. At 28 days, samples C0 and C25 had the lowest CS values of 35.00 and 35.50 MPa, respectively, while samples C10, C15, C20, C5, and C30 had values ranging from 36.50 to 38.00 MPa. At 180 days, samples C5, C10, C15, C20, and C25 had the highest CS values, while samples C0 and C30 had the lowest values.

Ultrasonic wave velocity

Fig. 5 shows the UPV of concrete samples at different ages (in days). The UPV of the concrete samples generally increases over time, and the strength of the concrete improves as it ages.

At 14 days, the UPV values ranges from 1.38 to 2.70 km/s. The highest value is for sample C20, while the lowest value is for sample C5. At 28 days, the UPV ranges from 2.00 to 3.80 km/s. The highest value is for sample C20, while the lowest value is for sample C5. At 180 days, the UPV ranges from 2.36 km/s to 4.40 km/s.

ISSN: 2178-7727

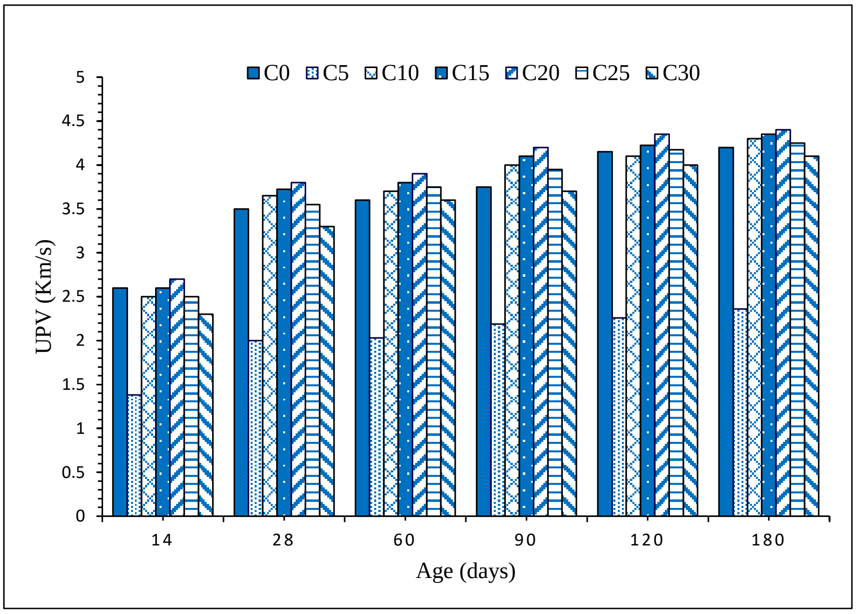

Fig. 5. UPV of concrete samples at different ages.

The highest value is for sample C20, while the lowest value is for sample C5. The highest UPV values for all samples are observed at 180 days, indicating that the concrete samples continue to improve in quality and strength even after several months of curing.

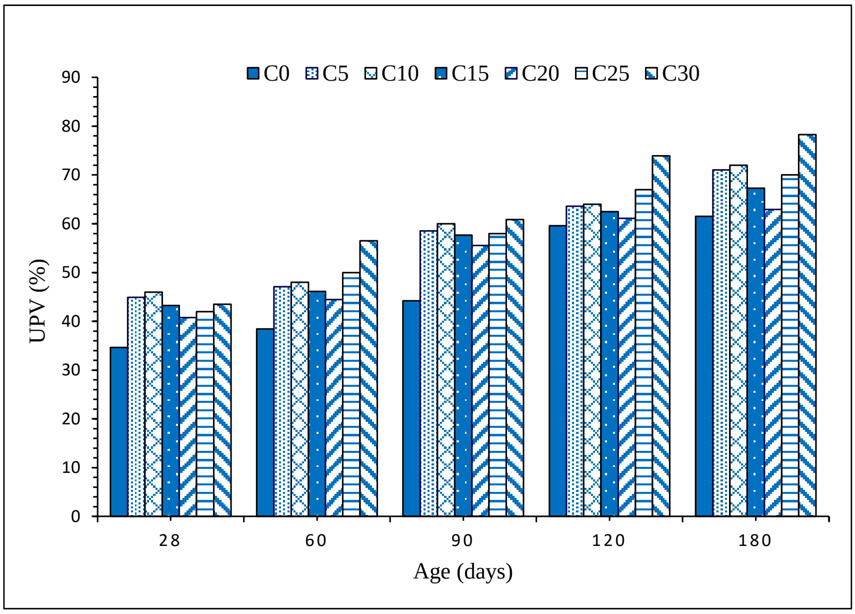

Fig. 6. Rate of change of the UPV of concrete samples at different ages.

Based on the Fig. 6, the initial UPV rate of change from age 14 (reference case) to 60 days is higher than from age 60 to 90 days, indicating that the trait is spreading more quickly in the earlier stages. In addition, the UPV rate of change from age 90 to 120 is relatively steady, suggesting that the trait is spreading at a consistent rate during this time period. Furthermore, there is a noticeable decrease in the UPV rate of change from age 120 to 180, indicating that the trait is spreading more slowly. One can explain why curing time affects the hydraulic cement paste by noting that there exists a negative correlation between the rate of ultrasound waves and the size of pores. As the duration of hydration increases, the degree of cement hydration reduces the volume of capillary pores in the samples.

CONCLUSION

The objective of this study was to examine the impact of incorporating natural pozzolan at varying weight percentages (5, 10, 15, 20, 25, and 30%) on concrete. The evaluation was conducted using two methods: compressive strength (CS) testing and the measurement of ultrasonic wave velocity (UPV). The following findings can be inferred:

- The CS of all samples typically exhibits an increase from 28 to 180 days; at 28 days, it was observed that samples C0 and C25 exhibited the lowest CS values of 35.00 and 35.50 MPa, respectively. On the other hand, samples C10, C15, C20, C5, and C30 had a range of CS values between 36.50 and 38.00 MPa. Moreover, samples C5, C10, C15, C20, and C25 had the highest CS values after a period of 180 days, whereas samples C0 and C30 demonstrated the lowest values.

- The velocity of ultrasonic waves in concrete samples was measured at various time intervals corresponding to different ages of the samples, expressed in days. The velocity of ultrasonic waves in concrete samples often exhibits a gradual increase over time. At 14 days, the recorded values for UPV ranged from 1.38 to 2.70 km/s. Sample C20 has the highest value, while sample C5 demonstrates the lowest value. On the other hand, the UPV at 28 days exhibits a range of 2.00 to 3.80 km/s. Moreover, the ultrasonic wave velocity at 180 days exhibits a range of 2.36 km/s to 4.40 km/s. The velocity of ultrasonic waves reaches its maximum at 180 days for all samples.

- The findings of this study suggest that the incorporation of natural pozzolan in concrete mixtures yields favorable outcomes in terms of mechanical qualities, particularly when considering extended durations. The incorporation of an optimal amount of natural pozzolan presents significant advantages in terms of both strength and cost-efficiency.

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