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ULTRASONIC EVALUATION OF DIFFERENT TYPES OF MORTARS SUBJECTED TO ATTACK BY PIG SLURRY

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ABSTRACT: This paper presents the mechanical behavior of different types of mortar subjected to attack by real pig slurry. The study of the behaviour of mortars was made by the ultrasonic velocity images, obtained by means of automatic inspection and mechanical test of compressive strength. The use of ultrasonic velocity has allowed the extraction of information on the state of damage to the inspected material.
The results obtained from non-destructive ultrasonic tests were compared to destructive testing of compressive strength, and they showed how ultrasonic velocity in the degraded material correlates well with the compressive strength. This conclusion allows us to affirm that the ultrasonic velocity can be used to characterize the process of degradation in cement mortars attacked by pig slurry. The study proposes a mathematic model for estimating compressive strength by measuring variations in ultrasonic velocity.

KEYWORDS: Ultrasound velocities, compressive strength, mortar, fly ash, pig slurry.

INTRODUCTION: Intensive growth in the pig industry has resulted in the production of large quantities of pig manure, which is used as fertilizer on farms. Manure storage structures are commonly manufactured with revetment brick or concrete. The degradation of these structures can cause the contamination of soils and underground water. In addition, slatted flooring (another structural pre-cast element) is affected by the action of manure and causes serious accidents to animals and consequently important economic losses.
Pig slurry is the result of dilution of manure with the water used to wash stock farms. It is a substance with a variable composition and, chemically, a complex compound of mineral and organic composites. The result is an aggressive agent, with a pH average of 7.5. Due to this value slurry should be considered a non-aggressive substance (MOPU, 1999). However, research data shows that agrarian facilities in contact with slurry, both mortars and concretes, deteriorate systematically, to the extent that serious losses in resistant capacity occur (De BELIE N., et al., 2000). This fact proves that the process of degradation is determined by the synergy of the different factors.
Non-destructive tests (NDE or NDT) and in particular non-destructive ultrasonic techniques are one of the methods frequently adopted for in-situ evaluation of the quality of concrete structures. Several authors have determined empirical relations between ultrasonic velocity and compressive strength for different types of cement-based material (DEMIRBOGA R., 2004). The ultrasonic wave velocity has been used to evaluate features such as the degradation of materials due to different aggressive agents (HERNÁNDEZ M.G. et al, 2006), the influence of admixtures and additives (De BELIE N. et al, 2005). Due to the highly heterogeneous nature of these materials and the various characteristics found in the

manufacture process, a general relationship between compressive strength and ultrasonic speed, valid for any cementitious material, has not been established yet.

This paper compared the results obtained from non-destructive ultrasonic tests with the destructive testing of compressive strength, in order to study the degradation sustained by cementitious materials under attack by pig slurry as an aggressive agent. The study of the behaviour of different types of mortar was made from the ultrasonic velocity images, obtained by means of automatic inspection.

METHODOLOGY: **Cements:** This study was carried out on cement mortars frequently used in the building of stock farms. The cement mortars were made of four types of cement: three with differing contents of fly ash (CEM II/A, 16%; CEM II/B-M, 20% and CEM IV/B, 40%) and one with sulphate resistant cement.

Three specimens (40 x 40 x 160 mm) of each cement type and time of immersion were made with 0.5 water/binder ratio and 3/1 sand/binder ratio. The samples were manufactured according to EN 196-1:194. The specimens were removed from the moulds after 24 hours and cured in water for 28 days at 22º C and 100% RH. They were then analyzed with ultrasound to test the initial ultrasonic velocity. After, the specimens were immersing in the pig slurry.

Aggressive medium: The aggressive medium used was pig slurry from a storage lagoon on a pig farm situated in Etreros, Segovia (Spain). The most important contents of the compounds that make up the slurry are ammoniac nitrogen, sulphurs, chlorides and acetic and propionic acids. The pH values are significant due to the fact that values between 7.5 and 8 make slurry an aggressive compound in relation to cement, which has a pH of 12.

Experimental procedures: After 3, 6, 12, 24 and 36 months, three specimens of each cement type were removed from pig slurry. The specimens were cleaned with water and then immersed in water for 48 hours. These samples were analyzed by non-destructive ultrasound and mechanical testing (compressive strength). Non-destructive characterization by ultrasound was made using the ultrasonic wave velocity measurement (described in the following section). The compression strength tests were carried out in a universal test machine, according to the current Spanish Standard EN 196-1:1994.

Velocity measurements: The samples were immersed in a water tank with controlled axis. The automatic inspection has several advantages relating to the accuracy and uniformity of the signals, the number and distribution of inspections and time saving. Ultrasonic longitudinal velocity was measured by using a pulser-receiver ULTIMO 2000, and ultrasonic signals were digitized and processed with the SENDAS system. The transmission technique employed used two broadband transducers, Krautkramer H2K, with 2 MHz of central frequency and 10 mm of aperture, emitting in longitudinal mode.

The samples were aligned on the bottom of the tank, and two ultrasonic transducers scanned all the surface of the samples with a spatial resolution of 1 mm and 4 mm horizontally and vertically respectively. A transmission inspection was made to calculate the final ultrasonic velocity of saturated samples. The measurements were made at several periods: 0, 3, 6, 12, 24 and 36 months of exposition of slurry, so that the evolution of the degradation processes could be observed.

Data analysis: The analysis of the data was carried out by an ANOVA with the StatGraphics programme. The variables studied were “compressive strength” and “variation of ultrasonic velocity” (difference between final ultrasonic velocity and initial ultrasonic velocity). Factors considered were “cement type” and “time”, as well as their interaction.

