Investigation on Aggressiveness of Organic Acids on Degradation of Ordinary Portland Cement Mortar

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ABSTRACT

Vulnerability of concrete when exposed to low pH acidic environment is a phenomenon known for its significance in the durability of concrete structures. These hostile low pH acidic conditions attack the cement paste and disrupts the equilibrium of the matrix. Mortar specimens prepared with ordinary Portland cement (OPC) responds differently to various organic acid solutions. This study examines the acid aggressiveness on degradation of OPC mortar specimens exposed to 10% concentration lactic acid, acetic acid, citric acid and propionic acid. Acids with higher aggressiveness exhibits higher degradation. This paper compares the effects of different organic acids on cement mortar specimens in terms of mass changes, compressive strength changes and pulse velocity changes. Propionic acid and acetic acid show lower acid aggressiveness comparing to citric acid and lactic acid. Citric acid exhibits a consistency in its degradation and is of higher magnitude. The investigation of aggressiveness of organic acids on OPC mortar aids in predicting degradation to structures on acid exposure and hence preventing the eventual failure of the structure.

Keywords: Acid attack, Acid exposure, Deterioration

1 Introduction

As the second most common material and the most commonly used building material, exposure of concrete to aggressive acidic conditions cannot be ignored [1]. Acid spillage and accidental leaks from industrial plants, organic acids present in effluents from agro-food industries, waste water systems, biogenic production of sulphuric acids in concrete sewer pipes, and power plants can cause degradation of concrete structures referred to as acid attack [2]–[6]. The aggressive liquid effluents from these sources have low pH and the exposure of concrete to these effluents would disrupt the chemical balance in the paste matrix causing degradation in concrete structures.

Acid attack in concrete structures can be due to organic and mineral acids. Organic acids like acetic acid and citric acid can degrade the cement matrix similarly to mineral acids like hydrochloric acid and nitric acid [7], [8]. The aggressiveness of an acid depends on the parameters such as acid type, concentration, polyacidity, acid dissociation constant for weak acids, the production of organo-metallic complexes and salt properties like molar volume, solubility of salts and affinity of salts to cement matrix [9]–[11].

Mortar prepared with ordinary Portland cement (OPC) responds differently to various organic acid solutions. This study examines the acid aggressiveness on degradation of OPC mortar specimens exposed to 10% lactic acid solution, 10% citric acid solution, 10% acetic acid solution and 10% propionic acid solution. This paper compares the effects of different organic acids on cement mortar specimens in terms of mass changes, compressive strength changes and pulse velocity changes.

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2 Materials and Methods

2.1 Materials

The current research focuses on mortar specimens composed of OPC 53, M sand, and potable water. The fraction of sand retained on the 2 mm sieve and passing through the 90-micron sieve was rejected in accordance with IS 650:1991 [12].

For degradation analysis, lactic acid solution was prepared from 88% pure lactic acid with a molecular mass of 90.08 and a density of approximately 1.21 g/ml. Acetic acid is produced from glacial acetic acid with a density of 1.05 g/ml and a molecular mass of 60.05. Crystals of 99.5% pure citric acid monohydrate with a molecular mass of 210.14 are used to synthesize citric acid solution. The solution of propionic acid is composed of 99% pure propionic acid with a density of 0.99 g/ml a molecular mass of 74.08.

2.2 Methods

12 specimens were cast for each acidic condition using a mortar mixture of 1 part cement and 1.5 parts prepared sand, with a water-to-cement ratio of 0.45 for the study. [13]. The specimen was cylindrical in shape having 50 mm height and 25 mm diameter [13]. After 24 hours, the specimens of cement mortar were demoulded and cured in a saturated lime water solution for 14 days. In order to prevent the acid attack on the end faces, grinding and surface coating the end faces of the cylindrical specimen with sodium silicate solution were carried out. The acid solution is replaced every seven days, and its volume is always kept at five times the volume of the specimen [13].

