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ORIGINAL ARTICLE

Analysis of the mass and deformation variation rates over time and their influence on long-term durability for specimens of porous material

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Abstract: In an environment subjected to continuous climatic evolution, the study of the long-term behavior of building materials subject to environmental aggressions becomes an extremely important factor in evaluating the sustainability of these materials over time. The damage due to the aggression of external agents does not only affect the surface of the building but can cause a loss of performance in the mechanical qualities of the material with the worsening of the safety conditions of the entire structure. The velocity of the damage evolution is an interesting item. Here the variation velocity of some parameters characterizing the porous materials subjected to aggressive actions is dealt with. Starting from standard material characterization tests, extending the test times, the rate of variation of the mass and the deformation induced by the absorption of saline solutions in the porous medium and the variation of these speeds over time were evaluated. Hypotheses are formulated on the influence that this speed on the degradation of the material in the short and long time. The results obtained show how long-term aggressive action can cause internal damage with a consequent critical increase in absorption, mass and deformation, phenomena that can induce even severe damage to structural elements.

Keywords: Sulphate attack; experimental tests; concrete; mortar; damage

1 Introduction

Climate change underway is putting a strain on all existing heritage. Frequent rains alternating with periods of drought induce concentrations of aggressive agents in the air and soil that undermine the resistance of construction materials, especially porous materials such as masonry and concrete. Furthermore, the violence of some phenomena such as tornadoes and thunderstorms can aggravate the already compromised quality of these materials, favoring the detachment of the surface layers to the point of compromising the safety of some structure and infrastructures. In fact, the superficial alteration of these materials due to the attack of aggressive environmental agents is a damage which, once certain levels have been reached, may no longer be sustainable from a structural point of view. The damage due to the aggression of external agents not only affects the surface of the building but can cause a loss of performance in the mechanical qualities of the material constituting the structural elements of it and the worsening of the safety condition of the entire structure or of some parts of it.

The durability of building materials subjected to an aggressive environment is a well-known problem.

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When a concrete structure is immersed in an aggressive marine-type environment or comes into direct contact with water and / or sulphate-rich environments, complex chemical reactions are created within the material that can compromise its integrity. For example, the phenomenon generally defined as “external sulphate attack” induces a propagation of sulphates inside the material which trigger chemical reactions that can lead to the formation of other chemical elements such as lead, gypsum, secondary ettringite and thaumasite. As a consequence, swellings and expansions are recorded which induce the formation of cracks and the expulsion of portions of material affected by this phenomenon.

Numerous experimental campaigns have been carried out and various investigation methods have been developed to study the durability of porous materials (masonry, cement, mortar, and concrete) subject to aggressive agents [1-13]. With a view to creating more sustainable materials, researches are underway concerning the packaging of cement with natural aggregates and with ashes; accelerated durability tests are also carried out on these materials to validate the material life-cycle [4-8]. Another very interesting and fruitful research field is the study of the behavior of fiber-reinforced materials against aggressive agents [9-10].

The experimental tests reported in the literature follow shared protocols but sometimes the results differ from each other. However, this should not be surprising, it should be emphasized that the results obtained in the laboratory depend on various factors such as: the test conditions, its duration, the cementitious material used in the packaging of the specimens, the type of aggregates and their particle size distribution, etc. However, the final aim of each study is always to evaluate the durability of specific materials with specific characteristics, and to ensure that the results characterize the behavior of that type of material analyzed and can be useful to industrial and scientific community [1-4].

On the other hand, an aspect that is neglected is the behavior of materials subjected to long-term tests. The long-term effects of aggressive attacks on porous materials are extremely important, in fact it is during the entire life span of a building that the materials are subject to the aggressive action of the environment. Nonetheless, laboratory tests extended beyond the terms defined by the protocols are rare. The prolonged test times require significant investments in terms of time and personnel and laboratories may not have the resources to carry out sufficiently long investigation campaigns. Therefore, this behavior is often simulated from the available data [13]. So the durability of materials is usually addressed in statistical terms, although the assessment of the long-term sustainability of the behavior of building materials subject to current climate change should also be addressed in probabilistic terms. [12-15].

In facing a probabilistic evaluation, a decisive step is the choice of the parameters whose evolution over time is to be studied. In the probabilistic evaluation of the durability of construction materials over time, usually the parameters assumed are parameters describing the loss of performance (loss of surface material, loss of mechanical strength, and increase in deformation).

The loss of performance is a parameter that suffers from many uncertainties as it depends both on the aggressiveness of the environment and on the quality of the material. Both factors affect the rate of damage and consequently the rate of performance loss. Although this aspect is quite evident, the velocity with which the loss of performance occurs and how it changes over time is an aspect that has not been addressed in the literature [16-18].

Evaluating the long-term behavior of materials that are differently composed and subject to different aggressiveness is certainly not easy and not even cheap. But this aspect is important for better calibrate the various damage simulation models that are indispensable in the life cycle structural modeling or, even more delicate situation, in the modeling of the propensity to damage the existing historical heritage.

The extension of laboratory tests beyond the natural duration required by the UNI standard tests is certainly not the optimal solution, but it certainly allows to have at least the awareness of what is the probable evolution of the damage over longer times.

Starting from standard material characterization tests described in the UNI standard [19] and extending the test times, the variation speed of the mass and deformation induced by the absorption of aggressive agents in the porous medium was addressed. The aim of this research is to detect the progress of mass and deformation variation over time in terms of rate of variation, or velocity of variation, and to evaluate the possible impact that this rate of variation could have on material damage in terms of loss of material and/or possible cracking.

The results here reported are concerning to an ongoing experimental campaign, carried out on prismatic samples made with cement paste and mortar samples made with the same type of cementitious binder and aggregates of different grain sizes. The purpose of this laboratory experimentation was also to observe the role played by the aggregate in the phenomenon of degradation in a material subject to aggressive environmental attacks. For this reason, cement mortar samples were prepared with two different types of aggregate. Therefore, to evaluate the behavior of the cementitious material subjected to various external aggressive attacks, samples of cement paste (P-CEM), samples of mortar with normalized sand (M-nor) and samples of mortar with siliceous aggregates with granulometric class were prepared 0.063mm to 2mm (M-agg). The samples were subjected to immersion cycles, simulating three different aggressive attacks: immersion in demineralized water, in saline solution with sodium sulphate concentration at 5% and 10%. Deformation was monitored over time by direct length measurement. The tests were performed according to EN 12617-4 [19] but lasted longer than the times indicated by the standard and are continuing. The purpose of this is to assess the long-term influence of an aggressive environment on the analyzed material.

In the 889 test days achieved so far, for each tested specimen the variation of the deformation behavior (shrinkage / expansion) and the variation of the mass were monitored.

The approaches proposed rather innovative, and little dealt with in the literature. Studies have been carried out on the transmissivity of the waves in the material [16-17], but not on the deformation rate of materials subject to degradation and possible connection with variation and variation rate of the mass recorded step by step of the test.

A similar approach is present in [18], which encourages the authors to continue along this path. The probabilistic modeling of the behaviors observed up to this phase of the work will be the future step in the development of this research and will aim to describe, always in probabilistic terms, the damage evolution velocity in porous materials due to aggressive environmental actions and the possible long-term impact of such damage on the structural safety.

The document is organized into sections. Section 1 is the introduction to the paper. The laboratory test procedure is presented in section 2. Section 3 is devoted to the presentation of the methodology used to evaluate the rate of change of mass and deformation as time varies. In section 4 the results obtained are discussed. Concluding remarks are presented in section 5.

2 Experimental Test

2.1 Packaging of Spacemen

The experimental campaign began 29 months ago and was conducted on prismatic samples of mortar and cement paste of 40mm x 40mm x 160mm size.

Three series of samples were prepared: cement paste samples (named in the paper with P_CEM), mortar samples with fine siliceous aggregate: 0.063 to 2.00 mm (named with M_agg) and mortar samples with standard siliceous aggregate (sand used for the certification of the mortar) (named with (M_nor) [20]. A Portland cement type CEM I 52.5R was used for all the samples and whose characteristics are reported in Table 1 and Table 2.

Table 1. Chemical composition of cement

Cement	Clinker	Limestone	C_3A	C_4AF	SO_3	Pozzolan
CEM I 52.5R	91,4%	3,2 %	4.22%	5.16%	3.61%	3.4%

The samples were packed in a climatic chamber at temperature T = 20 °C and relative humidity RH = 65 ± 5% and then placed for two days in a climatic chamber at temperature T = 20 °C and relative humidity RH = 95 ± 5% according to the legislation EN1015-11 [20].