RESULTS AND DISCUSSION: Tables 1 and 2 show the results of the variance analysis. Significant differences were found with a significance level of less than 1% for the compression strength and velocity variation factors.

Figure 1a) shows the compressive strength evolution and variation of ultrasonic velocity evolution for the different cements during the period of the study.

TABLE 1. ANOVA table for Compression strength

Source	S	df	Mean square	F
A: Cement	897.366	3	299.122	220.67**
B: Time	606.232	4	151.558	111.81**
AxB	185.844	12	15.487	11.42**
ERROR	40.6663	30	1.35554	
TOTAL	1858.38	49		

** p<0.01

TABLE 2. ANOVA table for velocity variation

Source	S	df	Mean square	F
A: Cement	0.134449	3	0.0448164	330.42**
B: Time	0.261671	4	0.0654178	482.31**
AxB	0.048159	12	0.00401325	29.59**
ERROR	0.00420465	31	0.000135634	
TOTAL	0.427163	50		

** p<0.01

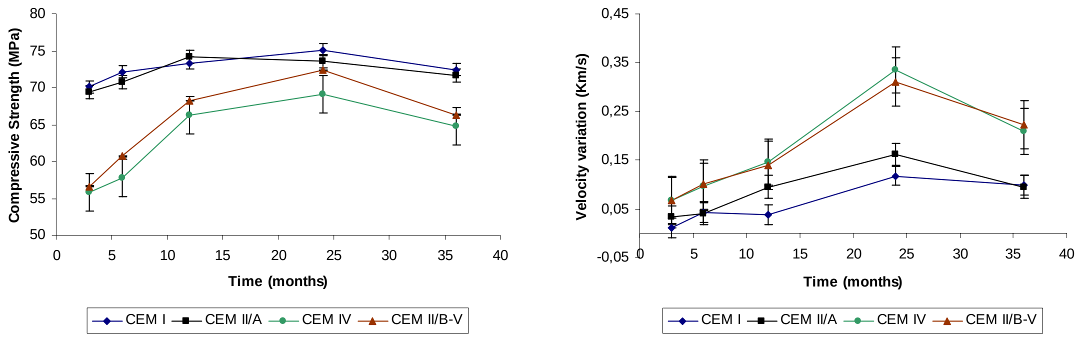

FIGURE 1. a) Compressive strength evolution and b) Variation of ultrasonic velocity evolution in the different mortars.

In the first 24 months, the resistance increased in all the samples. The increase of compressive strength in mortar with fly ash can be due to increased hydration age. This behavior has also been observed by other authors (YONG-XIN LI et al. 2006; CYR, M. et al., 2006; SANCHEZ E. et al., 2008). After 24 months, the resistance of the mortars submerged in pig slurry decreased, which indicated the beginning of the degradation of materials. This behavior agrees with the report by de BELIE (1997).
The differences in ultrasonic velocity demonstrate a similar evolution over time, apart from CEM1, which shows insignificant differences between 3 and 6 months. Over the period of the test, the compressive strength and differences in ultrasonic velocity showed similar behaviours with respect to time, in line with QASRAWI H.Y. (2000) and del RIO, L.M. et al. (2004).
A good correlation ($0.7<R^2<0.98$) exists between the variables considered and the polynomic functions of the time factor. The results of compression (f_c) and the variation of ultrasonic velocity values (Δv) are related by the ratio $\Delta v/fc$ that also follows a type (1) polynomic law.

$$f_c[MPa] = \frac{\Delta v\,[m/s]}{M(t)} \tag{1}$$

After the adjustment to the figures, the proposed model, for the fly ash cements, corresponds to a fourth degree polynomial without independent term (2) and with independent term (3) for the CEM1 cement, given that the variations of compression and velocity are negligible up to 6 months of exposure.

$$M(t) = a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 \quad (2)$$

$$M(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 \quad (3)$$

The coefficients of the models for each cement type are shown in table 3.

TABLE 3. Model coefficients for different cement mortars

Cement	a_0	a_1	a_2	a_3	a_4	R^2 (%)	F
CEM I	-1.548430	$7.32894\cdot10^{-1}$	$-8.25550\cdot10^{-2}$	$3.58380\cdot10^{-3}$	$-0.496026\cdot10^{-4}$	95.5548	42.99
CEM II/A		$2,08713\cdot10^{-1}$	$-1,9728\cdot10^{-2}$	$1,13576\cdot10^{-3}$	$-0,199764\cdot10^{-4}$	92,7752	34,24
CEM IV		$5,64\cdot10^{-1}$	$-6,56684\cdot10^{-2}$	$3,46352\cdot10^{-3}$	$-0,549008\cdot10^{-4}$	99,1506	350,2
CEM II/B-M		$5,52067\cdot10^{-1}$	$-6,16315\cdot10^{-2}$	$3,04295\cdot10^{-3}$	$-0,468054\cdot10^{-4}$	97,9526	143,52

CONCLUSION:

The degradation processes due to the action of pig slurry do not begin until after the first 24 months. These mortars, made with fly ash, showed better behavior than mortar without fly ash cement. This is due to the fact that fly ash cement increased notably more his compressive strength. The increase of fly ash content in cement causes mortars to be more sensitive to aggressive processes. The behavior of CEM I and CEM II/A submerged in pig slurry is similar.

Non-destructive testing by ultrasound has been used to evaluate the degradation process of mortars with different cement types from immersion in pig slurry.

The results of non-destructive testing by ultrasound have been compared to destructive testing, and a good correlation between the variation of ultrasonic velocity and compressive strength has been obtained. From these results, it is possible to affirm that the measurement of ultrasonic wave velocity can be used to evaluate the degradation by immersion in pig slurry.

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