The relative pulse velocity of the mortar samples is determined using an ultrasonic pulse velocity tester. The compressive strength of mortar was determined using a 50 kN capacity testing machine loaded at 360 N/s [13]. Relative mass and relative pulse velocity were recorded every seven days for 42 days, however relative compressive strength was only tested after 7 days and 28 days of acid exposure.

3 Results and Discussion

After evaluating various test conditions, the obtained data are examined and discussed in this section. The relative mass variations of specimens subjected to various organic acids are depicted in Figure 1. Figure 2 depicts the variations in relative pulse velocity and the compressive strength changes of the specimen are depicted in Figure 3.

3.1 Relative Mass

Figure 1 illustrates the impact of degradation due to acid attack in terms of relative mass. Relative mass is the mass of the specimen at any time of acid exposure to the mass of the mortar specimen immediately prior to acid exposure. Higher the relative mass, lower is the degradation. Lower the degradation, lower is the acid aggressiveness. Hence, higher the relative mass lower is the aggressiveness of the acid.

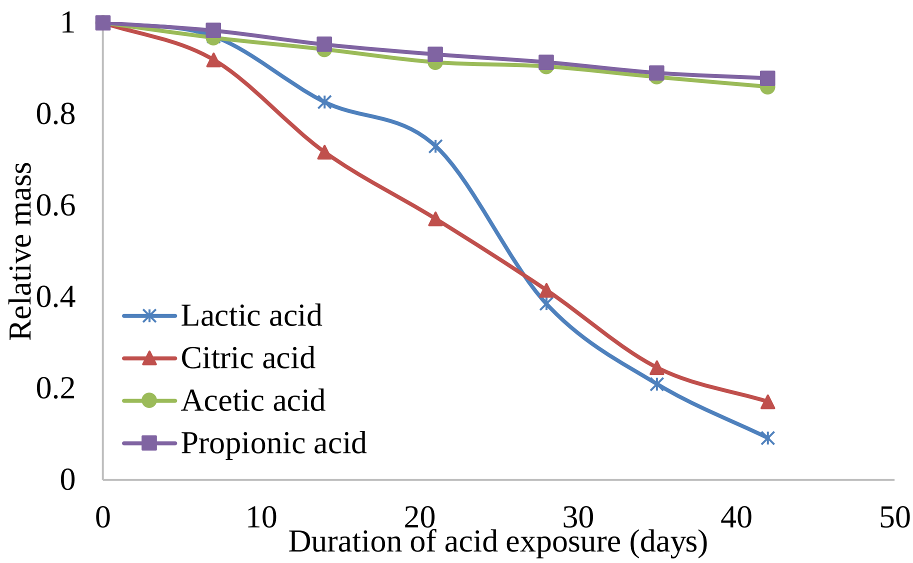

Figure 1: *Relative mass of OPC mortar specimens exposed to organic acids*

Acetic acid and propionic acid display similar aggressiveness as the relative mass of specimens are same throughout the duration of acid exposure as shown in the figure. The relative mass of specimens in acetic acid solution is 0.86 and the corresponding relative mass in propionic acid is 0.88 at 70 days of exposure. A maximum difference in relative mass of 0.02 was observed for specimens in acetic acid and propionic acid solutions at each time of testing, which is at an interval of 7 days. At 28 days of acid exposure, the difference in relative mass was only 0.01, same is the case with 35 days of exposure as well. Hence, the aggressiveness due to acetic acid and propionic acid are similar and significantly lower than that of lactic acid and citric acid. The similarity in aggressiveness of acetic acid and propionic acid could be possibly due to similar acid dissociation constant, monoacidic nature and solubility of calcium salts [14].