To evaluate the impact that some aggressive environmental agents could have on porous cement-based materials, three prismatic specimens were prepared for each type of mixture and laboratory tests were performed during which the samples were immersed in deionized water and in a 5% and 10% solution of sodium sulphate. After 24 hours from their packaging, the samples were subjected to measurement to evaluate their initial length and mass characteristics. These measurements represented the reference for the evaluation of deformation and mass variations in the short and long term.

Table 2. Chemical, Physical and Mechanical Requirement

CHEMICAL REQUIREMENTS	PHYSICAL REQUIREMENTS	MECHANICAL REQUIREMENTS
loss on ignition ≤ 5,0 %	initial setting time ≥ 45 min	early compressive strength (2 days) ≥ 30,0 MPa
insoluble residue ≤ 5,0 %	soundness (expansion) ≤ 10 mm	standard compressive strength (28 days) ≥ 52,5 MPa
sulfates (as SO3) ≤ 4,0 %		
chlorides ≤ 0,10 %		
Artificial raw materials (Ferrous sulphate, additives, calcium sulphate) 0.7%		
Secondary raw materials (recovered gypsum, fly ash) 1.3%		

2.2 Laboratory Test Procedure

The deformation of each specimen was recorded according to the standard [19], using a not hindered linear measurement method.

The procedure provides that after 24 hours from the casting, the specimens were cleaned from the moulds and prepared for the first measurement. Before the initial measurement, the adhesion of the measuring pins must be verified.

When the first measurement, L_0, were recorded for each sample, they were completely immersed in pure water (double-distilled) or in a solution with a concentration of 5% or 10% of sodium sulphate (Na_2SO_4).

The prisms were periodically extracted from the solutions, to be able to measure the variations in weight and length. Figure 1., shows a sample during the measurement phase and samples during the last curing period.

a) **b)**

Fig. 1. a) Samples during the measurement phase; b) Samples during the last curing period

3 Variations of Deformation and Mass

3.1 Deformation Survey

To measure the short- and long-term alterations suffered by samples of cement material immersed in water or saline solution, the UNI standards reported in [19] were followed. In the first 56 days, the variation in length and the variation in mass of each specimen were recorded at the time suggested in [19]. In the long term the measurements were less frequent but always carried out following the procedure reported by the UNI standards in [19]. The UNI procedure requires that at each measurement instant, t_i, the variation in length, ΔL_i, is always related to the initial length, L_0, measured after 24 hours of packaging and depending on the measuring pin used:

$$\Delta L_i=(L_i-L_0) \quad (1)$$

Where L_i is the length of the specimen at the time t_i.

The consequent deformation, ε_i, at each instant of measurement, t_i, is given by:

$$\varepsilon_i=\Delta L_i/L_0 \quad (2)$$

Where ΔL_i is the variation of length expressed by (1) and L_0 is the initial length of the specimen. In the case here proposed the length L_0 is equal to 160mm.

3.2 Mass Variation Measurement

In [19], section 6.7, the practice of measuring the mass variation is reported. Therefore, following [19], at each time t_i, the mass variation was recorded as:

$$\Delta M_i=(M_i-M_0] \quad (3)$$

Where: ΔM_i is the variation of mass at the time t_i; M_i is the mass of the specimen recorded at the time t_i and M_0 is the initial mass of the specimen.

The mass variation, m_i, expressed in percentage, is defined by:

$$m_i=[(\Delta M_i \cdot 100)/M_0] \quad (4)$$

3.3 Deformation and Mass Variation Rate

The behavior of the specimens immersed in the different solutions was also investigated as deformation rate and mass variation rate, to try to establish a relationship between deformation and mass variation once the classical maturation period of the material has been exceeded. This study is oriented to investigate the behavior of the porous material stressed by short-term and long-term aggressive attacks.

The assessment of the deformation rate, $\boldsymbol{v}_i$, must follow the classical definition:

$$\boldsymbol{v}_i=\varepsilon_i / [t_i-t_{(i-1)}] \quad (5)$$

Where: ε_i is the deformation defined in (2); t_i is the current instant of testing (measured in days) and (t_i−1) is the previous one.

The mass variation rate, $\boldsymbol{v}_{mi}$, can be expressed as follow:

$$\boldsymbol{v}_{mi}=m_i / [t_i-t_{(i-1)}] \quad (6)$$

Where: m_i is the mass variation defined in (4); t_i e (t_i−1) have the same previous definition.

Instant by instant, equations 5 and 6 allow to evaluate the deformation and the mass variation rates and to formulate hypotheses on the evolution of the phenomenon over time.

4. Discussion on the Results Obtained

To characterize the material mechanical properties laboratory tests were carried out following [19] for 56 days; the results recorded during this period permit to evaluate the material behavior stressed by short-term aggressive attacks.

To investigate the possible sustainable behavior of the porous material when it is stressed by long-term aggressive attacks the tests were continued reaching 889 days.

In the following sections the results obtained in the first 56 days of the test, for each type of sample and for each salt concentration, will be compared, both in terms of mass variation and deformation, as well as mass variation rate and deformation rate.

The comparison is also made for the period between 56th day and 889th day of testing.

4.1 Cement Paste P_CEM

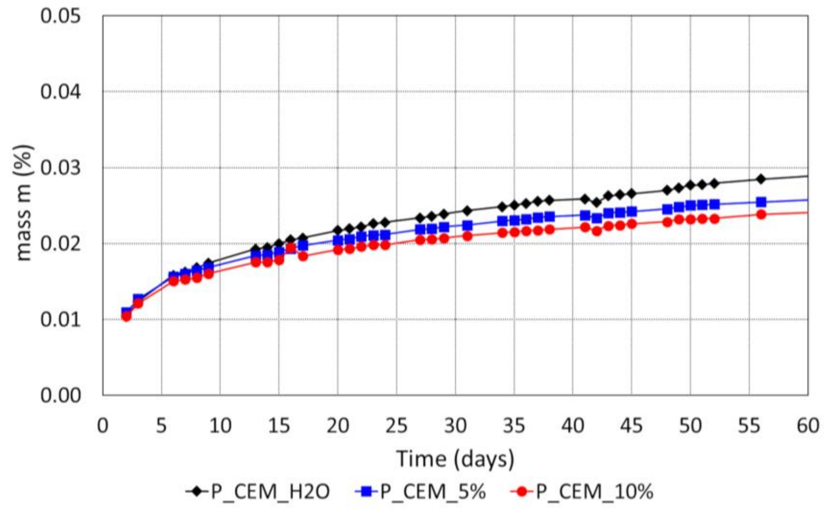
In this section will be discussed the short-term and long-term behaviors of the P_CEM specimen with respect to the three aggressive agents examined.

For the specimens P_CEM, the variation in mass and deformation during short-term attacks (first 56 days of the test), follow a similar trend for all three aggressive agents (Fig.2).

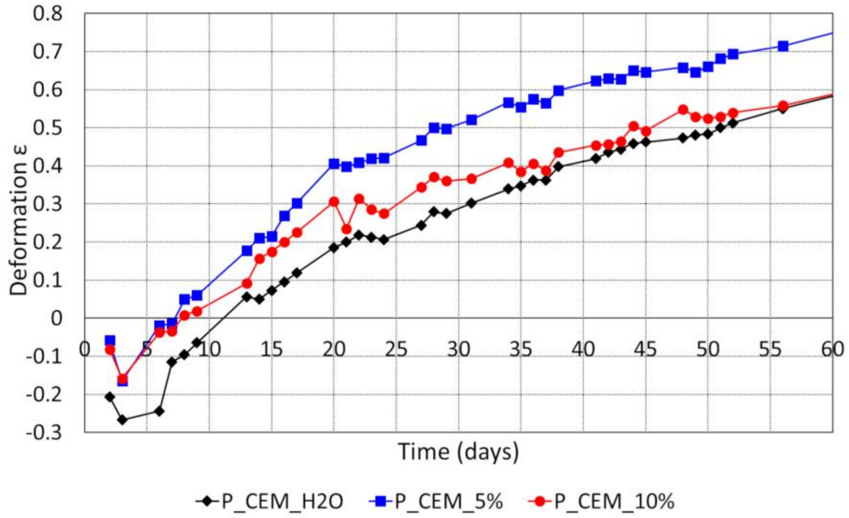
The variation of *m* (mass) is always a little higher for the specimens immersed in water (Fig.2a). This is due to the homogeneity and small porosity of the cement past that hinder the absorption of higher concentration of salts.

The variation of ε deformation is instead greater for the 5% of saline solution (Fig2b). Even if in less quantity compared to the absorption of water, the saline solution is still absorbed by the porous medium. The greater deformation recorded by 5% of saline solution, compared to the other two aggressive agents, is probably due to the crystallization of the salts inside the pores with consequent expansion of the volume of the porous medium. Probably this result is due to the easiest absorption of solution 5% than solution 10%.