It is clear from fig. 1 that lactic acid and citric acid exhibits higher aggressiveness than acetic acid and propionic acid. Specimens in 10% citric acid solution exhibits higher degradation than that in lactic acid solution during the initial 21 days of acid exposure. But, after 28 days of acid exposure, specimens in lactic acid solution reports higher degradation which represents higher aggressiveness of lactic acid solution during the later stages of acid exposure. Citric acid exhibits consistently higher degradation than other organic acids selected for the study throughout the period of exposure. But lactic acid exhibits only moderate degradation during the initial days and significantly increases the degradation during the later stages of acid attack.

In general, lower the relative mass, higher the degradation and higher the acid aggressiveness. Citric acid and lactic acid exhibit higher degradation than other organic acids selected for the study. The degradation due to acetic and propionic acids are very similar, with a relative mass higher than 0.86 exhibiting lower magnitude of degradation. So acetic and propionic acids can be said to be of lower aggressiveness than citric and lactic acids. So, the order of acid aggressiveness of selected organic acids of 10% concentration can be summarized as:

$$\text{Citric acid} \approx \text{Lactic acid} > \text{Propionic acid} \approx \text{Acetic acid}$$

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3.2 Relative pulse velocity

The ratio of pulse velocity of the specimen at any time of exposure to the pulse velocity value of the same specimen just before the acid exposure is termed as relative pulse velocity. Figure 2 portrays the effect of various organic acids on the degradation kinetics of OPC mortar specimens in terms of relative pulse velocity.

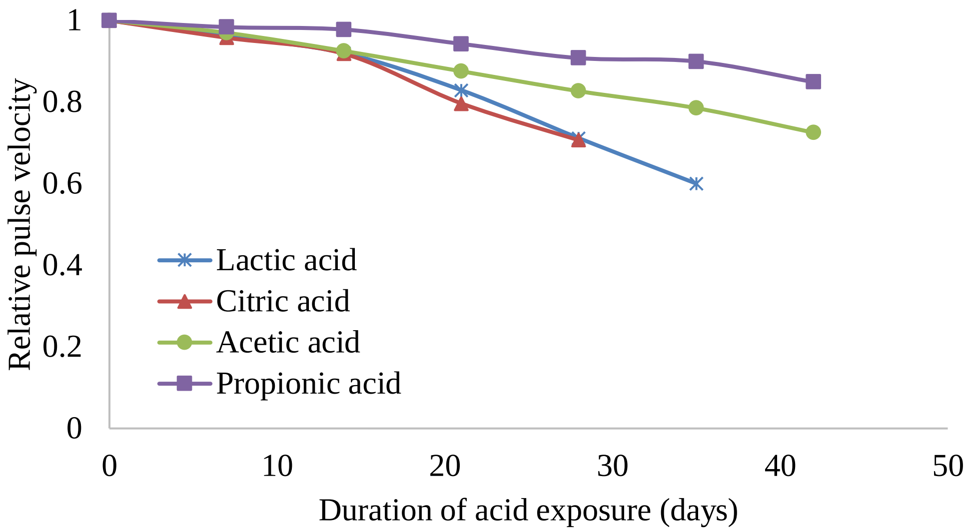

Figure 2: *Relative pulse velocity of OPC mortar specimens exposed to organic acids*

Specimens in citric acid and lactic acid shows lower relative pulse velocity during the 28 days of acid exposure which represents higher degradation in the specimens. Pulse velocity testing could not be conducted after 28 days of exposure for specimens in citric acid solution and after 35 days of exposure for specimens in lactic acid solution due to significantly lower dimensions of the specimen due to degradation of cement mortar. Specimens in citric acid exhibits marginally higher degradation than that in lactic acid solution. The greater deterioration of citric acid can be attributed to the precipitation of salts released during acid reactions. The increased molar volume of the precipitated salts induces cracking and fragmentation in the specimens. At high concentrations of lactic acid, the calcium salts in the outer deteriorated zone absolutely dissociate, causing the specimen to crumble and thereby accelerating degradation. Citric acid and lactic acid exhibits significantly higher degradation than acetic acid and propionic acid solutions.

Acetic acid represents marginally lower relative pulse velocity than propionic acid. A relative pulse velocity of 0.73 was observed for specimens in acetic acid solution whereas 0.85 was observed for that in propionic acid solution. The difference between the relative pulse velocity of specimens in acetic acid and propionic acid was found to be steadily increasing throughout the period. The difference was about 0.01 at 7 days of acid exposure, which increases to 0.08 at 28 days of exposure and reaches about 0.12 at 56 days of acid exposure. So, the acid aggressiveness is in the order:

testing to the average compressive strength just before acid exposure

Lactic acid ≈ citric acid < Acetic acid ≤ Propionic acid

3.3 Relative compressive strength

Figure 3 represents the degradation kinetics of OPC mortar specimens subjected to organic acids in terms of relatively compressive strength, which is the ratio of compressive strength at any time of testing to the average compressive strength just before acid exposure.

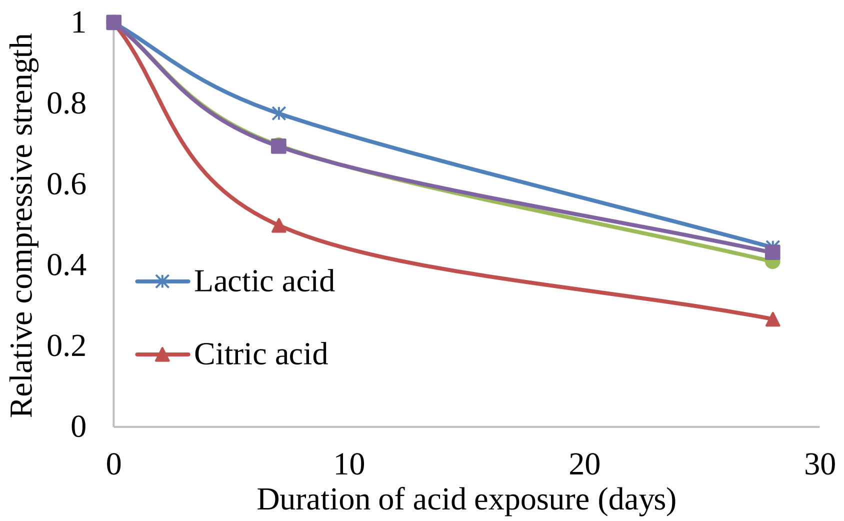

Figure 3: *Relative compressive strength of OPC specimens subjected to organic acids*

In case of relative compressive strength, lactic acid, propionic acid and acetic acid exhibits similar relative compressive strength values of 0.77, 0.69 and 0.70 at 7 days of exposure and 0.44, 0.43 and 0.41 at 28 days respectively. But specimens exposed to citric acid shows a lower relative strength of 0.50 and 0.27 at 7 days and 28 days of acid exposure respectively, which represents a higher degradation and thereby higher aggressiveness. In general, lactic acid, propionic acid and acetic acid shows a comparable degradation and the degradation due to citric acid is marginally higher in magnitude.

4 Conclusions

The purpose of the study is to assess the impact of various organic acids on the degradation of OPC mortar specimens. Various organic acids such as citric acid, lactic acid, propionic acid and acetic acid are studied using mass changes, pulse velocity changes and compressive strength changes and the results are analyzed to determine the acid aggressiveness of the selected organic acids which are mentioned below.

• Specimens immersed in solutions with higher aggressiveness exhibits higher degradation which is represented by lower relative value.

• Lactic acid and citric acid exhibit higher acid aggressiveness than acetic acid and propionic acid.

• Citric acid exhibits a consistency in its degradation pattern and for all test conditions, the degradation is of higher magnitude.

• Acetic acid and propionic acid show similar aggressiveness which may be due to similar acid dissociation constant, monoacidic nature and solubility of calcium salts.

5 Declarations

5.1 Warning for Hazard

The work involves use of acids when come in human contact may cause mild burning sensations, and skin irritations. Precautions should be ensured before the study.

5.2 Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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