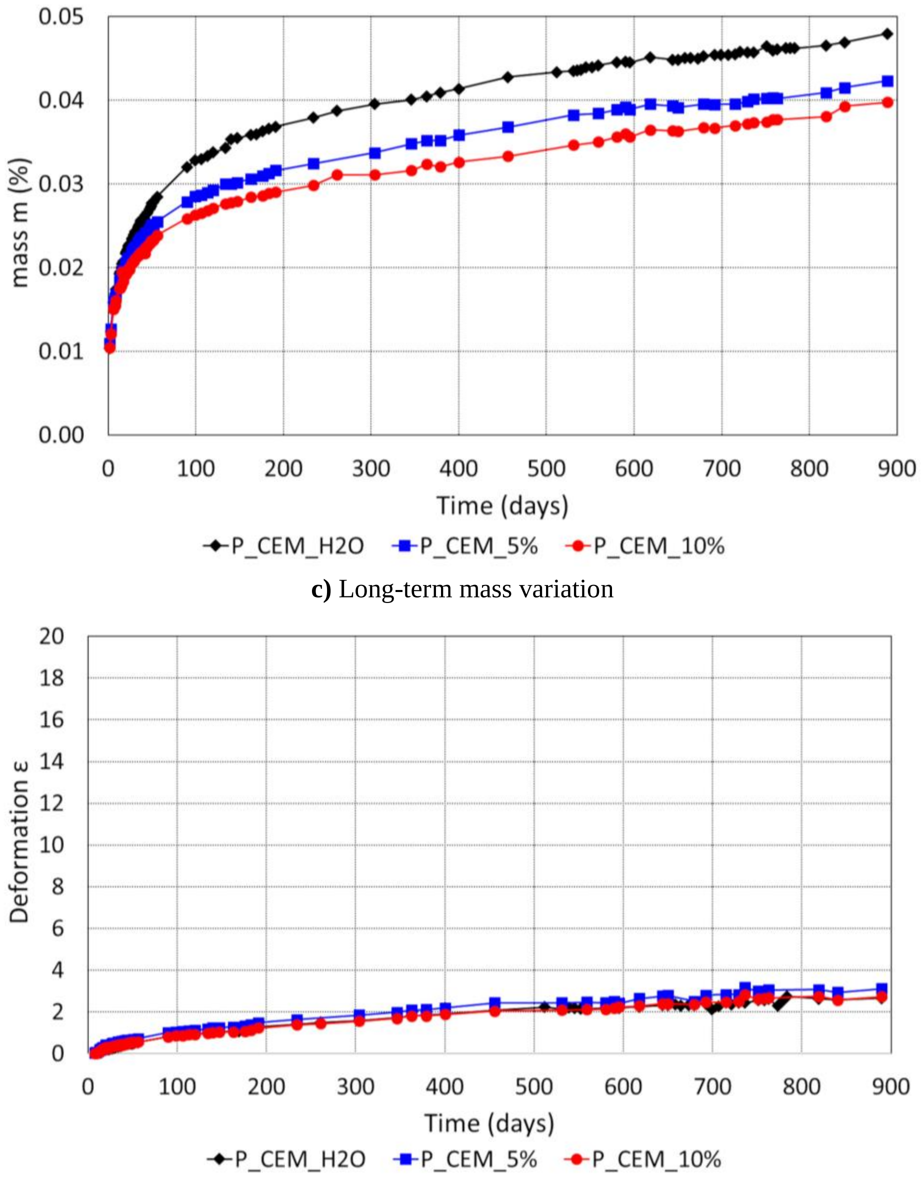
During the long-term phase, the specimens immersed into the three different aggressive agents show very similar behaviors (Fig.2c and d). This is always due to the composition of the cement paste specimens which, resulting in lower porosity, it seems to have not yet reached complete saturation. Specimens immersed in 5% saline solution are increasingly sensitive to variations in weight and deformation then specimens immersed in 10% saline solution, this occurs for the same reasons explained for the short-term behavior phase and it is more evident precisely in this phase. After the 50th day the behavior of material at the three aggressive agents it is very similar, in fact the lines reported in Figure 2c seem almost parallel.



a) Short-term, mass variation



b) Short-term, deformation



c) Long-term mass variation

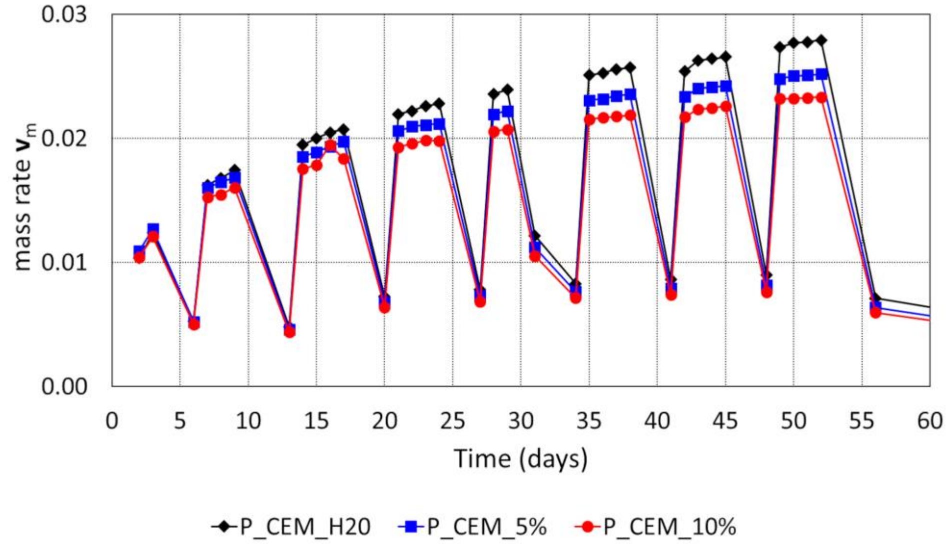
d) Long-term deformation

Fig. 2. P_CEM behavior for the three aggressive agents tested

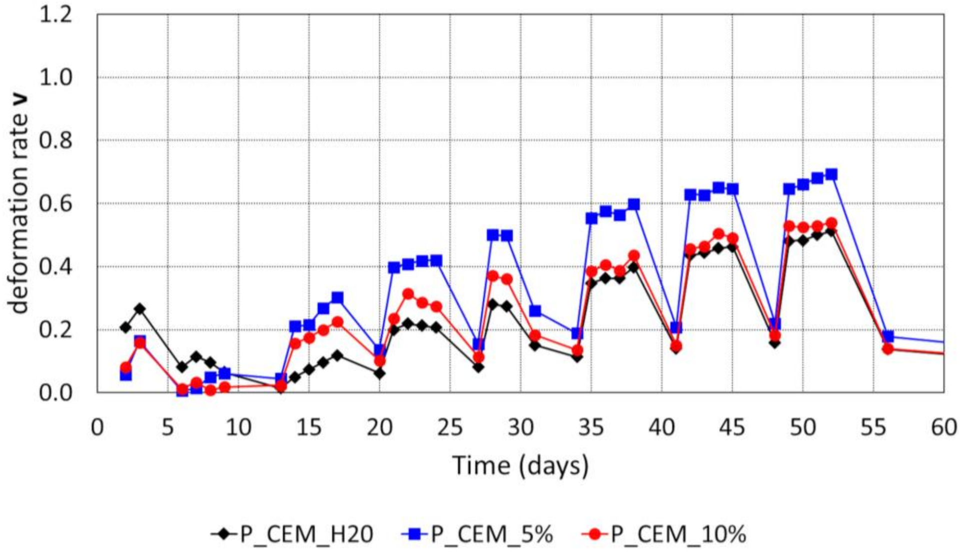
Figure 3 shows the long-term behavior of the mass and deformation rate for the specimens P_CEM always subjected to the three aggressive agents.

During the short-term aggressive period the samples show a cyclical behavior both for the mass variation and for deformation rate (Figures 3a and b). The behavior is connected to the test procedure. During the first 56 days the measurement were made day by day for three or four days, then there is time interval of 3-4 days before the other stock of measurements. After an interval the results have a decreasing, this is due to the ratio made in (5) and (6). For longer intervals, $(t_i-t_{i-1})>1$, in fact the denominator value is greater and therefore the ratio value decreases. This behavior was recorded for all the series analyzed (P_CEM, M_agg and M_nor) and indicates that for the first 56 days of the test there is no direct relationship between immersion time and variation rates of deformation and mass variation.

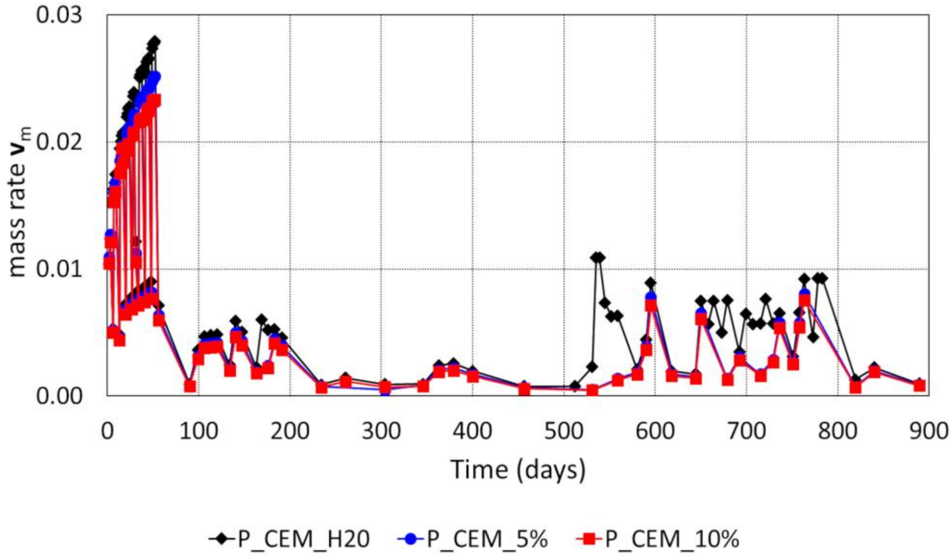
During the long-term phase, the mass variation and deformation rates decrease drastically, up to the 500th day after which they start to rise again (Fig. 3c). For the deformation rates after the 500th day there are still peaks in speed almost like those of the first period (Fig. 3d) and with measuring interval greater than one day. Also, in this case it is likely that the degradation level is facilitating absorption and the subsequent deformation rate. Considering that the measurement intervals are longer, it is probable that the deformation rate is rather high than the short-term phase and therefore it could be a symptom of degradation in progress.



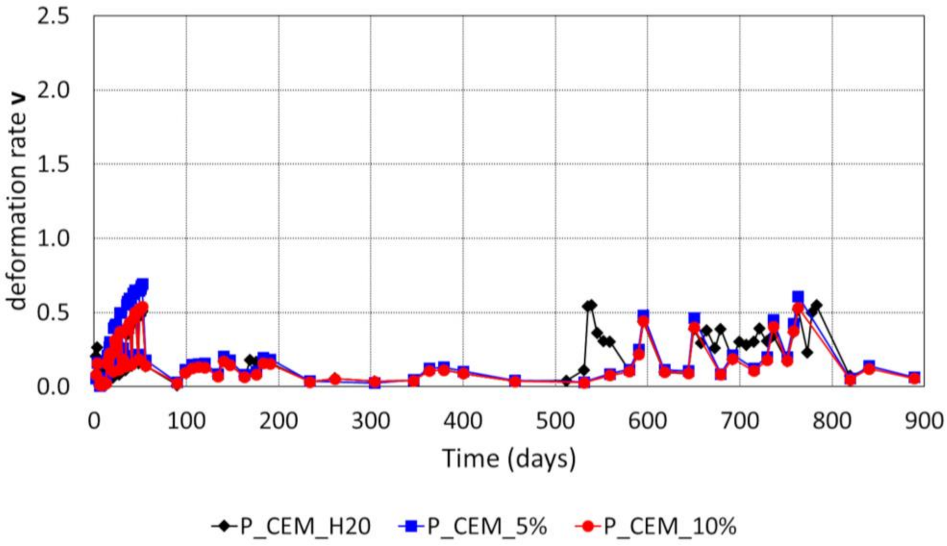
a) Short-term, mass variation rate



b) Short-term, deformation rate



c) Long-term mass variation rate



d) Long-term deformation rate

Fig. 3. P_CEM.: rate of deformation and mass variation over time due to three aggressive agents

4.2 Mortar with thin aggregates M_agg

In this section, the short and long-term behaviors of specimens made with M_agg mortar prepared with thin aggregate and subjected to aggressive actions will be discussed. The M_agg specimens have a more porous structure than the P_CEM specimens and less porous than the M_nor specimens.

Figure 4a shows that in the short-term phase the mass variation for the samples M_agg is very similar for the three types of aggressive solution samples with an increase for the specimen immersed in water only. This could be justified because of the absorption of salt solutions is difficult compared to the absorption of water.

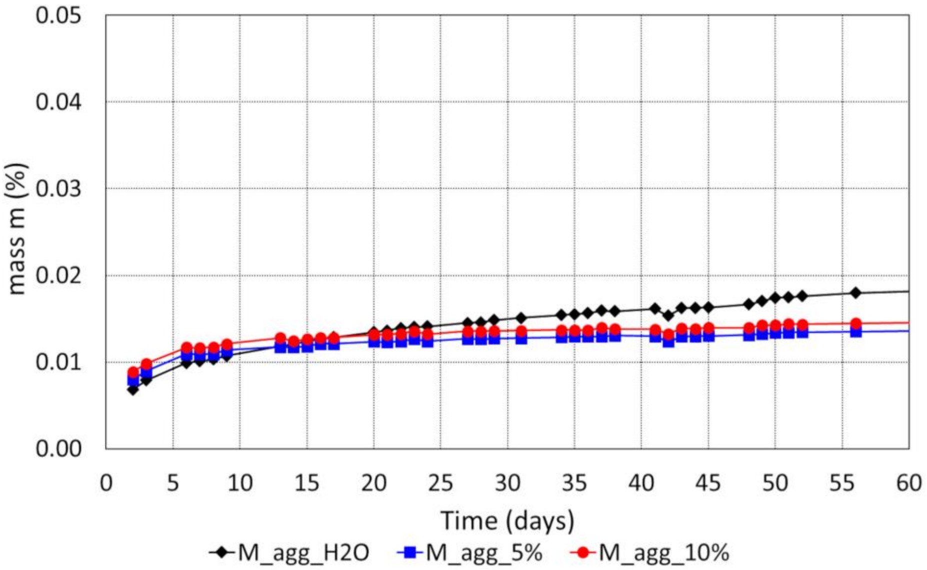
Different is the results obtained for the deformation during the short-term period. Figure 4b shows a greater deformation observed in the specimens during the absorption of for saline solutions compared to the deformation observed during the absorption of pure water. This phenomenon is probably due to the greater volume of salts present in water that increase the deformation especially for the 10% salt concentration.

The mass variation completely changes the behavior after the first 60 days (Fig.4c). For the salt solutions the trend up to 200 days of testing is very similar. A significantly greater mass increase is observed for the pure water solution.

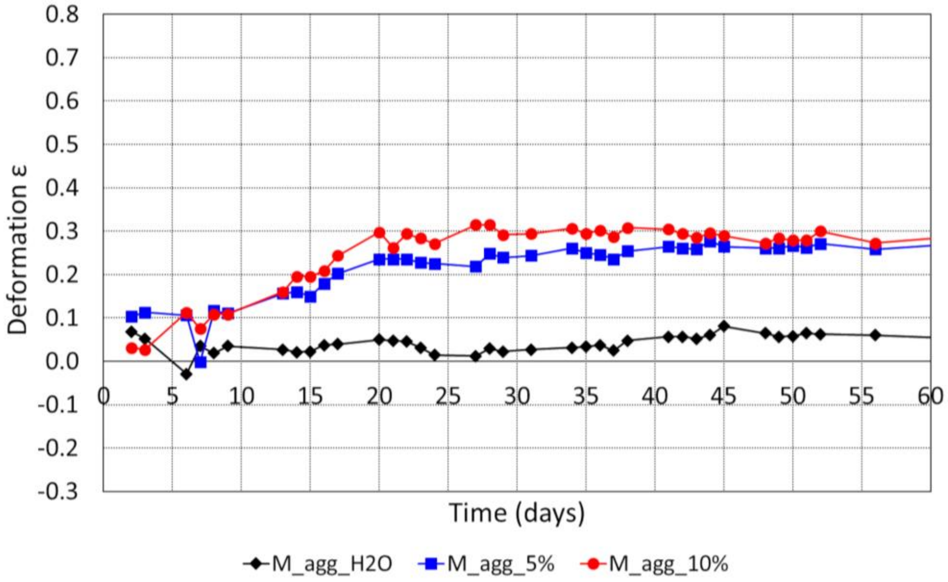
The following period is characterized by a different behavior between the saline solution and the saline solutions. The behavior observed for samples immersed in water alone may be due to a greater ease of absorption by the material of the salt-free solution, up to saturation, after which the increases in mass stabilize.

The increase in mass, on the other hand, continues to be progressive for the samples immersed in saline solution, this is probably due to the continuous action of the salt which, acting on the microstructure of the material, causes micro fractures that carry the solution more easily and increase its absorption. Furthermore, the saturation may not yet have been reached (Fig4c).

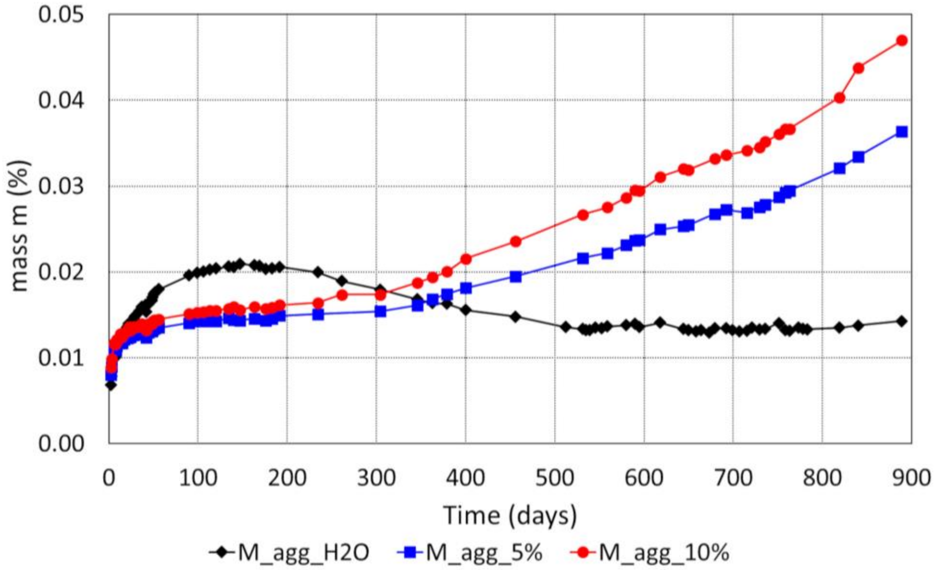
This behavior observed seems justified by the trend of the deformation, for the specimens immersed in water it seems to remain fairly constant while for the specimens immersed in saline solution it is increasing (Fig.4d).



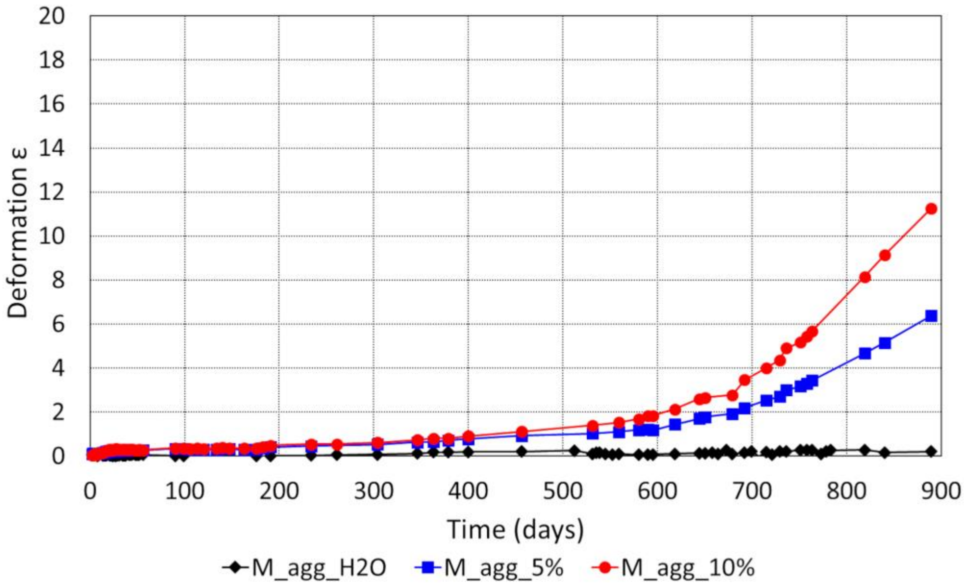
a) Short-term, mass variation



b) Short-term, deformation



c) Long-term mass variation



d) Long-term deformation

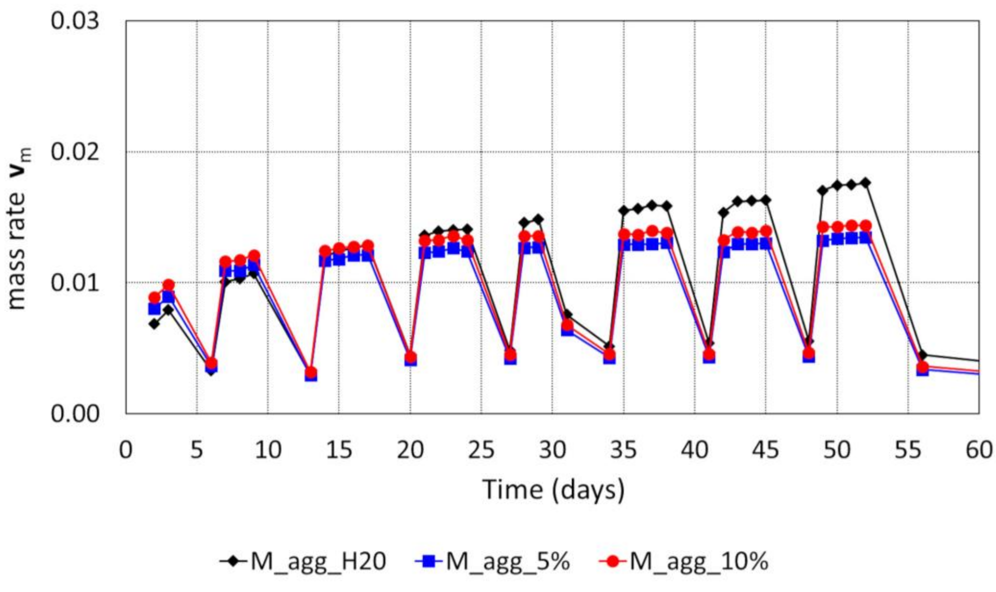
Fig. 4. M_agg.: behavior recorded for the three aggressive agents tested

The comparison between the rate shows a cyclical behavior for the first 56 days both for mass variation rate and for the deformation rate (Fig5a and b) with a more regular behavior for the mass variation rate (Fig.5a). In figure 5b the behavior of the deformation rate is significantly higher for the specimens immersed in saline solution and for a higher concentration of salts.

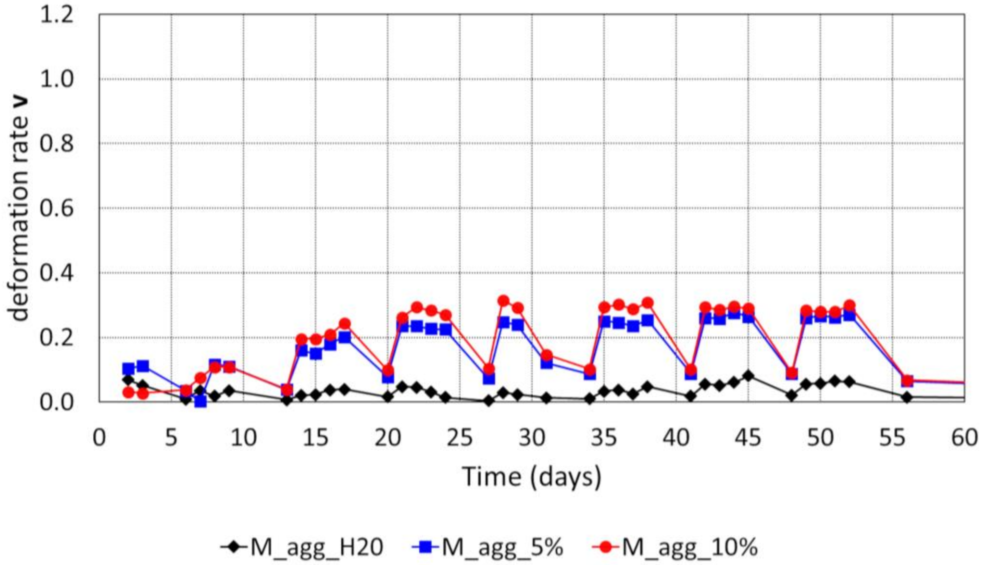
After the 56th day, the cyclicality is no longer so evident. There is a marked slowdown between the 60th and 500th day of testing (Fig. 5c and d). In the period between the 500th and 850th day of the test, peaks in mass variation and deformation rates were detected.

The mass variation rates are contained compared to those of the first period and are, in any case, greater for the specimens immersed in saline solutions, a symptom of probable almost complete saturation of the material immersed in water (Fig.5c).

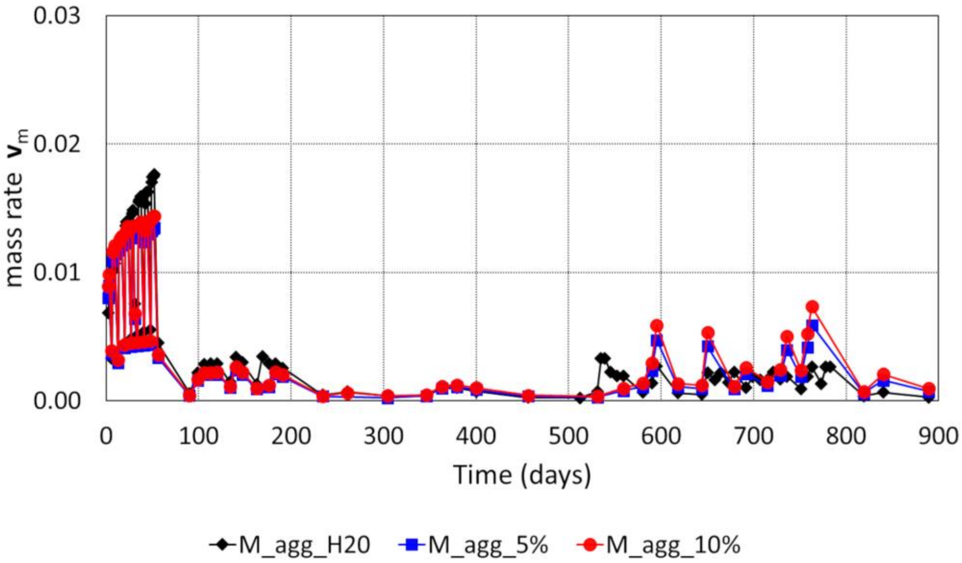
The speeds recorded for the deformations for the specimens immersed in salt solutions (Fig.5d) are almost of a higher order than those of the first period, a symptom of a faster deformation in accordance with what is shown in Figure 4d.



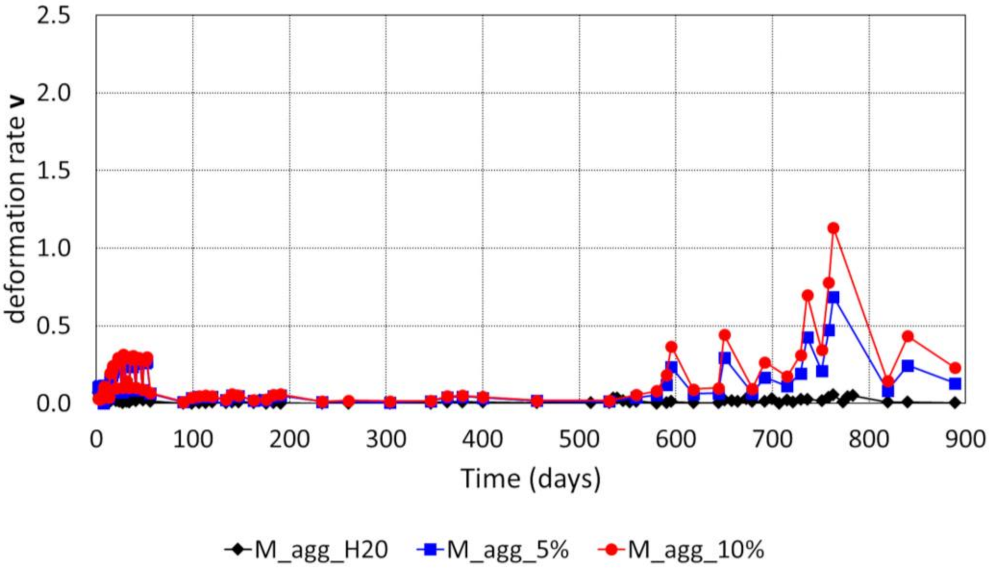
a) Short-term, mass variation rate



b) Short-term, deformation rate



c) Long-term mass variation rate



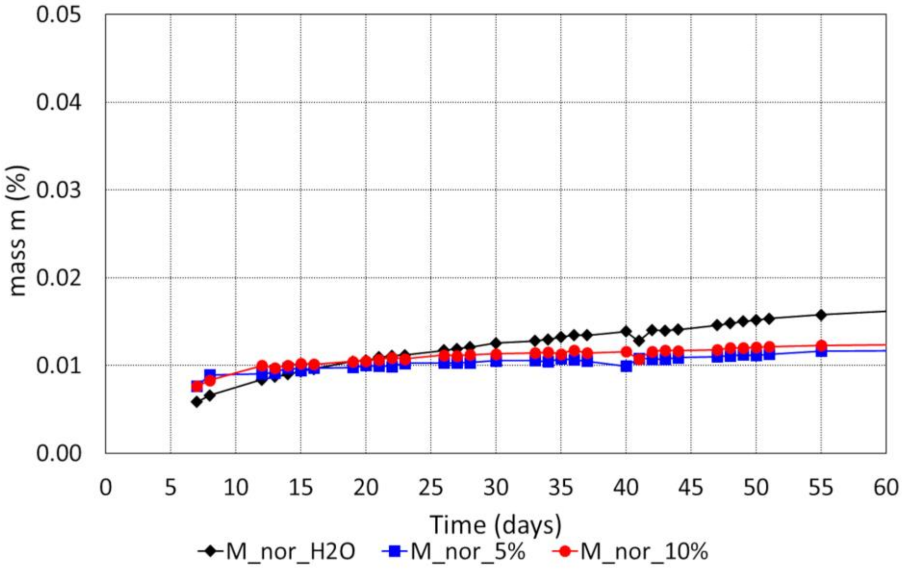
d) Long-term deformation rate

Fig. 5. M_agg.: rate of deformation and mass variation over time due to three aggressive agents

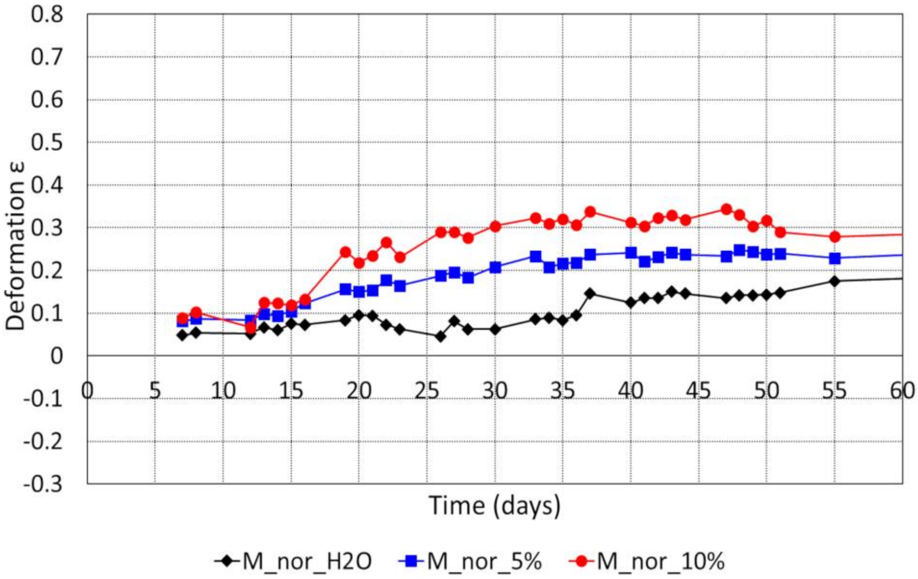
The fast deformation could be a symptom of deterioration/crumbling of the material. As in the previous case study, the test intervals are longer in the long-term phase so these picks could be a symptom of an important damage.

4.3 Mortar with standard aggregates M_nor

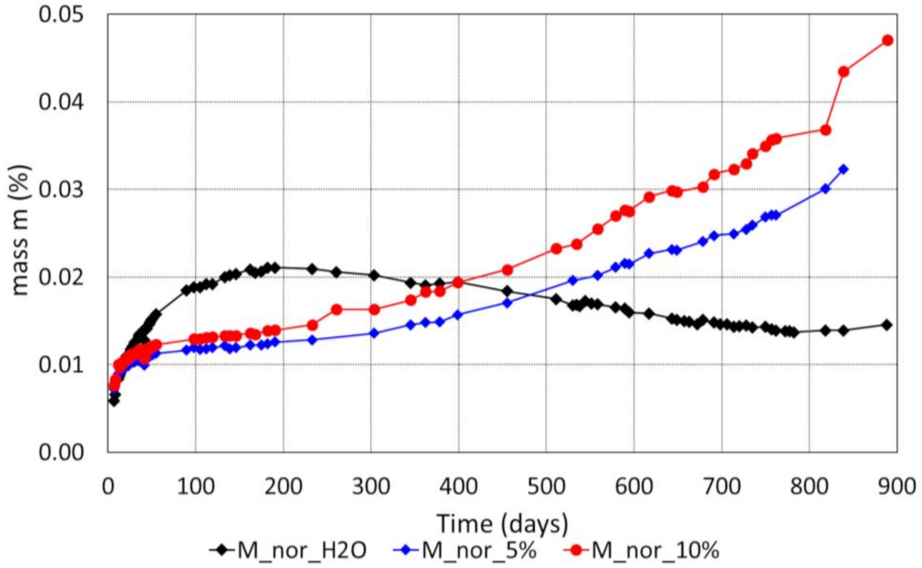
For the samples M_nor the behavior shown in Figure 6 is similar to the behavior shown in Figure 4 and concerning the samples of M_agg. The behavior shown in the long term may be due to internal damaging which could compromise its resistant capabilities. The behavior of the mass variation rate and the deformation rate is similar to the behavior in Figure 7 and Figure 5, but with different magnitude.



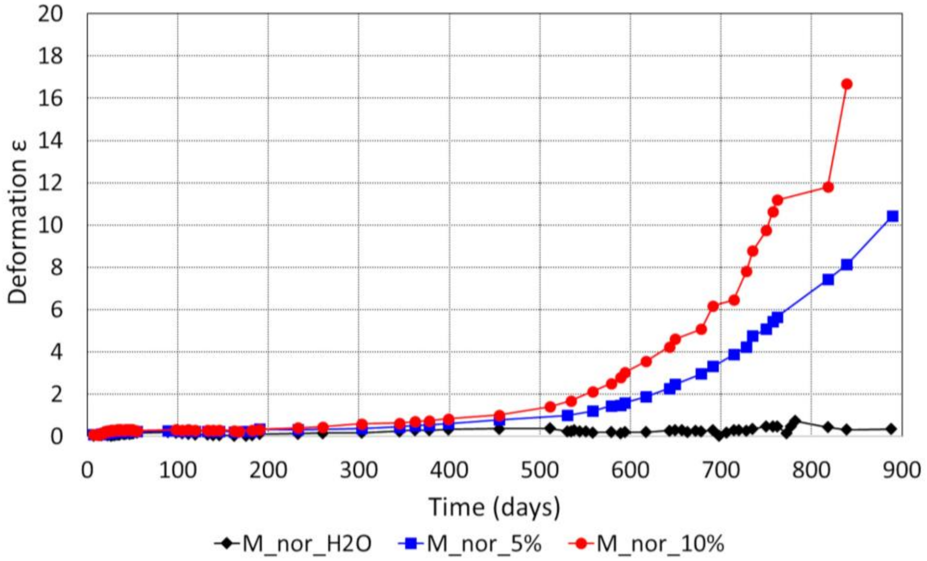
a) Short term, mass variation rate



b) Short term, deformation rate

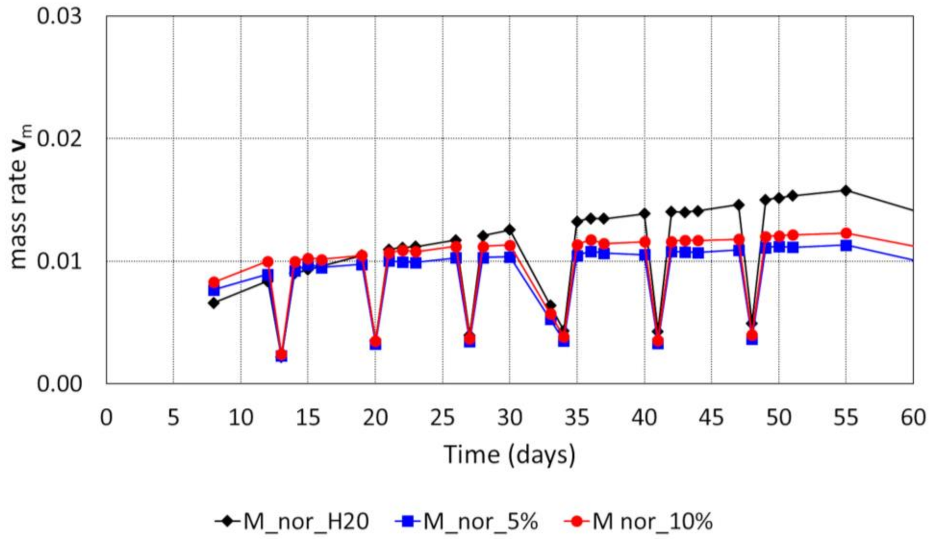


c) Long term mass variation rate

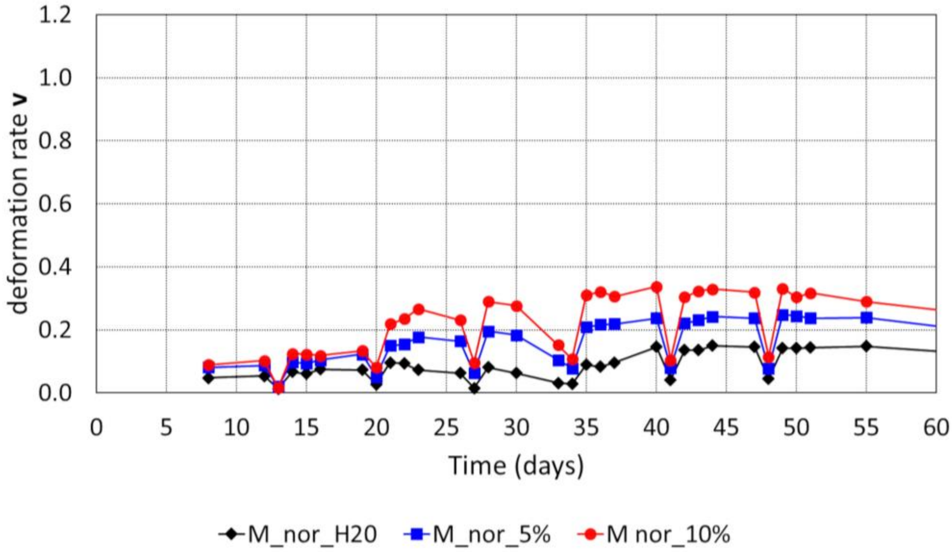


d) Long term deformation rate

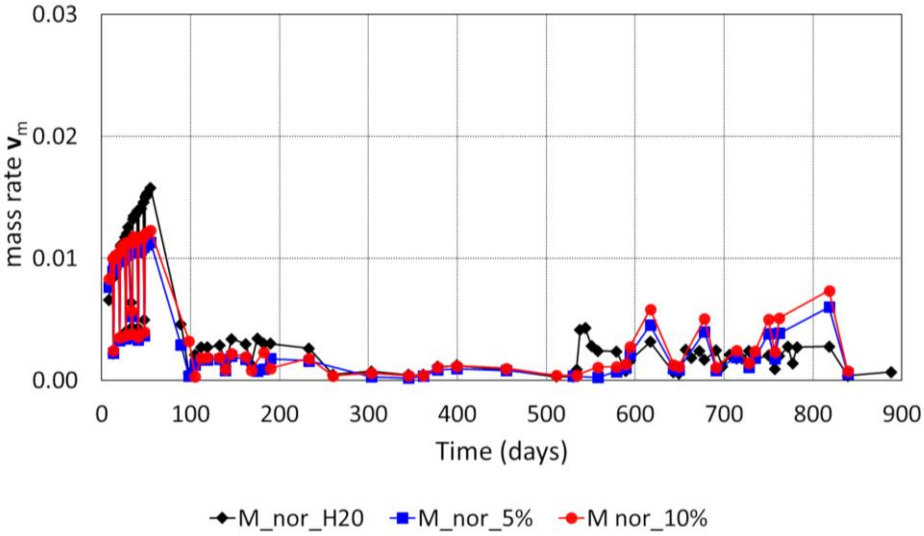
Fig. 6. M_nor.: behavior recorded for the three aggressive agents tested



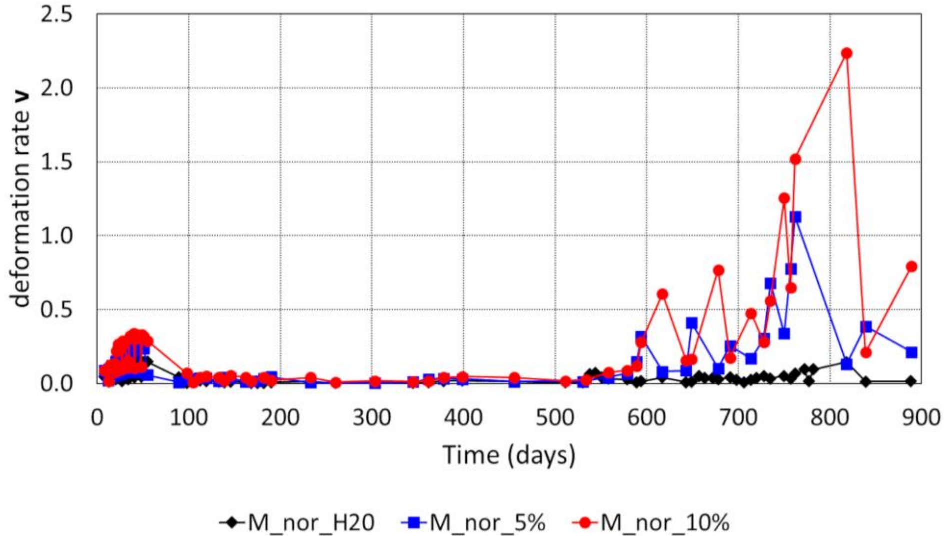
a) Short-term, mass variation rate



b) Short-term, deformation rate



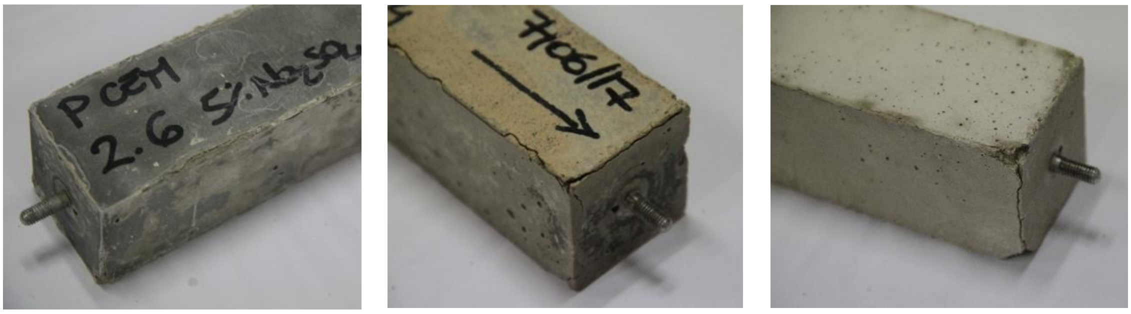
c) Long-term mass variation rate



d) Long-term deformation rate

Fig. 7. M_nor.: rate of deformation and mass variation over time due to three aggressive agents

The observations made in the previous paragraphs on the probable evolution of the damage starting from the results obtained in reading the evolution of the deformation rate and of the variation of the mass, seem to be confirmed by the visual observations of the damage present on the tested specimens.



a) **b)** **c)**

Fig. 8. Visual observations of the damage reported by the specimens immersed in a saline solution with a concentration 5% of sodium sulphate (Na_2SO_4) after 600 days of testing. a) P_CEM; b) Samples M_agg; c) Samples M_nor.

a) **b)** **c)**

Fig. 9. Visual observations of the damage reported by the specimens immersed in a saline solution with a concentration 10% of sodium sulphate (Na_2SO_4) after 600 days of testing. a) P_CEM; b) Samples M_agg; c) Samples M_nor.

Figure 8 and 9, highlight the level of degradation of the specimens after 600 days of testing.

The images show the presence of superficial micro fractures and fractures especially in samples called M_agg and M_nor. The surfaces of M_agg and M_nor show also disintegration (Fig.8b-c and Fig.9b-c) that can favour the absorption of the saline solution with consequent triggers of internal damage. This deformation behaviour is highlighted by the graphs in Fig. 4d and 6d relating to the mortar samples M_agg and M_nor.

The results here reported show that the collapse mechanism is generated by the crystallization of the salts in the dry-wet interface. The increase in the volume of the salts causes micro-cracks inside the material with consequent detachment of the surface layer preceded by swelling and the presence of micro cracks on the external surface, as shown in figures 8 and 9.

This phenomenon is emphasized by the less homogeneity of the cement past (M_agg and M_nor) because of a more widespread porosity emphasizes the absorption of salts and in the dry-wet cycles saline crystallization occurs with greater aggressiveness. This happens with greater severity in the cases of M_agg and M_nor, (Fig. 8b-c and Fig.9b-c) where the behaviour is very similar and the differences are due to a greater porosity or less porosity of the part.

5. Conclusions

In an environment subjected to a constantly changing climate, the studying of the long-term behavior of building materials subjected to environmental aggressions, both new and already in use, becomes an extremely important factor to evaluate the sustainability of these materials over time.

The assessments on the durability of the materials carried out on site and in the laboratory are aimed at evaluating the capabilities of the material subjected to certain aggressive actions, but they are difficult to deal with the long-term study of such phenomena and their possible acceleration due to the progress of the degradation of the material itself. Certainly, to address this issue the required test times must be much longer, and the data collected must be processed in probabilistic terms.

The durability analysis is not usually based on the probabilistic assessment of the life-cycle of a material and on the assessment of the speed of reaching certain degradation levels but the authors believe that this aspect is relevant in an evaluation of material behavior subjected to aggressive environmental actions in the long term. In fact, limiting the evaluation of durability to the occurrence of the first damage excludes any reflection on the behavior of materials in use for several centuries and which are only currently subjected to harmful attacks due to an aggressive environment in continuous evolution. These materials already present a level of damage due to their natural aging that aggressive attacks can only accelerate. Their durability is thus compromised if you do not intervene with targeted maintenance actions and adequate timing. But planning appropriate maintenance actions means evaluating the likely evolution of the damage in the long term.

To follow the long-term evolution of the tested specimens, the programmed laboratory tests must be non-destructive tests and the parameters to be taken as "damage alert" must be able to be obtained from non-destructive tests.

This work dealt with the issue of evaluating the rate of variation of two parameters obtained precisely from non-destructive tests and usually measured in the characterization of cementitious building materials subjected to aggressive actions: the mass variation and the deformation variation. The research carried out so far has revealed the importance of studying the variation of these two parameters as it already seems to be a symptom of possible damage trigger. To detect this symptom, it was important to proceed with the test beyond the period defined for the standard test.

For the cases studied, the test has now reached 889 days, but the authors intend to continue this test to try to achieve the collapse of the specimens.

The results obtained so far show that in the first 56 days the weight variation is quite similar for all the specimens of the three series with an ever-greater variation for the specimens immersed in water. The deformation variation is increasing for the three series of specimens with higher values for the specimens immersed in saline solution. The behavior is more regular in P_CEM specimens than in mortar specimens, even if the deformation is greater. This may be due to the greater homogeneity of the mixture.

The variation in mass and the strain rates follow a cyclical trend due to the irregular rhythm with which the measurements are made. This phenomenon stabilizes between the 56th and the 500th day of testing, while it returns predominantly after the 500th day of testing.

Considering that after the 56th day the measurement intervals are longer and even less regular, the peaks present in the study of mass variation rates and deformation rates must be interpreted as an important symptom of possible damage. In fact, the increase in the speed of variation of the mass is probably due to the triggering of micro fractures in the material and the consequent greater and faster diffusion of the absorption. This result is accentuated for the specimens of mortar than in the specimen on cement past and subjected to aggression with 10% salt solution. This is probably due because the mortar specimens are more porous and less homogeneous than the cement paste specimens. This promotes the absorption of the test solutions. The saline solutions crystallizing in the pores cause micro fractures which propagate more easily than in a homogeneous medium. The presence of a higher saline percentage certainly accentuates the phenomenon and accelerates the propagation of micro fractures.

After the 550th day of tests there is a significant increase also in deformation for most of the specimens (especially for the specimens immersed in saline solution), this seems to be a symptom of greater internal damage probably due to salt crystallization.

The results obtained from this first investigation already show how important it is to analyze for a long time the behavior of a material subject to aggressive action. It is of considerable interest to identify the instants in which the behavior changes, this because on the basis of these symptoms it is possible to plan preventive maintenance actions aimed at consolidating risk situations and extending the useful life of the damaged elements avoiding the achievement of critical absorption thresholds which can cause a significant degradation.

From the analyzes carried out, it is also evident that the use of materials with performing granulometric characteristics can certainly postpone the beginning of the fourth phase, that is the most critical phase during which the velocity of absorption increases due to the damage already reached. This phase that can be postponed with maintenance but hardly avoided.

The authors think that the proposed investigation has an important innovative character but believe that various aspects and themes still need to be explored. However, already at this stage the procedure proposed offers interesting insights also in the application to innovative and sustainable materials in order to estimate the trigger speed of the damage and evaluate their behavior over time.

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Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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